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EFFECT OF INTEGRATED USE OF LIME AND NITROGEN FERTILIZERS RATES ON SOIL PHYSICOCHEMICAL PROPERTIES, YIELD AND YIELD COMPONENTS OF MAIZE (Zea mays l.) AT NITISOLS OF BURIE AREA, NORTHWESTERN ETHIOPIA

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BAHIR DAR UNIVERSITY

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GRADUATE PROGRAM

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M.SC THESIS

BY

BIRTUKAN AMARE KEBEDE

August, 2020

Bahir Dar, Ethiopia

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M.Sc Thesis

By

Birtukan Amare Kebede

A thesis Submitted to Graduate Studies of College of Agriculture and Environmental Science, Bahir Dar University in Partial Fulfillment of the Requirements for the Degree of Master of Science (MSc.) Watershed Management and Soil-Water Conservation

Advisors:

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Bahir Dar, Ethiopia

THESIS APPROVAL SHEET

As member of the Board of Examiners of the Master of Sciences (M.Sc.) thesis open defense examination, we have read and evaluated this thesis prepared by **Mrs. Birtukan Amare** entitled **Effect of Integrated Use of Lime and Nitrogen Fertilizer Rates on Soil Physicochemical Properties, Yield and Yield Components of Maize (*Zea mays l.)* At Nitisols of Burie Area, Northwestern Ethiopia**. We here by certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Sciences (M.Sc.) in Watershed Management and Soil, Water Conservation.

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DECLARATION

This is to certify that this thesis entitled "**EFFECT OF INTEGRATED USE OF LIME AND NITROGEN FERTILIZER RATES ON SOIL PHYSICOCHEMICAL PROPERTIES, YIELD AND YIELD COMPONENTS OF MAIZE (Z*ea mays l.)* AT NITISOLS OF BURIE AREA, NORTHWESTERN ETHIOPIA**" submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in "**Watershed Management and Soil, Water Conservation**" to the Graduate Program of College of Agriculture and Environmental Sciences, Bahir Dar University by Mrs. **Birtukan Amare Kebede** (IDNo.096368) is an authentic work carried out by her under our guidance. The matter embodied in this project work has not been submitted earlier for award of any degree or diploma to the best of our knowledge and belief.

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DEDICATION

This thesis is dedicated to my beloved mother Hamelmal Bekele, whom I lost during the study period.

ACRONYMS AND ABBREVIATION

ATA	Agriculture Transformation Agency
AMH	Amhara Hybrid
ANRS	Amhara National Regional State
BH	Bako Hybrid
EARS	Ethiopian Agricultural Research System
EIAR	Ethiopian Institute of Agricultural Research
ESE	Ethiopian Seed Enterprise
GB	Gross Benefit
IAR	Institute of Agricultural Research
IFPRI	International Food Policy Research Institute
MoARD	Minister of Agriculture and Rural Development
MoU	Minister of Universities
NPS	Nitrogen Phosphorus Sulfur
MRR	Marginal Rate of Return
SARI	South Agricultural Research Institute
SNNP	Southern Nation, Nationality and Peoples
TVC	Total Variable Costs

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ABSTRACT

Soil fertility problem is the limiting factor for agricultural productivity in the highlands of Ethiopia. Soil acidity coupled with soil nutrient depletion negatively affect the performance and yield of maize in the Amhara National Regional State (ANRS) region. The attention given to lime with nitrogen fertilizer is none. This study was carried out at Burie district in one cropping season to determine the effect of integrated use of lime and urea fertilizer rate on soil physicochemical properties, yield and yield components of Maize. The treatments include lime (0 and 0.5 t ha^{-1}), urea (0, 100, 200,300, and 400 kg ha^{-1}). Recommended NPS (19% N, 38% P2O5 and 7% S) was used uniformly to all plots at the time of seed sowing. The maize variety BH-661 was used as a test crop. The experiment was laid out in a randomized complete block design (RCBD) with ten treatments replicated three times. Five representative soil samples were collected and one composite sample was taken for surface soil physicochemical properties analysis. After harvesting, disturbed soil samples were collected for soil chemical properties analysis. A total of thirty undisturbed soil samples were collected from three blocks for bulk density determination. Physical properties of soil texture before and bulk density were analyzed before and after harvesting. The change in chemical properties of soil including pH, SOC, OM, CEC, TN, Available P, and EC was also analysed following the standard laboratory procedure. The Morpho-phenological parameters (50% tasselling,50% silking, days to 90% maturity, plant height, number of leaves per plant, number of cobs per plant, number of grain per cob, 1000 grain weight, grain yield, above ground dry biomass yield, harvest index, straw yield were collected and analyzed. Analysis of variance (ANOVA) was carried out using the SAS statistical package program version 9.0. Duncan’s test was used to evaluate differences among treatment means where significant differences were obtained by ANOVA. Soil physicochemical properties were changed due to lime and urea. Field experiments revealed that individual, as well as combined application of lime and urea, improved yield and yield components of maize. The maximum grain yield of maize was 7,122 kg ha^{-1} with the net benefit of 58,891 ETB ha^{-1}. The economic analysis of maize result indicated that the application of lime and Nitrogen fertilizer was found economically feasible for maize production. Plots treated with mineral fertilizer were the best in nutrient use efficiency (5.88%). The recommended treatments are T2 (100 kg ha^{-1} Nitrogen), T7 (0.5 t ha^{-1} lime and 100 kg ha^{-1} Nitrogen), T8 (0.5 t ha^{-1} lime and 200 kg ha^{-1} Nitrogen) and T9 (0.5 t ha^{-1} lime and 100 kg ha^{-1} Nitrogen). Because Mariginal rate of return of these treatments was greater than 100%. Based on the highest net benfit combined application of 0.5 t ha^{-1} lime and 300 kg ha^{-1} urea is economically feasible and recommended to the farmers.

Keywords: Economical, liming, Nitrogen, Optimum, Soil acidity

I. INTRODUCTION

1.1. Background and Justification

Declining soil fertility is a fundamental impediment to crop production and a major reason for slow growth of food production in Sub-Saharan Africa (SSA). Soil fertility management for food and livelihood security is a major concern in the face of persistent poverty and widespread environmental degradation in Sub-Saharan Africa (SSA) including Ethiopia (Bello *et al*., 2010).

About 97% of agricultural land in SSA is under rain fed system (Bello *et al*., 2010) which remains dominant source of food production shortly. In addition Mosisa Worku *et al*. (2012) explained that, nutrient depletion is the chief biophysical factor limiting small-scale production in Africa.

In Ethiopia, soil degradation and nutrient depletion have gradually increased in area and magnitude and have become serious threats to agricultural productivity (Fasil Kebede and Charles, 2009). Soil acidity is one of the limiting factors to acid-sensitive crop production in the Northwestern highlands of Ethiopia. Its effects on crop growth are those related to the deficiency of major nutrients and the toxicity of aluminum (Al), manganese (Mn) and hydrogen (H) ions in the soil to plant physiological processes (Mesfin Abebe, 2009). To secure sustainable crop production and reasonable yield, acidic soils have to be corrected by the addition of agricultural lime to a pH range which is suitable for better yield of crop production (Mesfin Abebe, 2009).

Agricultural liming material is the most common soil management practices whose addition to agricultural soil in moderate amounts may be beneficial as plant nutrients, minimize soil acidification (Kebede Dinkecha and Dereje Tsegaye, 2017). The beneficial effects of liming soil are neutralization of exchangeable Al, increase Ca, Mg, P and Mo, availability, stimulate microbiological activity in the soil, and improve the physical structure of soil (Woubshet Demssie *et al*., 2017).

Nitrogen fertilizer application is required to optimize maize grain yields and tends to improve physical grain quality in maize by increasing kernel weight and protein concentration (Kena Kelbesa, 2015). Jiban (2013) stated that higher nitrogenous fertilizer delays the senescence of leaves and increased succulence of plants therefore; physiological maturity was increased with increment in nitrogen level. Likewise, successive increment in nitrogen rate from 0 to

200 kg N ha^{-1} significantly increased maize grain yield (Singh *et al.*, 2001). Singh *et al.* (2001) also reported that application of 200 kg N ha^{-1} increased grain yield of maize.

Ethiopia is the fifth largest producer of maize in Africa and smallholder farmers make up 94% of the crop production (Miteku Woldesenbet and Asnakech Haileyesus, 2016). Maize is cultivated in a wide range of altitudes, moisture regimes, soil types, and terrains, mainly by smallholder crop producers. It is mainly produced in southern, western, central, and eastern regions of Ethiopia (MoARD, 2009). But specifically, the mid-altitude, sub-humid agro-ecology (1,000-1,800 m.a.s.l) is the most important maize producing environment in Ethiopia (Wende Abera, 2013).

The popularity of maize in Ethiopia is partly because of its high value as a food crop as well as the growing demand for the straw as animal fodder and source of fuel for rural families (Tsedeke Abate *et al.*, 2015). Maize is used as human food (accounting for 62% of all household cereal consumption), as a source of cash income (accounting for about 54% of cash income), as fuel (about 25%), feed for livestock and industrial purposes (Mosisa Worku *et al.*, 2002). Farmers consume maize by preparing different dishes, including bread, *injera*, thick porridge, boiled maize, roasted maize and local beer. Green cobs are also sold in big cities and towns (Berhanu Gebremedhin *et al.*, 2007). The smallholder farmers' of Ethiopia owning 97% of the total maize land contribute 95% of the national maize production (CSA, 2011). On the other hand, commercial farms owning only 3% of land contribute 5% of the total production. In the Amhara region, maize production accounts 519,495.71 ha^{-1} with productivity of 37.79 qt ha^{-1}, while in west Gojjam it accounts 212,556.78 ha^{-1} with a productivity of 42.28 qt ha^{-1} (CSA, 2011).

The low productivity of maize is mainly attributed to many factors including frequent occurrence of drought, declining soil fertility (IFPRI, 2010), poor agronomic practice, limited use of inputs, poor seed quality, disease, and pests (Wende Abera, 2013). Among these, declining soil fertility (due to continuous cultivation with low input) is a major limitation to crop production and productivity in smallholder farms in Ethiopia (Mosisa Worku *et al.*, 2012).

Although, the ANRS region especially Burie District is a potential area for maize production the productivity is generally low, which is attributed to several factors one of which is poor soil fertility and nutrient management. Thus, identifying effective Integrated Nutrient Management (INM) ways is needed to replenish the soil nutrients and increase the maize grain productivity in the study area. Therefore, this study was initiated to investigate the effect of integrated use of lime and nitrogen fertilizers on soil physicochemicalproperties, maize yield and yield components on the Nitisols of Burie area, Northwestern Ethiopia.

1.2. Statement of the Problem

In the mid and highlands area of Ethiopia the soil is acidic and deficient in nitrogen and phosphorus due to soil erosion, leaching of basic cations, intensive and continuous cultivation of land with poor soil fertility management practices (Kebede Dinkecha and Dereje Tsegaye, 2017). Efforts to ameliorate the harmful effects of soil acidity must therefore be accompanied by measures to replenish soil N and P. Use of inorganic fertilizers is recognized as an effective way for overcoming nitrogen and phosphorus deficiencies.

However, in acid soils, response to fertilizers may not occur because of constraints imposed by soil acidity. Therefore, liming is the most effective practice to control soil acidity (Peter *et al.,* 2018). Moreover, farmers of the study area are not well familiar in applying lime on acidic soil and the attention concerning integrated use of lime with nitrogen fertilizers is none. Similarly, fertilizer rate recommendations for the integrated application of lime and nitrogen fertilizer are not available in the study area. Therefore, conducting a research on the integrated application of lime and nitrogen fertilizers and evaluating their combined effect on soil physicochemical properties and maize yield is crucial.

1.3. Objectives of the Study

1.3.1. General objective

The general objective of this study was to investigate the effect of integrated use of lime and nitrogen fertilizers on soil physicochemical property, yield and components of maize (*Zea mays l.)* in the Nitisols of Burie area, Northwestern Ethiopia

1.3.2. Specific objectives

The specific objectives of this study were;

- To illustrate the surface soil physicochemical properties of study area soils;
- To explain the effect of integrated use of lime and N on selected soil properties;
- To indicate the effects of integrated use of N fertilizer and lime on yield and yield components of maize and
- To determine the optimum dose of N fertilizer and lime that increase maize productivity on the Nitislos of the study area.

1.4. Hypothesis

There will no be significant difference in soil properties, yield and, yield components of maize by integrated application of lime and N fertilizers.

II. LITERATURE REVIEW

2.1. Soil Fertility

Soil fertility refers to the ability of the soil to supply the nutrients needed by the plants (Orkaido, 2004*)*. According to Martin (1993), the study of soil fertility involves examining the forms in which plant nutrients occur in the soil, how these become available to the plant, and factors that influence their uptake. This is usually done by adding fertilizers, manures and amendments to the soil but sometimes by supplying nutrients directly to the plant parts using sprays (Orkaido, 2004*)*.

Importance of soil fertility and plant nutrition to health and survival of all life cannot be understated as the human population continues to increase, human disturbance of earth's ecosystem to produce food and fiber will place a greater demand on soils to supply essential nutrients. Therefore, we must increase our understanding of the chemical, biological and physical properties and relationships in the soil-plant-atmosphere continuum that control nutrient availability (Tisdale Semahegn *et al.*, 1995). If we do not improve and/or sustain the productive capacity of our fragile soil, we cannot continue to support the food and fiber demand of our growing population (Orkaido, 2004*)*. Soil nutrient status of most farming systems is widely constrained by the limited use of inorganic and organic fertilizers and by nutrient loss mainly due to erosion and leaching (Balesh Tulema *et al*., 2007).

2.1.1. Soil fertility determining factors

Several factors contribute to reducing the fertility status and quality of soil in Ethiopia.The major ones being land degradation because of massive deforestation, human and livestock population pressure, limited use of crop residue and animal dung and little or no use of modern technologies to restore soil fertility, the high price of mineral fertilizer, and low use of organic nutrient sources (Taye Belachew and Yifru Abera, 2010). The physical and chemical properties of soil are the major determinant factors of soil fertility status. Different physical and chemical properties of the soil relate to one another and hence, the presence of one can indicate the status of the other (Brady and Weil, 2004).

2.1.1.1. Soil physical properties

Physical properties of soils determine their adaptability to cultivation and the level of biological activity that can be supported by the soil. Many soil physical properties change with changes in land use system and its management practices such as intensity of cultivation,the instrument used and the nature of the land under cultivation, rendering the soil less permeable, and more susceptible to runoff and erosion losses (Sahrawat *et al.,* 2010).

White (1997) found that bulk density (Bd) ranges from less than 1 g/cm^3 for soils high in OM, 1.0 to 1.40 g/cm^3 for well- aggregated loamy soils, and 1.4 to 1.8 g/cm^3 for sands and compacted horizons in clay soils. Soils having low and high Bd exhibit favorable and poor physical conditions respectively (Mitiku Haile *et al.,* 2006). Bulk density normally decreases as mineral soils become finer in texture. Bulk densities of soil horizons are inversely related to the amount of pore-space and soil OM (Brady and Weil, 2002).

2.1.1.2. Soil chemical properties

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

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

Descriptive terms commonly associated with certain ranges in pH are extremely acidic (pH< 4.5), very strongly acidic (pH 4.5-5.0), strongly acidic (pH 5.1-5.5), moderately acidic (pH 5.6-6.0), slightly acid (pH 6.1-6.5), neutral (pH 6.6-7.3), slightly alkaline (pH 7.4-7.8), moderately alkaline (pH 7.9-8.4), strongly alkaline (pH 8.5-9.0) and very strongly alkaline (pH > 9.1) (Rowell, 2014).

Soil organic matter (SOM) is the organic fraction of soil derived from the decayed tissue of plants, animals and from animal excreta (Teklu Erkossa, 2005). Soil OM helps to bind soil particles together that improve the physical properties of the soil making it easier for roots to penetrate. Organic matter forms complexes with micro-nutrients and prevents them from being lost through leaching. During the anaerobic fermentation process, about 25 to 30% of the OM from the manure is converted into biogas while the rest becomes available as residual manure (Chendu, 2006).

Dense populations of micro-organisms inhabit the upper soil surface and have access to the soil N sources. If the ratio of the substrate is high there will be no net mineralization and accumulation of N. They further noted that as decomposition proceeds, carbon is released as CO_2 and the C: N ratio of the substrate falls. Conversion of carbon in crop residue and other organic materials applied to the soil into humus requires nutrients (Lee, 2005).

The ability of a soil to retain cations such as potassium (K^+), ammonium (NH_4^+), hydrogen (H^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) in a form that is available to plants is known as cation exchange capacity (CEC). The CEC of soils also is the capacity of soils to adsorb and exchange cations (Brady and Weil, 2002). There is a fairly constant equilibrium between adsorbed cations and those moving freely in the soil moisture.

The equilibrium is disturbed, ion exchange between the solid and liquid soil phases occur, resulting in either adsorption or release of cations (Samuel Taye *et al.,* 2000). In general, CEC is a crucial factor in the determination of soil fertility for two fundamental reasons. First, the total quantities of nutrients available to plants as exchangeable cations depend on it, and second are it can influence the degree to which hydrogen and aluminum ions occupy the exchange complex and thus, affect the pH of soils (Sahlemedhin Sertsu and Taye Bekele, 2000).

2.1.2. Nutrient critical value

Several elements take part of the growth and development of plants, and those absorbed from the soil are generally known as plant nutrients. Besides these, plant takes up carbon, oxygen, and hydrogen, either from the air or from the water absorbed by roots. In all, 16 elements have been identified and are established to be essential for plant growth (Ethio SIS, 2014). There are carbon (C), hydrogen (H), Oxygen (O), nitrogen (N), phosphorus(P), potassium(K),calcium (Ca), magnesium (Mg), iron (Fe), sulfur (S), zinc (Zn), manganese (Mn), copper (Cu), boron (B), molybdenum (Mo), and chlorine(Cl) (Ethio SIS, 2013). These elements serve as raw materials for the growth and development of plants, and the formation of fruits and seeds. Most of the essential elements are found in abundant quantities in the mineral soils. Even though these are available inadeuately, they may not be available to the plants, as they are tied up in mineral and chemical compounds (Taylor and Francis, 2006). The roots cannot absorb and deliver them to the growing plants for synthesis, and hence, the need for assessing the plant available amounts of nutrients in the soil and meeting deficiency by application of manures and fertilizers to such soils for optimum crop production (Taylor and Francis, 2006).

The proper rates of plant nutrients can be determined by knowledge about the nutrient requirement of the crop and supplying power of the soil. However, Ethiopian farmers used to apply only chemical fertilizers Di-ammonium phosphate (DAP) and urea to increase crop yields for about five decades and this did not consider soil fertility status and crop nutrient requirement (Tilahun Getahun, 2007).

Critical levels may vary with crop, soil type, and climate and they are also specific to the soil test method used. Optimally critical values should be calibrated for each crop and for conditions that are as similar as possible to the conditions under which the fertilizer recommendations are applied (Ethio SIS, 2013).

Generally, critical nutrient level for different nutrients was given as follow as; Nitrogen (0.2%), Phosphorous (15mgkg^{-1}), Potassium (190mgkg^{-1}), Calcium (50mgkg^{-1}), Magnesium (10mgkg^{-1}), Sulphur (20mgkg^{-1}), Zinc (1.5mgkg^{-1}), Boron (0.8mgkg^{-1}) (Ethio SIS, 2014).

2.1.3. Role of urea in plant growth

According to Orkaido Olte (2004) N has been identified as being the most often limiting nutrient in plant growth. It is found to be an essential constituent of metabolically active compounds such as amino acids, proteins, enzymes, co-enzymes, and some non-proteinous compounds. Plants absorb nitrogen in its cationic form (NH_4^+) or the anionic form (NO_3^-), to less extent as urea and NH_3. Plants obtain readily available N forms from different sources. The major sources include biological nitrogen fixation by soil microorganisms, mineralization of organic N, industrial fixation of N gas, and fixation as oxides of N by atmospheric electrical discharge (Orkaido Olte, 2004). Soil pH and its mineral nutrient status, photosynthesis, climate and crop management influence the availability of N through biological N-fixation (Tisdale Semahegn *et al.*, 1995). Similarly, mineralization of organic N to inorganic forms depends on temperature, level of soil moisture, and supply of oxygen (Tisdale Semahegn *et al.*, 1995).

Dry plant material contains about 1 to 4% N and N is an indispensable elementary constituent of numerous organic compounds of several importance; amino acids, proteins, nucleic acids (Mengel and Kirkby, 1996). It is involved in all major processes of plant development and yield formation. Besides a good supply of N to the plant stimulates root growth and development as well as uptake of other nutrients (FAO, 2000; Brady and Wiel, 2002). Similarly, Sugiharto *et al.* (1990) reported that in maturing photosynthetic leaf cells of maize lack of N causes the reduced level of PEPC enzyme, which helps to replace Krebs-cycle acids used in the synthetic reactions and help to form malate needed in charge balancing functions (Salisbury and Ross, 1992).

When N supply is insufficient, carbohydrates will be deposited in vegetative cells, causing them to thicken whereas under adequate N supplies and favorable conditions for growth; proteins are formed from manufactured carbohydrates resulting in more protoplasm (Tisdale *et al.,* 1993). Nitrogen affects plant growth and productivity by helping the crop to have a better root growth and establish vigorous root system enabling the plant to mobilize soil moisture and nutrients more efficiently, alter leaf area photosynthetic capacity through increased plant height and girth growth and secure better canopy structure (Devi *et al.,* 2001).

2.1.4. Methods of urea fertilizer application

The best use of nitrogen is obtained when 50% of the total requirement is applied at sowing and the remaining 50% is given as top dressing. The other option is an application of the total requirement in three equal splits at sowing, knee-height, and flag leaf emergence (Tolessa Debele *et al*., 1994). The best time for the top dressing is 30-35 days after emergence (knee-height stage) just after the first weeding and again 60-65 days after emergence just after the second weeding or before tasselling (with the emergence of the flag leaf). Fertilizer should be carefully applied away from the plant to avoid injury. The best response from the nitrogen is obtained when the top-dressed fertilizer is immediately incorporated in the soil (Tolessa Debele *et al.,* 2001).

Application of N at later vegetative stages of maize extended growth phase (Amanullah *et al.,* 2009) and produced relatively more assimilates by maize crop in response to the longer growth period, as a result, plant height, mean single leaf area and leaf area per plant were significantly increased and that might be the possible cause of greater biomass yield of maize.

Rajcan and Tollenaa (1999) reported that the difference in the dry matter accumulation in maize is attributed to post-silking N uptake and it significantly increased with an increase in N rate. Mariga *et al.* (2000) reported that biomass yield in maize considerably increased when N was applied up to the tassel initiation stage. Nitrogen is one of the most limiting macro-nutrients to maize grain yield worldwide (Hefny and Aly, 2008).

Maize starts taking up N rapidly at the middle vegetative growth period and the maximum rate of N-uptake occurs near to silking stage (Kena Kelbesa, 2015). During the silking stage, the maintenance of N uptake is a critical aspect in minimizing the requirement for N remobilization from vegetative to reproductive stage, therefore decreasing green leaf area, and concurrently dry matter accumulation becomes low (Kena Kelbesa, 2015). It is thus necessary to apply the optimum dose of N at critical stages.

2.1.5. Nitrogen use efficiency

Nitrogen use efficiency (NUE) is the maximum economic yield produced per unit of N applied, absorbed, or utilized by the plant to produce grain and straw yields (Fageria and Baligar, 2005). Nitrogen use efficiency is the grain yield produced per unit of N supply from soil or fertilizer (Sowers *et al.,* 1994). Nitrogen use efficiency can be subdivided into components that identify soil and plant processes that contribute to the overall use of N (Moll *et al.,* 1982). Van Ginkel *et al.* (2001) indicated that, under high N input, high uptake efficiency is a desirable trait describing NUE whereas under low input system the development of cultivars with high utilization efficiency is considered more desirable. It may be affected by crop species, soil type, temperature, the application rate of N fertilizer, soil moisture condition, and crop rotation (Halvorson *et al.,* 2006).

Plant use efficiency of N also depends on several factors including application time, rate of nitrogen applied, cultivar, and climatic conditions (Moll *et al*., 1982). Mahler *et al*. (1994) indicated that research is required to increase crop NUE and profitability in semi-arid conditionand to develop sustainable farming systems in response to continually increasing economic and environmental pressures. Lopez *et al.* (2001) showed that N efficiency indices were significantly affected by crop rotation and N fertilizer rate.

At low N supply, crop growth rate slows down causing reproductive structures to decline, as a result, lower maize grain yield (and its components), as well as lower harvest index and leaf area duration, are achieved (Lemcoff and Loomis, 1986, Below *et al.,* 2000). Similarly, in maize during the silking stage, the maintenance of N uptake is a critical aspect in minimizing the requirement for N remobilization from vegetative to reproductive stage, therefore decreasing green leaf area, and concurrently dry matter accumulation becomes low (Rajcan and Tollenaar, 1999). It is thus necessary to apply an optimum dose of N at critical stages (Gungula *et al.,* 2003). Several researchers attributed lower yield in maize when the crop was subjected to a high dose of N, while the time of N application improved N uptake and protected the soil environment (Karlen *et al.,* 1998).

2.1.6. Phosphorous fertilizer application methods

Phosphorus is a critical element in natural and agricultural ecosystems and its management need is second only to the need for the management of N for the production of healthy plants and profitable yields (Brady and Weil, 2002). The maximum efficiency of phosphorus fertilizer is obtained when the fertilizer is applied in a band 5cm to the side of seed at sowing time. Even a small quantity of P (11 kg P ha^{-1}) applied in a band increased the yield of maize as much as 22 kg P ha^{-1} applied in row or broadcast. Phosphorus at the rate of 22 kg P ha^{-1} applied in a row increased maize yields by 0.4 t ha^{-1} over the broadcast application, while the same amount applied in a band gave 1 t ha^{-1} over row application (Tolessa Debele *et al.,* 2001). While P that applied in a band is exposed to less surface contact with the soil, there is a higher concentration of nutrients available for maize per unit soil mass. The highest yield that was obtained with banded phosphorus was obtained within a row or broadcast phosphorus at higher P rates (Tolessa Debele *et al.,* 2001).

2.1.7. Application of lime and its effect in acidic soil

Acidic soils are made less acidic by adding a liming material. Agricultural lime is a material containing calcium (Ca) and/or magnesium (Mg) compounds capable of neutralizing soil acidity. A liming material with a higher CCE value will have greater effectiveness than one with a lower CCE value. Impurities, such as clay and organic matter that naturally occur in liming materials, produce variations in CCE among various liming materials (Mark, 2009). The common liming materials used to ameliorate acidity are Calcium Oxide (CaO) and Calcium Carbonate ($CaCO_3$) in powdery formulations (Peter *et al.,* 2018).

Factors to consider in selecting a liming material include available lime sources in the area, the length of time between application of lime and planting of the crop, degree of soil acidity, the need for magnesium, value of the crop, and the intensity of cropping (Nagle, 1983). According to Nagle (1983) use a slow or a quick-acting liming material can be a difficult and confusing decision. If lime can be applied three to six months ahead of planting, then more coarsely ground limestone can be used. Agricultural lime works best when applied in this manner. However, the fine particles (percent passing 100-mesh) in Agricultural lime will react very quickly and yield benefits will be seen even if lime is applied at the time of planting.

As Bertsch (1981) stated that extractable soil calcium and magnesium increased more rapidly with suspension limestone applications as compared to conventional Agricultural lime. However, after 16 weeks, pH and exchangeable calcium and magnesium levels were nearly the same for the two liming materials. Moreover, corn yields responded equally to suspension and conventional ground Agricultural lime. Agricultural lime immediately reacts with soil acidity and does produce a crop response even when lime is applied at the time of planting (Bertsch, 1981).

In strongly acid soils, it may be desirable to use crushed lime or one of the burnt or hydrated limes (Bertsch, 1981). These liming materials will benefit crops and reduce the level of soil acidity more quickly. Though the cost per area may be somewhat greater, improved crop performance may result in higher net income. The value of the crop should be considered in determining what lime source to use, especially for those crops that are acid-sensitive or have a critical pH requirement (Bertsch, 1981).

On the other hand application of ammonium and urea types of N fertilizers increases the need for lime. Because, the natural nitrification process of these fertilizers produces acid and tends to speed the acidification of soils. A soil test every two or three years will reveal the need for lime. As reported by Bertsch (1981) the maximum increase in soil pH occurred within approximately two years after the lime application. Sandy soils generally require less lime at any one time than silt or clay soils to increase pH by a given amount. Sandy soils, however, usually need to be lime more frequently (Bertsch, 1981). Lime should be mixed to tillage depth.

According to Bertsch (1981), the best time to lime is any time that a lime need has been determined. Agricultural lime can be applied anytime between the harvest of a crop and the planting of the next. Lime is usually broadcast on the soil surface and then incorporated into the soil during tillage operations. Spring applications are excellent for fall crops since there will be adequate time for significant soil pH adjustment. Application of good quality agricultural lime can adjust soil pH adequately in 45 to 60 days (Bertsch, 1981). Broadcasting lime by hand followed by incorporation is recommended on smallholder farms to enhance their effectiveness but this is laborious (Peter *et al.*, 2018).

2.2. Soil Fertility Status in Ethiopia

Agriculture in Ethiopia has long been a priority and focus of national policy such as Agricultural Development Led Industrialization (ADLI) and various large scale programs such as the Plan for Accelerated and Sustained Development to End Poverty (PASDEP) (Alemayehu Seyum, 2008). However, the sector is characterized by low productivity and the prevalence of a fragmented smallholder and subsistence farmer population that is relegated to highly degraded/marginal land due to loss of soil fertility.

Low productivity can be attributed to limited access by small farmers to agricultural inputs such as inorganic fertilizer, poor attitude on organic fertilizer, financial services, improved production technologies, irrigationand agricultural outputmarket and, more importantly, to poor land management practices that have led to severe land degradation in some areas (MoARD, 2010).

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

2.3. Maize Production and Effecte of Niterogen on Maize Yield

Maize (*Zea mays* L.) is a member of *Gramineae* family, and it was originated in America and first cultivated in the area of Mexico more than 7,000 years ago (Hilaire, 2000). In world production, maize is ranked as the third major cereal crop after wheat and rice (Zamir *et al.*, 2013). It is one of the most important food crops worldwide. It has the highest average yield per hectare and it is grown in most parts of the world over a wide range of environmental conditions (Geremew Taye, 2009).

Maize is generally less suited to semi-arid or equatorial climates, although drought-tolerant cultivars adapted to semi-arid conditions are now available. The crop requires an average daily temperature of at least 20^oC for adequate growth and development; the optimum temperature for growth and development ranges between 25 to 30^oC; temperature above 35^oC reduces yields (Brink and Belay, 2006). Frost can damage maize at all growth stages and a frost-free period of 120 to 140 days is required to prevent damage. Leaves of mature plants are easily damaged by frost and grain filling can be adversely affected. Currently, maize is widely grown in most parts of the world over a wide range of environmental conditions ranging between 50^o latitude north and south of the equator. It is also grown from sea level to over 3000 meters above sea level (m.a.s.l) elevation. In the tropics; maize does best with 600-900 mm well-distributed rainfall during the growing season (Brink and Belay, 2006).

The most appropriate soil for maize is one with good effective depth, favorable morphological properties, good internal drainage, and an optimal moisture regime, sufficient and balanced quantities of plant nutrients, and chemical properties that are favorable specifically for maize production. Although large-scale maize production takes place on soils with a clay content of less than 10% (sandy soils) or over 30% (clay and clay loam soils), the textural classes between 10 and 30% (clay) have air and moisture regimes that are optimal for healthy maize production and productivity (Kena Kelbesa, 2015).

The accessibility of quality seed with required inputs at the right time and place with a reasonable price is vital. The maize productivity gap between stressed and high potential areas is not only an issue of technology but also differences in climatic factors. The non-availability of suitable maize varieties is also responsible for such a significant yield reduction. Wise utilization and conservation of natural resources will also have a considerable impact on maize grain production (Mosisa Worku *et al*., 2001).

Nitrogen is a key factor in achieving optimum grain yield. On the other hand, grain yield is the main target of crop production. Grain yield of maize is a product of three yields components, *i.e.* the number of ears per unit area, the number of grains per ear and the unit grain weight (Gardner *et al*., 1985). Increase or decrease in any one of these components, keeping the size of other components constant, contributes to increase or decrease in grain yield, respectively, and thus any exercise whether agronomic (management) or breeding type (genotype), which increase any of these components, keeping the other components constant, will increase the final grain yield. Devi *et al.* (2001) reported that ears plant^{-1}, ear length, number of kernels ear^{-1} and 1000-kernel weight directly influence the grain yield and indirectly affect several other parameters. Any kind of stress, for example a drought stress, during or around the stage(s) at which these components are formed may severely affect grain yield.

Differences in biomass yield and N uptake varied partly due to decreased soil N mineralization and partly due to the drier weather conditions of different years, and N uptake rate has been found to assist the improvement of dry matter yield in maize (Greef *et al.*, 1999). Maize biomass yield increases with increase in plant density and N rate (Gaurkar and Bharad, 1998). Yield is significantly affected by both N application timing and N rates. Nitrogen levels significantly increase the grain yield. Yield varying between 4,744.8 kg ha^{-1} in no N application and 7,355.5 kg ha^{-1} with application of 225 kg N ha^{-1} have been reported by (Ali and Raouf, 2012).

Sanjeev and Bangarwa (1997) reported that grain yield increased with increasing N rate. The fact that grain yield varied significantly with timing and regimentation of N strongly underscores the necessity of fine tuning N application to match nutrient supply to crop demand. N applied at 35 days or in equal splits at 0 and 35 day after sowing or at 35 and 70 days after sowing gave consistently more grain yield than other modes, particularly when N rate was 120 kg N ha^{-1}. The findings confirm the agronomic benefits of split nitrogen application in crops (Mungai *et al*., 1999).

According to Taylor and Francis (2006) grain yield was increased over control per kg N applied and time of N application in maize has been due to good synchrony if N is applied nearest to the time it is needed by the crop. Nitrogen fertilizer use has played a significant role in increase of crop yield. Yield reduction in corn due to N deficiency is more than of other elements deficiency (Mohammadi *et al.,* 2008). Uhart and Andrade (1995) found that nitrogen deficiency decreases grain weight and grain yield of corn, respectively by 9-25 % and 14-80 % than to control treatment.

Sabri *et al*. (2007) reported that N is the main plant nutrient which limits plant growth. It plays a pivotal role in several physiological processes inside the plant. It is fundamental to establish the plant's photosynthetic capacity (Hageman and Below, 1984); it prolongs the effective leaf area duration, delaying senescence; it is important for ear and kernel initiation, contributing to define maize sink capacity (Tollenaar *et al*., 1997) and it helps to maintain functional kernels throughout grain filling, influencing the number of developed kernels and kernel final size (Jones *et al.,* 2002). Nitrogen is the nutrient that most often limits maize grain yield and quality (Thanki *et al.,* 1988). Even under conditions where grain yield is not limited, N can affect composition and quality. Although maize is usually considered as energy food, it contains important quantity of protein. The percentage of N in maize actually varies according to the supply of nitrogen to the crop (fertilizer plus soil), genetic characteristics of the hybrids, planting rate and weather conditions (Kena Kelbesa, 2015).

III. MATERIALS AND METHODS

3.1. Description of the Study Area

The experiment was conducted in Burie District, West Gojjam Zone of Amhara National Regional State (ANRS) during the 2018/2019 rainy season (Figure 3.1). It is located between the latitude of 10°43'0" to 10°47'0" North and longitude of 37°3'0" to 37°6'0" East. The area is located in the northwestern part of Ethiopia at a distance of 411km from Addis Ababa and 148km Southwest of Bahir Dar city. Burie town in the district has eight (8) villages of which four (4) are urban and four (4) are rural villages. The experiment was conducted at Burie Poly Technic College farm site.

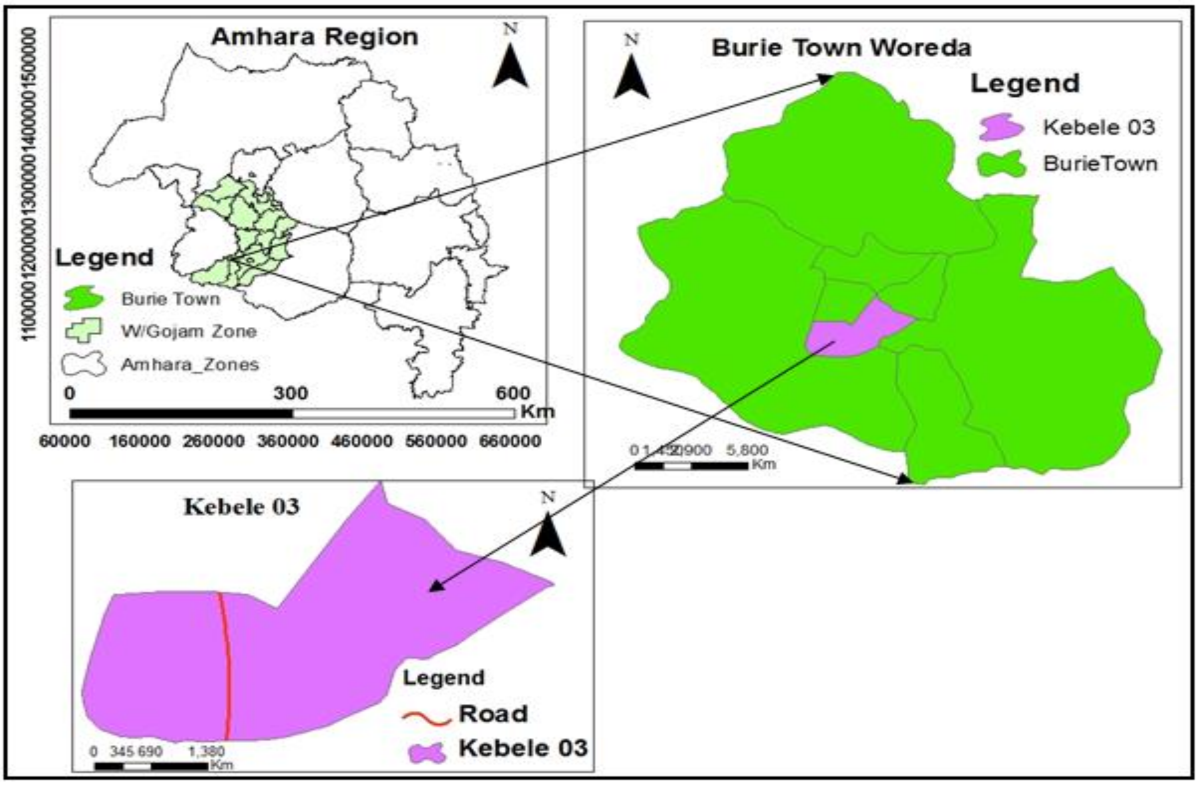

Figure 3. 1. Location map of the study area

3.1.1. Altitude, climate and soils

The altitude of Burie district ranges from 2087 to 2,637 m.a.s.l. According to the Amhara Meteorological Agency report (2020), indicates that the past ten years mean annual rainfall of the District was 1375.8mm (Appendix Table 15). The rainy season stretches from March to November with maximum rainfall intensity in June, July and August. The mean minimum, mean maximum and average air temperature of ten years (2010-2019) in the study area was 12.31°C, 25.93°C and 19.12°C, respectively (Figure 3.2).

The soil of the area is characteristically humic Nitic and eutric vertisols, relatively fine in texture (BWAO, 2019). In general soils of the area are well drained, clay in texture and strongly to moderately acidic in reaction (BWAO, 2019).

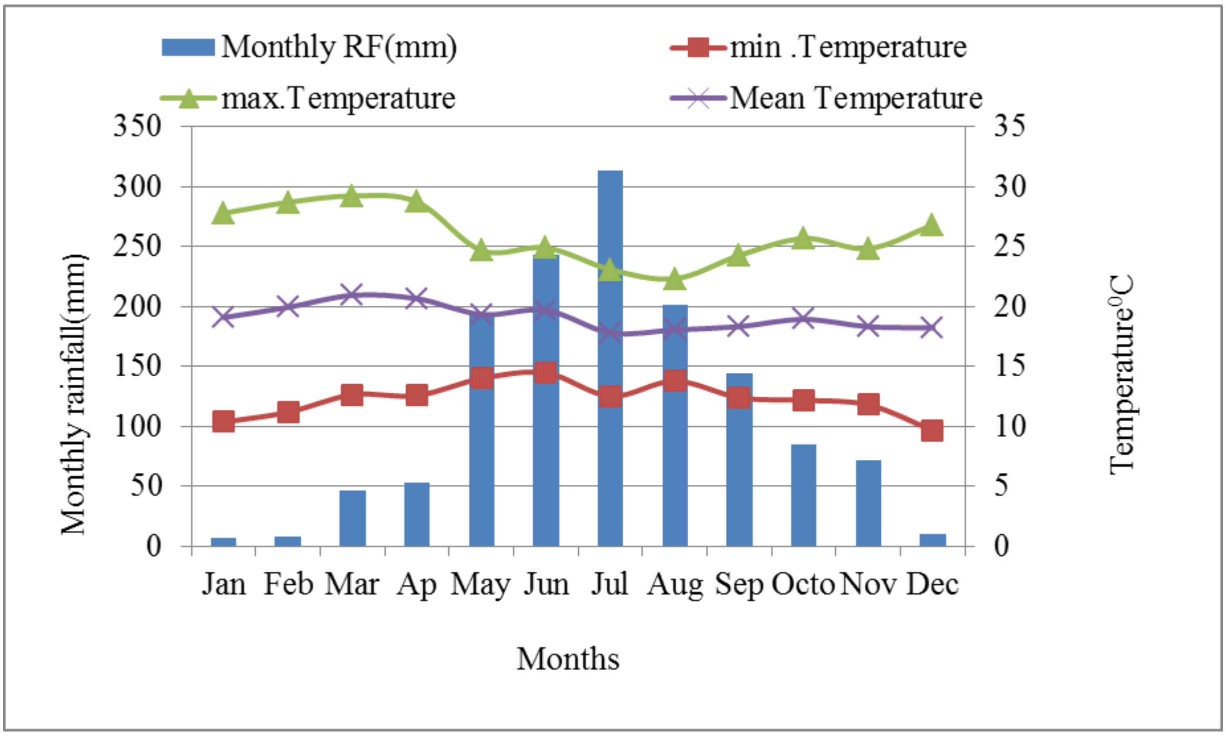

Figure 3. 2. Monthly rainfall (mm), minimum, maximum and average air temperature (°C) of the study area during 2010-2019

3.1.2. Farming system

Burie District has a total of 29,629 ha productivity area from this 42.8% is covered by maize crop in the 2018/2019 crop production year (BWAO, 2019). The mean yield of maize from all variety of maize was 5.5 t ha^{-1}. The land use history of the experiemental site was wheat crop.The recommended N and NPS fertilizers in the study area is 200 kg ha^{-1} N and 200 kg ha^{-1} NPS, respectively (BWAO, 2019).

According to BWAO (2019), the main crops grown are maize (*Zea mays*), Barley (*Hordeumv ulagre*), Wheat (*Triticum aestivum*), Field pea (*Pisum sativum*), Chick peas (*Cicer arietinum*) , Beans (*Phaseolus vulgaris*), Nug (*Guizotia abysinica)*, Telba (*Line seed*),Onion (*Allium cepa*),Garlic (*Allium sativum*),Cabbage (*Brassica oleracea var. capitata*), Carrot (*Daucus* *carota subsp. Sativus*), Finger millet (*Eleusinecoracana*), Potato (*Solanum tuberosum*), Pepper (*Capsicum annuum*) and Teff (*Eragrostis tef*).

3.2. Experimental Material and Treatments

3.2.1. Plant material

The maize variety H-661 (Bako Hybrid-661) which is adapted to the agroecology and registered at the national level was collected from Amhara Seed Enterprise and used as a test crop. This variety was released by Bako research center and has one of the most successful hybrid varieties. It is a three-way cross-hybrid and the most prominent throughout Ethiopia due to high productivity and coverage. It gives an average 7 t ha^{-1} in farmer's trial (Esayas Eyasu *et al.,* 2018).

3.2.2. Fertilizer materials

Urea (46% N) was applied at five different levels. It was applied in one dose at the time of knee height at different rates (0,100, 200, 300, and 400 kg ha^{-1}). This fertilizer was applied by banding at knee height approximately 2 to 3 cm distance from plant and immediately covered with soil. The recommended rate of NPS (19% N, 38% P_2O_5, and 7% S) fertilizer was used uniformly to all plots at the time of planting.

Lime material in the form of calcium carbonate ($CaCO_3$) which has present passing100-mesh was applied. According to Burie District Agricultural Office Manual (2019), there are two way of lime application. First, during seed sowing (i.e row application) when the lime type is powder and second, broad casting application when the lime type is granular. Broad casting application is recommended to apply one or two months before seed sowing (BWAO, 2019). Lime was added based on soil pH of the experimental site. In order to apply during seed sowing 1/4th of the recommended rate of broad casting (i.e 2 t ha^{-1} lime) was used. If the pH (H_2O) value of the soil is between 5.14 to 5.32, the recommended lime is 2 t ha^{-1} for broad casting application (BWAO, 2019).Thus based on the District recommendation, the experimental site soil pH was 5.2. Lime was added during seed sowing, the amount of lime rate added during maize sowing was 1/4th of 2 t ha $^{-1}$ (i.e 0.5 t ha^{-1}). The treatment of lime powder was applied to the plots as per treatment in row and immidatly coverd by soil.

3.3. Methods

3.3.1. Evaluation of the changes in soil physicochemical properties

Before the sowing of the seed, a soil sample was taken at a depth of 0 to 20 cm at different points by vertical insertion of a shovel and mixed to get one composite sample. The composite soil sample from surface soil was properly labeled and placed both inside and outside the plastic bags. Similarly, soil sample collection was done after harvest from each plot within a block. The composite surface soil and individual soil samples from each plot after treatment was properly labeled and placed both inside and outside the plastic bags and was transported to soil laboratory of Amahra Design and Supervision institute.

3.3.2. Soil analysis

3.3.2.1. Analysis of soil physical properties

Soil bulk density was measured from undisturbed soil samples collected using a core sampler (which was weighed at field moisture) after drying the pre-weighed soil core samples to constant weight in an oven at 105 ^{0}C as per the procedures described by Blake (1965). Then soil samples were dried in an oven at 105 ^{0}C to constant weights. Then soil bulk density was calculated by dividing the masses of the oven dried soils by their respective total volume of the core sampler. Bulk density (g/cm^3) =Weight of oven dried soil (g)/core volume of the soil (cm^3)

3.3.2.2. Analysis of soil chemical properties

The composite soils samples were air-dried, mixed well and passed through a 2 mm sieve for the analysis of selected chemical properties. The soil pH was determined in pH-H2O with soil to water solution ratio of 1:2.5 by using pH meter as outlined by Van Reeuwijk (1993). Soil organic carbon was determined by the Walkley and Black wet digestion method (Walkley and Black, 1934) and the soil organic matter (OM) was calculated by multiplying the percent organic carbon by a factor of 1.724. Total nitrogen was determined using the micro-Kjeldahl digestion, distillation and titration procedure as described by Bremner and Mulvaney (1982). Available P was determined using the standard Olsen extraction method (Olsen *et al.,* 1954). To determine the cation exchange capacity, the soil samples were first leached with 1 M ammonium acetate, washed with ethanol and the adsorbed ammonium was replaced by Na. Then, the CEC was measured titrimetrically by distillation of the ammonia that was displaced by sodium (Chapman, 1965).

3.4. Treatments and Experimental Design

This experiment was laid out as a randomized complete block design (RCBD) with three replications and ten treatments. Two factors was involved in the study, namely five levels of N (0,100,200,300 and 400 kg ha^{-1} urea) and two level of lime (0 and 0.5 t ha^{-1}) to have a total of ten (10) treatments that were arranged in 5*2 factorial combinations (Table 3. 1).

Table 3. 1. Factorial combination of Nitrogen fertilizer and lime

		Nitrogen				
		N0	N1	N2	N3	N4
Lime	L0	L0N0	L0N1	L0N2	L0N3	L0N4
	L1	L1N0	L1N1	L1N2	L1N3	L1N4

Treatments were:-

T1. L0N0
T2. L0N1
T3. L0N2
T4. L0N3
T5. L0N4
T6. L1N0
T7. L1N1
T8. L1N2
T9. L1N3
T10.L1N4

Note:

- L0N0 was the control without lime and N fertilizer
- L0N1was without lime and 100 kg ha^{-1} N fertilizer
- L0N2 was treatment and 200 kg ha^{-1} N fertilizer
- L0N3 was treatment without lime and 300 kg ha^{-1} N fertilizer
- L0N4 was treatment without lime and 400 kg ha^{-1} N fertilizer
- L1N0 was treatment with 0.5 t ha^{-1} lime and 0 kg ha^{-1} N ertilizer
- L1N1 was treatment with 0.5 t ha^{-1} lime and 100 kg ha^{-1} N fertilizer
- L1N2 was treatment with 0.5 t ha^{-1} lime and 200 kg ha^{-1} N fertilizer
- L1N3 was treatment with 0.5 t ha^{-1} lime and 300 kg ha^{-1} N fertilizer
- L1N4 was treatment with 0.5 t ha^{-1} lime and 400 kg ha^{-1} N fertilizer

3.4.1. Application of treatments and field management

The field was leveled and divided into three blocks which were lastly divided into 30 plots. The plots were leveled and ridges were prepared manually. Each gross plot had an area of 3.75 m × 3.5 m (13.125m^2) and consists of 5 rows of 3.5 m length. The spacing between rows and between plants was 0.75m and 0.25m, respectively and the spacing between plots and blocks was 0.5m and 1m respectively. The treatments were assigned to each plot randomly. The one which was the outer most rows from each side 12.5cm and 37.5cm length from both ends of each row was considered as a border. Thus, the net plot was 3 rows of 2.25m width and 2.5m length (2.25m× 2.5m = 5.625m^2). The total area used for this research was 39.5m by 13.25m (523.375m^2). Seeds of maize variety BH661 were sown by hand at a rate of 100 kg ha^{-1} on May 30, 2019 and lime was applied in row with 0.5 t ha^{-1} rate. At physiological maturity maize crop was harvested on December 26, 2020, sun dried and threshed on January 6 and 7, 2020 to determine grain yield.

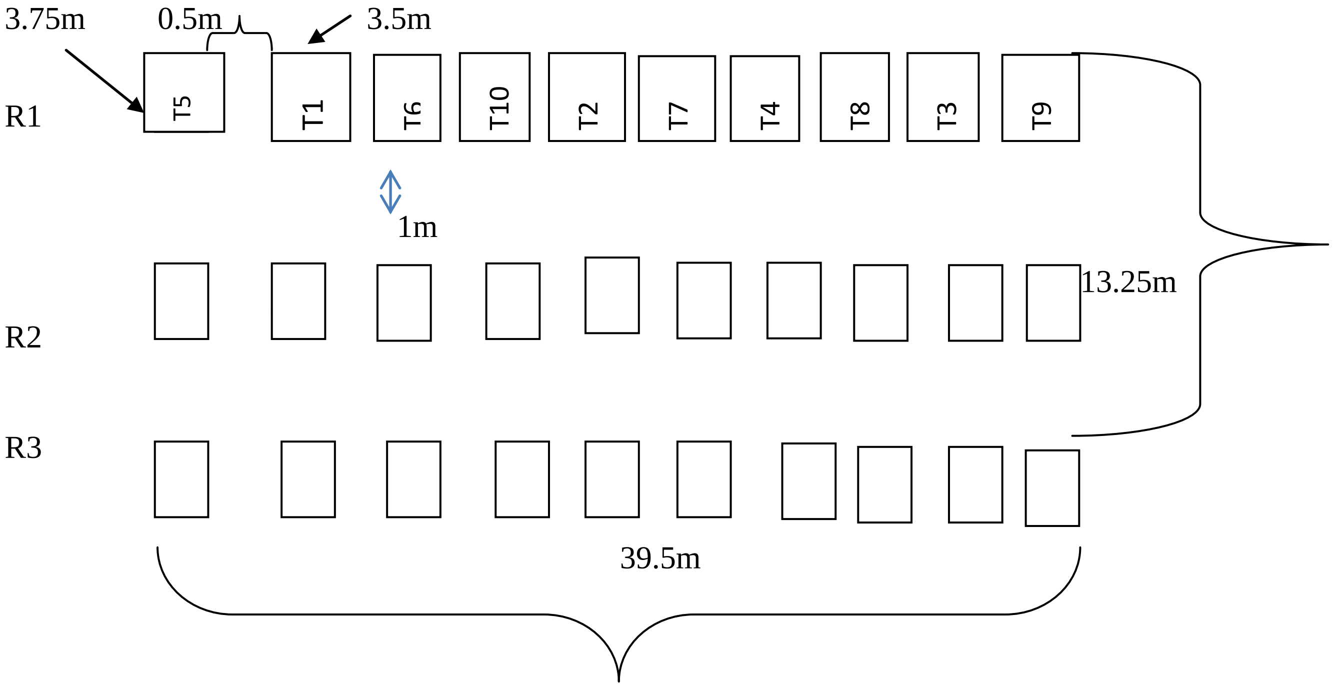

Figure 3. 3. Field layout for maize trial

3.5. Experimental Procedure

Fertilizer application and field activities

The experimental plot was plowing by tractor and oxen. Accordingly, the field was plowing three times, the first plowing, was done in the first of April with disck plough. The second & final plowing was conducted by oxen driven local plow “*Maresha”* at first and last May and seeding or sowing was conducted as per the spacing of the treatment.The experimental field was hand weeded twice at 25 and 45 days after planting to control weeds.A late emerging weed was removed by hoeing to avoid interference with the maize plants for the N applied from NPS source. All other agronomic practices such as fertilization, hoeing, disease, insects and weeds management was as per the recommendation. Finally, maize plants in the central net plot area were harvested.

3.6. Collected Data for Yield and Yield Components of Maize

The following phonological, yield and yield components of maize crop data were collected.
Days to 50% tasseling was recorded when more than 50 percent of the plants produced tassels in each plot.

Days to 50% silking was recorded when more than 50 percent of the plants produced silks in each plot.

Days to 90% maturity was recorded as the number of days from emergence to the date on which about 90 percent of the plants in a plot matured (ninety percent plants showed drying of cobs husk).

Plant height (cm): five plants were selected randomly from each net plot. Plant height was measured as the distance from the base of the plant to the height of the first tassel branch and average height was calculated.

Number of leaves per plant: Five plants were randomly selected from three central row of each net plot and counted and their average was worked out.

Number of cob per plant: Five plants were selected randomly and the total numbers of cobs were divided by the total number of plants harvested.

Number of grains per cob: five cobs in each net plot were randomly selected, and then number of grains in each cob were counted and averaged.

Thousands grain weight (g): Two samples of thousand grains had taken at random from each treatment then weighed by digital balance and average was recorded. The 1000 grain weights was weighed after testing seed moisture content by using seed moisture tester instrument at Ethiopia commodity exchange (ECX) office, Burie branch. The final dry weight of 1000 grains was computed using 12.5% as market standard seed moisture content of maize.

Grain yield (kg ha^{-1}): After sun drying, the cobs were threshed manually and yield was recorded on per plot basis, with moisture content 12.5 %, and then converted into kg ha^{-1}.

Above ground dry biomass yield (kg ha^{-1}): Plants from the net plot area were harvested at physiological maturity and weighed after sun drying.

Harvest index: The harvest index (HI) was computed as the ratio of grain yield (GY) to the total above ground Dry-mass (DM) yield.

Straw yield: was determined by subtracting grain yield from above ground dry biomass.

3.7. Data Analysis

The collected data were computed by Analysis of variance (ANOVA) using SAS statistical package program version 9.0 (SAS, 2004). All significant treatment means were compared using the least significant difference (LSD) test at 5% probability level. Pearson correlation analysis was used to determine the relationship between yield and yield components of maize crop.

3.8. Economic Analysis

The mean grain data was adjusted down by 90% (to reduce the grain gap between experimental plots and farmers field) partial budget analysis was performed following the CIMMYT partial budget methodology (CIMMYT, 1988).

The gross benefit was calculated as grain yield (kg ha^{-1}) multiplied by field price that farmers receive for the sale of the crop. Total variable cost is the sum of cost that has variable or specific to a treatment against the control. Net benefit was calculated by subtracting total variable cost from the gross benefit.

Analysis of marginal rate of return (MRR) was carried out for non- dominated treatments, and MRR were compared to a minimum acceptable rate of return (MARR) of 100% in order to select the optimum treatments to recommend for farmers. Marginal rate of return was calculated using the procedures described by CIMMYT (1988).

Marginal rate of return (MRR) = the change in NB dividing by change in TVC and multiply by hundred. Calculation of MRR is used to show acceptable rang. MRR below hundred is not acceptable range for developing countries like Ethiopia. A treatment having acceptable MRR and highest NB is said to be economically profitable and will be recommended for farmers (CIMMYT, 1988).

3.9. Agronomic Efficiency

The NPS, urea and lime fertilizer agronomic efficiency was calculated using the procedure described by Craswell and Godwin (1984) as: $AE\left(\frac{Kg}{kg}\right)=\frac{Gf\,(kg)-Gu\,(kg)}{Na\ (kg)}$, where; AE stands for agronomic efficiency, Gf and Gu for grain yield in fertilized and unfertilized plots, respectively, and Na for quantity of lime, urea and NPS fertilizer applied.

IV. RESULTS AND DISCUSSION

4.1. Surface soil Physicochemical Properties of the Experimental site

The results of soil analysis before planting maize are presented in Table 4.1. Before harvesting Bd of the soil was 1.42 g/cm^3 with clay texture (Table 4.1). The highest Bd value might be due to compactness of the soil, and lower OM content that resulted from continuous cultivation and removal of plant root and residues.

This was supported by Assefa Derebe (2009) who found that compaction increases bulk density by decreasing soil pore space. It is an increase in bulk density and soil strength and a decrease in soil porosity by the application of mechanical forces to the soil. Based on this soil of the study area has higher Bd as per the critical value rated by Ethiosis team analysis (2014). Bulk densities of soils are inversely related to the amount of pore space and soil OM (Brady and Weil, 2002 and Gupta, 2004). Any factor that influences soil pore space will also affect the bulk density. For instance, exhaustive cultivation increases bulk density resulting in a decrease of total porosity (Brady and Weil, 2002).

The soil reaction (pH- H_2O) was highly acidic with value of 5.2 (Table 4.1). According to EthioSIS (2014) pH was classified as< 4.5: strongly acidic, 4.5-5.5: highly acidic, 5.6-6.5: moderately acidic, 6.6-7.3: neutral, 7.4-8.4: moderately alkaline,>8.5: strongly alkaline.
Therefore, soils of the study area were strongly acidic, that are deficient in basic cations, which needs the application of lime for amendment.

The soil OC contents was 1.32% (Table 4.1), which is rated as very low (< 1.7%) to low (2-4%) based on the rating of soil test values interpretation by Landon (1991). Based on this result soil OC of the study area rated as very low as compared with critical value (3%). This might due to the removal of plant tissues and root residue from soil. For a soil to be productive, it needs to have OC content in the range of 1.8-3.0% to achieve a good soil structural condition and structural stability (Charman and Roper, 2007).

The content of Total Nitrogen (TN) also followed the trend of soil OC which had the content of 0.12% (Table 4.1). According to EthioSIS (2014), TN rated as very low (< 0.1%), low (0.1-0.15%) and optimum (0.15-0.3%). Based on this ratings therefore, the study area had lower TN content. This minimum soil OC and TN values are expected in the maize-growing fields of the study area where there is complete removal of biomass from the field, lower application rate of fertilizers and continuous cultivation that favors rapid rate of mineralization (Abera Girma and Endalkachew Woldemeskel, 2013). That is why it was treated with N source fertilizers to improve maize yield.

Available P before the application of lime and urea fertilizer was very low (8.86 mg kg^{-1}) in the clay textured Nitisols of the study area (Table 4.1). The value is below the critical level of available P for maize (i.e 30 mg kg^{-1}) as per the rate suggested by EthioSIS (2014). This might be attributed to P fixation due to the acidic nature of the soil. The low application rates of P-containing fertilizers, continuous crop uptake, losses due to erosion and fixation by acidic soils in this maize-growing field of the study area might be linked to the inadequate P levels recorded in the studied soils.

The CEC value of Nitisols of the study area was 19.57 $cmol_c$ kg^{-1} which was rated as medium as per the ratings of Landon (1991). According to this author, soils having CEC of >40, 25-40, 15-25, 5-15, < 5 $cmol_c$ kg^{-1} categorized as very high, high, medium, low and very low, respectively Landon (1991). The level of CEC could be associated with the texture of the soil which is clay. Clay soils have more cations as they have the caracterstics of increasing negative surface charges of a soil.

The laboratory result showed that the EC content of the study area before harvesting was low (0.145%) (Table 4.1). Soils having EC of >15, 8-15, 4-8, <4dS/m categorized as very high, high, medium, low, respectively (Landon, 1991). Therefore, the experimental site soil was non-saline.

Table 4. 1. Soil physicochemical property status before harvest

Soil properties	Values	Critical values	Reference
Sand (%)	22		
Silt (%)	31		
Clay (%)	47		
Classes	Clay		
BD g/ cm^3	1.42	1.2 g/cm^3	ETosis,2014
pH (H_2O)	5.20	7.3	ETosis,2014
TN %	0.12	0.2%	ETosis,2014
Available P mg kg^{-1}	8.86	30 mg kg^{-1}	ETosis,2014
Organic carbon (%)	1.32	3%	Landon ,1991
Organic matter (%)	2.27	5.16%	Landon ,1991
CEC cmol$_c$ kg^{-1}	19.57	15 cmol$_c$ kg^{-1}	Landon ,1991
EC (dS/m)	0.145	4(dS/m)	Landon ,1991

4.2. Effect of Integrated use of Lime and Nitrogen Fertilizer on soil Physicochemical Properties

4.2.1. Change in soil bulk density

Application of lime and N solely or in combination affected soil bulk density. Due to the application of lime, bulk density was reduced in all plots (Table 4.2 and Table 4.3). However, the highest reduction (from 1.42 to 1.21 g/cm^3) was recorded in plots treated with 0.5 t ha^{-1} lime with 400kg ha^{-1} urea. This might be due to the increasing effect of soil organic matter (SOM) after harvest which makes the soil less compact and reduces the Bd.

The result was in line with Tesfaye Bayu (2017) who found that a decrease in soil bulk density as a result of integrated use of soil fertilizers at Yilmana Densa district northwestern Ethiopia in maize. The result was also similar with Muhammad *et al*. (2013) who found lower bulk density as a result of nutrient and crop management on crops sugarcane, maize, sorghum, and cotton residues at Gatton, Southern Queensland Australia. However, as Wondimu Bayu *et al*. (2006) reported, the application of inorganic fertilizers alone had no significant effect on bulk density of the soil.

The result was in agreement with Shirani *et al*. (2002) that reported significant decrease in soil bulk density just after harvesting a maize field supplied with integrated use of soil fertilizers. Similarly, Onwonga *et al. (2010)* reported, the positive effect of integrated use of lime, manure and mineral fertilizers on soil physical and chemical properties on maize production at the Kenya Agricultural Research Institute field station located 5 km from Molo Town in Molo District.

4.2.2. pH change of soil

This experiment indicated that pH was affected by integrated nutrient management which was increased with the application of lime and N fertilizer as compared to the control (Table 4.2 and Table 4.3).

In the sole application of urea fertilizer, the highest (5.51) and lowest pH (4.98) was recorded in plots treated with 100 kg ha^{-1} and 400 kg ha^{-1} urea, respectively (Table 4.2). This might be due to effect of nitrification on nitrogen fertilizers. Though, nitrogen fertilizers increase crop yield, at the same time they also increase soil acidity. This is because when the nitrification process converts ammonium to nitrate, hydrogen-ions are released which is one the contributing factors leading to acidification. Hence, the application of N fertilizers containing NH_4^+ or even adding large quantities of organic matter to a soil can ultimately increase soil acidity and lower the pH (Guo *et al.*, 2010). Similarly, Peter *et al.* (2018) found that pH of soil treated with inorganic urea fertilizer was 5.21 as compared with control pH (4.92) in acidic soils of Western Kenya on the Maize crop.

On the other hand, the sole application of lime effectively increased the soil pH from 5.2 to 5.85 (Table 4.2). This rise in pH of soil is associated with the presence of basic cations (Ca^{2+}) and anions (CO_3^{2-}) in lime that are able to exchange H^+ ions from exchangeable sites to form ($H_2O + CO_3^{2-}$). The increase in soil pH resulting from the application of lime provides a more favorable environment for soil microbiological activity which increases the rate of release of plant nutrients, particularly N. Reduced acidity due to liming increased the availability of other plant nutrients mostly P (Kebede Dinkecha and Dereje Tsegaye, 2017).

The result was in line with Peter *et al. (*2018) that reported increased soil pH (5.26) after the application lime as compared to the control that had a pH value of 4.92 in acid soils of Western Kenya. Similarly, Woubshet Demissie (2017) found increased soil pH after the application of lime, where it was changed from extremely acidic pH of 3.8 to medium and neutral pH of 6.63-6.86 in acid Soils of Wolmera District, West Showa, Ethiopia.

This result was also supported by Waluchio *et al.* (2015) who reported the effect of lime in raising the soil pH and increase the availability of soil P by unlocking the soil fixed P into available P for crop use. Lime increases availability of other nutrient elements mostly basic cations essential to crop use especially Ca which forms plant structure (Kebede Dinkecha and Dereje Tsegaye, 2017).

Table 4. 2. Effect of lime and Nitrogen fertilizer on soil physicochemical properties after nine months of lime incorporation

	Soil physicochemical properties							
Treatment	BD (g/cm^3)	pH (H_2O)	SOC (%)	OM (%)	TN (%)	Available P (mg kg^{-1})	CEC (cmol$_c$ kg^{-1})	EC (ds/m)
T1	1.4	5.56	1.33	2.29	0.124	12.24	22.17	0.140
T2	1.39	5.51	1.36	2.34	0.126	15.28	22.19	0.142
T3	1.37	5.49	1.39	2.39	0.129	16.30	22.64	0.144
T4	1.35	5.21	1.59	2.73	0.147	17.78	22.68	0.143
T5	1.32	4.98	1.86	3.18	0.179	26.04	23.36	0.143
T6	1.26	5.85	1.29	2.22	0.120	18.60	27.25	0.138
T7	1.24	6.59	2.23	3.84	0.205	22.84	31.43	0.136
T8	1.23	6.71	2.45	4.21	0.226	24.73	33.21	0.134
T9	1.22	6.76	2.48	4.28	0.228	25.62	34.46	0.132
T10	1.21	6.85	2.51	4.33	0.231	30.43	35.38	0.131
Mean	**1.29**	**6.11**	**1.85**	**3.18**	**0.172**	**21.87**	**27.07**	**0.14**

*T1-control (*200 kg ha^{-1} NPS)*; T2- NPS (200 kg ha^{-1}) + Urea (100 kg ha^{-1}); T3- NPS (200 kg ha^{-1}) + Urea (200 kg ha$^{-1)}$; T4- NPS (200 kg ha^{-1} + Urea (300 kg ha^{-1});T5- NPS (200 kg ha^{-1}) + Urea (400 kg ha^{-1}) ;T6-Lime (500 kg ha^{-1}) +NPS (200 kg ha^{-1});T7-Lime (500 kg ha^{-1}) + NPS (200 kg ha^{-1})+ Urea (100 kg ha^{-1});T8- Lime (500 kg ha^{-1}) + NPS (200 kg ha^{-1})+ Urea (200 kg ha^{-1});T9- Lime (500 kg ha^{-1}) + NPS (200 kg ha^{-1})+ Urea (300 kg ha^{-1});T10- Lime (500 kg ha^{-1}) + NPS (200 kg ha^{-1})+ Urea (400 kg ha^{-1})*

Combined application of lime and inorganic fertilizer improve soil pH. The highest pH (6.85) was recorded from plots treated with 0.5 t ha^{-1} lime with 400 kg ha^{-1} urea (Table 4.2). This is due to the dissociation of urea which releases NH_4^+, so plants take NH_4^+ and release HCO_3^- which reacts with H^+ and form H_2CO_3 acid. This acid is a weak acid and dissociates into H_2O and CO_2. So, CO_2 released to atmosphere water stays in the soil increasing pH by decreasing H^+ ion concentration in the soil solution. On the other hand, dissolution of minerals as ($CaCO_3$) dissolved with H_2O into Ca^{2+} which can be taken by the plant from the soil solution and release CO_3^{2-} to the soil. The increase in OM also increases pH since it can minimize the H^+ from soil solution by forming an organic complex.

This result is supported by Peter *et al.* (2018) that indicated the integrated effect of lime and N fertilizer in increasing soil pH in acid soils of Western Kenya. Similar increases in pH using integrated soil fertility management have been reported by (Whalen *et al.*, 2002; Moreira and Fageria 2010; and Buni Adane, 2014). This was due to the application of lime integrated with N fertilizers.

4.2.3. Change in soil organic carbon (OC)

The maximum SOC content (2.51%) was recorded in plots treated with 0.5 t ha^{-1} lime with 400 kg ha^{-1} urea which was an increase by 52.6% from the initial soil OC analysis result (1.32%). The minimum SOC (2.23%) was recorded from plotes treated with 0.5 t ha^{-1} lime and 100 kg ha^{-1} N (Table 4.2 and Table 4.3). The increase in SOC could be associated with decomposition of dead plant tissue like root and leaves the addition of plant biomass after the addition of lime.

The increased microbial activities by liming are likely to increase SOC mineralization when the soils are cultivated and exposed to increased microbial activity (Six *et al*., 2000). Liming might increase labile C content through SOC incorporating into microbial biomass even though it did not change total SOC content (Nang *et al.*, 2016) at Trobe University farm Victoria, Australia.

The finding was similar with Antill *et al*. (2001) who found that the higher OC of the soil after the application of lime integrated with NP fertilizers at Haryana Agricultural University, India. Besides, Sharma and Subehia (2003) also reported greater levels of SOC under integrated treatments of lime with inorganic fertilizer in acidic soil in the western Himalayas on maize crop. In a similar study Tadesse Moges *et al.* (2018) reported increased amounts of

OC from 2.23%, to 2.49% after the application of lime with integrated inorganic feretilizers in the malt barley crop in Angolela Tera district.

However, the sole application of lime reduced SOC from 1.32% to 1.29%. This is supported by Tadesse Moges *et al.* (2018) found in sole application of lime 4 t ha^{-1} and 6 t ha^{-1} SOC was 2.12% and 2.07%.

4.2.4. Total Nitrogen content

The maximum TN (0.231%) was recorded in T10, i.e in plots treated with 0.5 t ha^{-1} of lime and 400 kg ha^{-1} N. The lowest TN (0.205%) was recorded in plots treated with 0.5 t ha^{-1} of lime and 100 kg ha^{-1} urea (Table 4.2 and Table 4.3). Hence, it is clear that the application of lime with chemical fertilizers increased TN, which may be attributed to mineralization of N from OM during decomposition of organic matter. Generally, the combined application of lime and mineral fertilizers at different rates affects the contents of total N in the study area.

The result was supported by Fassil Kebede and Charles Yamoah (2009) who reported an increased amount of TN in the Vertisols of the Central highlands after the application of lime with mineral fertilizers. An increase in TN after the application of organic integrated with inorganic fertilizers has also been reported by different authors elsewhere in Ethiopia (Getachew Agegnehu and Taye Bekele, 2005; Muhammad *et al*., 2013)

4.2.5. Change in available phosphorus

In the sole application of inorganic fertilizer, the highest and lowest available P was 26.04 mg kg^{-1} and 15.28 mg kg^{-1} recorded in treatments T5 and T2 respectively, (Table 4.2 and Table 4.3). On the other hand the combined use of lime and P fertilizer increased SOC to 2.27 after harvesting of malt barley in one growing season in Angolela Tera district (Tadesse Moges et al., 2018).

After the combined application of lime and urea, the maximum and the minimum values of available phosphorous content was 30.43 mg kg^{-1} and 22.84 mg kg^{-1} in treatments T10 and T7 respectively. Thus, the combined use of lime and chemical fertilizers increased the available P content in the soil by mineralization or solubilizing of the native P reserves in clay soil (Haynes and Naidu, 1997). As a result, soil available P after harvesting was much higher than initial levels in the lime treated plots. Therefore, the major benefits of liming acid soils are the increased utilization of residual fertilizer phosphorus by maize crops. This might be due to mineralization of OM and plant residues.

Table 4. 3. Soil physicochemical properties change after harvest

Soil properties	Values before treatment	Mean Values after harvest	Change	Change Percentage (%)
Bd g/ cm^3	1.42	1.29	-0.13	-9.15
pH (H_2O)	5.20	6.11	0.91	17.5
TN %	0.12	0.172	0.052	43.33
Available P mg kg^{-1}	8.86	21.87	13.01	146.8
Organic carbon (%)	1.32	1.85	0.53	40.15
Organic matter (%)	2.27	3.18	0.91	40.08
CEC $cmol_c$ kg^{-1}	19.57	27.07	7.5	38.32
EC(ds/m)	0.145	0.14	-0.005	-3.33

The incorporation of lime has been shown to increase the amount of soluble organic matter which were mainly organic acids that increase the rate of desorption of phosphate and thus improves the available P content in the soil (Zsolnay and Gorlitz, 1994). Similarly, Kimiti Winnie (2018) showed an increase in soil available P after the application of lime, combined with manure and P fertilizer. Generally, the application of lime and mineral fertilizer gave increased P content.

The result was in line with Gawai (2003) and Tesfaye Bayu (2017) who showed that combination of compost with chemical fertilizer helped in increasing the available P in the soil by mineralization or solubilizing the native P reserves in Yilmana Desnsa district, Northwestern Ethiopia.

4.2.6. Change in Cation exchange capacity

In the sole application of mineral fertilizer, the highest CEC was 23.36 $cmol_c$ kg^{-1} and the lowest 22.19 $cmol_c$ kg^{-1} in treatments T5 and T2 respectively (Table 4.2). This might be due to increased pH, so do the number of negative charges on the clay or organic matter particles, and thus increase CEC. Similarly, Tesfaye Bayu (2017) found an increase in CEC value after the application of mineral fertilizers in the soils of Yilmana Desnsa district.

Similarly after the application of lime alone, CEC was increased from 22.17 cmolc kg^{-1} to 27.25 cmolc kg^{-1} in treatments T1 and T6 respectively. This increase in CEC may be due to an increase in pH that increase the negative surface charges on the soil colloids which subsequently increase the cation holding capacity or CEC of the soil. Similarly, Buni Adane (2014) higher values of CEC after lime treatment in Sodo Zuria Woreda at Kuto Sorpela Kebele, Southern Ethiopia.

Likewise, Getachew Agegnehu *et al.* (2019) found the highest (values of CEC in soils treated with the highest lime rate (3.75 t ha^{-1}) in the Welmera and Endibir district South Western Ethiopia.Besides, in the combined application of lime and N fertilizer, the highest and lowest CEC value was 35.38 cmol$_c$ kg^{-1} and 31.43 cmol$_c$ kg^{-1} recorded in treatments T10 and T7 respectively. This indicates that the combined application of lime and mineral fertilizer increased CEC so as to hold higher amount of nutrients and that readily available to plants. This change was the result of addition of cations from mineral fertilizer and lime.

The result was in compliment with Fassil Kebede and Yamoah (2009) who found high CEC due to an increase in OC and OM after treatment of lime and mineral fertilizer. The result was similar to Agegnehu Getachew *et al*. (2014) who found higher CEC value due to integrated nutrient management.

4.2.7. Electrical conductivity content of soil

The application of lime, urea and their interaction does not affect EC value (Table 4.2 and Table 4.3).

In the sole application of lime, EC was 0.138 dS/m. In the combined application of lime and mineral fertilizer, the highest and lowest EC value was 0.136 ds/m and 0.131 dS/m (Table 4.2). Similarly,Woubshet Demssie *et al.* (2017) found that integrated use of lime and mineral fertilizer (0.611t lime + 2.5 t compost + 75 kg NPSB + 50 kg KCl +36 kg N ha^{-1}) reduce EC of soil from 0.14dS/m lime alone to 0.11dS/m than the control plot (0.07dS/m). This result was in line with Yuli *et al.* (2016) the effects of lime; N fertilizers and their interaction on soil EC was not significantly different.

4.3. Effect of Integrated Use of Nitrogen and Lime on Yield and Yield Components of Maize

4.3.1. Effect of Nitrogen fertilizer and lime on moropho-phenological parameters

4.3.1.1. Days to 50% tasselling

The ANOVA revealed that the application of lime and N ($P \leq 0.01$) and the interaction effect ($P \leq 0.05$) significantly affected days to 50% tasselling of maize (Appendix Table 2).

The analysis also showed that, the maximum and minimum tasselling period was 88 days from plots treated with 0.5 t ha^{-1} lime and 100 kg ha^{-1} urea (i.e treatment T7), and 85 days was recorded in 0.5 t ha^{-1} lime and 400 kg ha^{-1} urea (i.e treatment T10) (Table 4.5). This might be due the uptake of most of the Ca and N by plants that come from lime and N, respectively.

This result was agreed with Negash Teshome (2018) who reported the significant ($P \leq 0.001$) influence of the interaction of lime and potassium on the number of days required for 50% flowering on the soybean crop on acidic soil in Gobu sayo district, western Ethiopia. Further more, Woubshet Demissie *et al.* (2017) found synergistic effect of applied lime and inorganic plant nutrient sources and highly influenced phonological parameters of Barely on acid soils of Wolmera District, West Showa, Ethiopia.

The tasseling period slowed as the nitrogen level decreased and the maximum days to 50% tasseling was 91 days that was recorded under 0 kg urea ha^{-1}. The fastest 50% tasseling was 85 days recorded in the plot treated with 400 kg urea ha^{-1} (Table 4.4). This might be due to the uptake of more N by the maize plant for growth as tasseling time is affected by the amount of N in the soil. Thus, with an increase in urea rate the availability of nutrients in the soil increased. This condition might lead to uniform flowering.

This result was in line with Begizew Golla (2018) that reported a decrease in days of 50% tasseling from 82.44 to 80.89 days in the maize crop when the N rate was increased from 0 to 115 kg ha^{-1}. This result is also in consistent with the finding of Shrestha (2013) who observed the earlier days to tasseling in the maize crop treated with increased rates of N.

The delaying of flowering date in response to N deficiency has been previously acknowledged by different researchers (Tollenaa *et al.,* 1997; Gozubenli, 2010; Shrestha, 2013; Jassal *et al.,* 2017). Brady and Weil (2004) also explained that, in addition the direct nutritional role to the plant, the deficiency of N affects the optimum and efficient utilization of other elements in the soil. However, the result of this study disagreed to Imran *et al.* (2015) that reported a consistent increase in days to 50% tasselling due to the prolonging vegetative growth period, when the rate of nitrogen applied increased. Similarly, the sole application of lime ($CaCO_3$) had a significant ($P \leq 0.01$) effect on days to 50% tasselling between treatments. The minimum tasselling period was 87 days as compared with the control (i.e 89 days) (Table 4.4).

Table 4. 4. Moropho-phenological parameters influenced by as main effect of lime and Nitrogen fertilizer

Main effect	DT (day)	DS(day)	DM(day)
Urea levels (kg ha^{-1})			
0	91.16^{a}	95.17^{a}	143^{c}
100	88.50^{b}	93^{b}	146.33b
200	87.50^{c}	91^{c}	146.50^{b}
300	86.33^{d}	89.67^{d}	147.67^{a}
400	85.66^{e}	89^{d}	148.33^{a}
Mean	87.83	91.5	146.36
LSD (0.05)	0.506	0.484	0.672
CV	0.539	0.564	0.304
SE±	0.26	0.26	0.508
P	**	**	**
Lime (kg ha^{-1})			
0	88.53^{a}	92.86^{a}	146.2^{a}
500	87.13^{b}	90.26^{b}	146.533^{a}
LSD	0.32	0.306	0.42
CV	0.539	0.564	0.304
SE±	0.09	0.092	0.508
P	**	**	*

DT=Days to 50% tasseling, DS=days to 50% silking, DM=Days to 90%maturity,CV: Coefficient variation and LSD=least significance difference, Means within column followed the same letter are not significantly different at 5% probability level,, significantly different at p<0.05, **highly significantly different at p<0.05*

Table 4. 5. Mean moropho-phenological parameters as influenced by the interaction effect of lime and Nitrogen fertilizer

Interaction effect			Growth parameters		
Lime	Urea fertilizer rate	Treatments	DT(day)	DS(day)	DM(day)
L0	N0	T1	92.33^{a}	96.33^{a}	143.67^{e}
	N1	T2	89^{c}	95^{b}	146^{d}
	N2	T3	88^{d}	92^{d}	146^{d}
	N3	T4	87^{e}	91^{e}	147.66^{b}
	N4	T5	86.33^{ef}	90^{f}	147.67^{b}
L1	N0	T6	90^{b}	94^{c}	142.33^{f}
	N1	T7	88^{d}	91^{e}	146.66^{cd}
	N2	T8	87^{e}	90^{f}	147^{cb}
	N3	T9	85.66^{fg}	88.33^{g}	147.66^{b}
	N4	T10	85^{g}	88^{g}	149^{a}
Mean			87.83	91.56	146.36
LSD			0.7157	0.68	0.95
SE±			0.21	0.252	0.333
CV			0.475	0.43	0.37
p			*	**	**

*DT=Days to 50% tasseling,DS=days to 50% silking, DM=Days to 90% maturity, LSD= Least significance difference, SE± =Standard error; CV= Coefficient of Variation, p=probability level; ** significantly different at p<0.05. Means followed by the same letters in a column are not statically different at p<0.05.*

4.3.1.2. Days to 50% silking

The ANOVA revealed that the main effect of N, lime, and their interaction effect significantly (P≤0.01) affected days to 50% silking (Appendix Table 3). Similar to days to tasselling, days to silking were delayed with N deficiency.

The statistical analysis also indicated that the maximum (91 days) and minimum (88 days) DS was recorded in plots treated with 0.5 t ha^{-1} lime and 100 kg ha^{-1} urea as compared with control DS (94 days) (Table 4.5). This result was agreed with Kumar *et al.* (2018) and Habtamu Yigermal *et al.* (2019) that showed the significant influence of fertility management on days to silking on maize crop in central plain zone of Uttar Pradesh, India and Ethiopia respectively. Based on Abdissa Bekele *et al.* (2018) works, days to silking were also hastened with the application of 5 t vermicompost ha^{-1} and 20 kg P ha^{-1} with lime. Likewise, Amanullah Khalid (2015) also recorded delayed (68 days) of silking was after the application of cattle manure (5 t ha^{-1}) with phosphorus (160 kg P ha^{-1}) and with or without PSB.

In the sole application of urea, the early DS (89 days) was recorded in the 400 kg ha^{-1} urea treated plots (Table 4.4). Days to 50% silking were decreased with an increase in nitrogen rates. This decrease in the silking period in response to the increase in the N rate might be associated with hastiness in growth period and promoting silk extrusion. Time of silking is the critical stage of plant growth next to tasselling for effective fertilization and kernels development after flowering (Cantarero *et al.*, 2014). Thus, the factors that affect silking and duration of silking may affect the period of physiological maturity as well as grain production of maize.

The result was agreed with Begizew Golla (2018) that reported decreased days to 50% silking when rate of N added increased from 0 kg N ha^{-1} to 115 kg ha^{-1} maize crop at Bako, Western Ethiopia. Similarly, Dawadi and Sah (2012) and Jassal *et al.* (2017) reported an increase in the earliness of tasselling and silking stages after an increase application of N fertlizers on mize crop in Nepal, Tropical Agricultural Research.

However, there has been some controversy regarding the phenological parameters of maize. According to Imran *et al.* (2015) and Sharifi, and Namvar (2016) maize took more time to tasselling and silking in plots that received the highest rate of N fertilizer in maize in acidic soils. This is also agreed with Raouf and Ali Namvar (2016) that found the maximum days to 50% silking (68.2 days) after the application of 225 kg N ha^{-1}, after three split applications of N fertilizer.

With regarding to the effect of lime, the maximum days to 50% silking (92 days) was recorded in the control and early DS (90 days) was recorded in plots treated with 0.5 t ha^{-1} lime. This might be due to the delaying effect of tasselling.

4.3.1.3. Day to 90% maturity

The effect of N fertilizer significantly ($P \leq 0.01$) affected days to 90% maturity and lime rate also had significant ($P \leq 0.05$) effect on days to 90% maturity although their interaction had highly significantly ($P \leq 0.01$) affected days to 90% maturity (Appendix Table 4).This indicates that increasing the N rate significantly increased the number of days to physiological maturity.

The analysis showed that, days to 90% maturity was affected by the interaction effect of lime and N. The shortest (144) days to maturity was recorded from the control and the longest (149) days to 90% maturity was recorded from plots treated with 0.5 t ha^{-1} lime and 400 kg ha^{-1} urea (Table 4.5). This is due to the availability of N in the soil from urea fertilizer. This might be to increase shoot growth, leave to be green, and maximizes the number of days required to be matured.This might be because of increasing N from urea and Ca^{2+} from lime enhances days to maturity (Brady and Weil, 2002). As the rate of N fertilizer and lime increased days to 90% maturity was increased. The result was inline with Rahman *et al.* (2012) who reported maximum maturity by combining compost and mineral fertilizer. According Abdissa Bekele *et al.* (2018), physiological maturity was significantly extended by applications of lime, vermicompost and chemical P fertilizeron the maize crop in Ebantu District, Western highlands of Ethiopia.

The maximum days to attained 90% physiological maturity were recorded under maximum urea rate (400 kg urea ha^{-1}) which was 148.33 days, but statistically similar days (147.66) to 90% maturity were recorded under application 300 kg urea ha^{-1}. The shortest day to attained 90% physiological maturity was obtained in control plots (143) days (Table 4.4). As the nitrogen rates increased, the days to physiological maturity was also numerically increased. This might be higher N fertilizer delays the senescence of leaves and plant remained more prolong as green stage this could increase the days required to attained physiological maturity.

This result agreed with Shrestha (2013); Sharifi and Namvar (2016); Anwar *et al.* (2017) and (Begizew Golla, 2018) who reported the delay in the process of physiological maturity with the increasing rate of N application in the maize crop. Similarly, Dawadi and Sah (2012) reported that increasing the nitrogen level from 120 kg ha^{-1} to 200 kg ha^{-1} decreased the tasselling, silking, and anthesis-silk interval but increased the physiological maturity and seed fill duration of maize crop. In the sole application of lime, the maximum (147 days) to maturity was recorded from plots treated with 0.5 t ha^{-1} lime while the shortest (146 days) from the control.

4.3.2. Effect of Nitrogen fertilizer and lime rates on vegetative growth parameters

4.3.2.1. Plant height

The analysis showed that the plant height of maize was highly significantly ($P \leq 0.01$) affected by the application of urea and lime but significantly affected by the interaction of the two ($P \leq 0.05$) (Appendix Table 5).

In the combined application, the maximum (352.3cm) plant height was recorded from plots treated with 0.5 t ha^{-1} lime with 400 kg ha^{-1} urea, and minimum (287cm) was recorded from plots treated with 0.5 t ha^{-1} with 100 kg ha^{-1} urea (Table 4.7). This might be a synergetic effect of urea and lime. Increased plant height with the increasing rate of lime and mineral fertilizer rate might be due to the addition of Ca^{2+} nutrient and reduce P fixation and, reduce Al^{3+} and H^{+} ion from the soil, improve CEC, aeration, root penetration, water storage capacity of the soil (Rehman *et al.,* 2012). This is in line with the finding of Mitiku Weldesenbet *et al.* (2014) who found a significant effect of the combined application of organic and inorganic fertilizers on plant height. Likewise, Woubshet Demissie (2017) reported that the integrated application of lime with inorganic fertilizer and compost had a significant effect on Barley plant height.

The maximum mean plant height was recorded from plots treated with 400 kg N ha^{-1} (349.33cm) and the minimum was from control plots (250cm) (Table 4.6). Thus the mean plant height of maize was significantly increased with an increase of urea fertilizer rates. This might be due to the nature of maize crop which take more N for vegetative growth. Also might be improved soil organic carbon and the plant can take N nutrient from urea.

The result agrees with Yihenew G.Selassie (2015) that reported the variance in plant height in the later stages of plant growth than in the earlier stages due to the application of higher N fertilizers maize crop on Alfisols of North-western Ethiopia. Similarly, Alam *et al.* (2003); (Ghafoor, 2016) and (Tolcha Tufa, 2018) reported the significant increase of the maize plant height an increase of N fertilizer application rates.

The result is also coincides with Adekayode and Ogunkoya (2010) who explained a very high significant difference in maize plant height in plots treated with high fertilizers compared with the control. A similar result was reported by Ghafoor and Akhtar (1991) who stated that the application of high N rates had a significant effect on plant height of maize. Likewise, Abera Kechi (2013) reported that an increase in N rates extend vegetative growth period of maize and increases photosynthetic assimilate production and its partitioning to stems that might have favorable impacts on heights of maize.

Plant height was significantly ($P \leq 0.01$) affected by the lime rate. The highest mean plant height (306cm) was recorded from plots treated with 0.5 t ha^{-1} lime and the lowest (291.4cm) was from the control. The result agreed with Woubshet Demissie (2017) that reported increased plant height of barley after application of lime with balanced fertilization.

4.3.2.2. Number of leaves per plant

The analysis of variance revealed that Number of leaves per plant (NLPP) was highly significantly ($P \leq 0.01$) affected by the application of urea and lime as well as the interaction of the two (Appendix Table 6).

The ANOVA indicated that there was a significant increasing in the number of leave per plant by the interaction effect of lime and N fertilizers ($P \leq 0.01$) (Table 4.7). The maximum (14.67) NLPP was recorded from plots treated with 0.5 t ha^{-1} lime and 400 kg ha^{-1} urea while the minimum (11.33) mean NLPP was recorded from plots treated with 0.5 t ha^{-1} lime and100 kg ha^{-1} urea (Table 4.7). This might be added lime and N in acidic soil improves N and P deficiency of the soil which leads to the greenes of maize plant and to be vegetative as well as increase leaf formation.This result also agreed with Woubshet Demissie (2017) that recorded higher number of effective tillers of Barley and NPBS due to the synergetic effect of lime, organic and inorganic fertilizers on acidic soils of Wolmera district West Showa.

The maximum mean number of leaves (14) were recorded in plots treated with 400kg urea ha^{-1} while the smallest mean number (9.5) of leaves were observed from the control (Table 4.6). The photosynthetic activity of a plant which influences growth and yield of the crop is also determined by the number of leaves on a plant. Therefore, the increase in the number of leaves with an increasing rate of N application could be due to the positive effect of N on vigorous vegetative growth and inter-nodal extension.

This result was in line with Adekayode and Ogunkoya (2010) who explained a significant difference in height and number of leaves per plant in maize crop as in plots treated with higher N fertilizer rates as compared with control. This increase in number of leaves in response to higher rates of Nhas been confirmed in the findings of Wajid *et al.* (2007), Gokmen *et al.* (2001), Mitku Woldesenbet and Asnakech Haileyesus (2016) and Tesfaye Bayu (2017), that reported increased height and number of leaves of maize plant with increasing nitrogen fertilizer rates .

Regarding to the effect of lime, the highest NLPP was 12.7 recorded from plots treated with 0.5 t ha^{-1} lime and the lowest was from the control. This might be due to lime increased the uptake of nutrient elements especially P and leaf production. The result was in line with Hassan *et al.* (2007) that reported increased growth and development of maize plants after the application of 0.25 t ha^{-1} lime. Hassan *et al.* (2007) shows that production of maize forage for livestock production can be achieved at this optimum level (0.25 t ha^{-1}).

Table 4. 6. Effect of Nitrogen fertilizer and lime on vegetative parameters as influenced by the main effect

Treatments	PH(cm)	NLPP
Urea levels (kg ha^{-1})		
0	250^{e}	9.50^{e}
100	275.83^{d}	10.83^{d}
200	290.33^{c}	12.17^{c}
300	328.33^{b}	13.5^{b}
400	349.33^{a}	14^{a}
Mean	298	12
LSD (0.05)	0.077	0.411
SE±	0.035	0.173
CV	2.89	3.52
p	**	**
R value	0.981	0.962
Lime (kg ha^{-1})		
0	291.46^{b}	11.27^{b}
500 kg ha^{-1}	306.06^{a}	12.73^{a}
Mean	298.77	12.00
LSD (0.05)	0.049	0.259
SE±	0.022	0.109
CV	2.89	3.52
p	**	**
R value	0.981	0.962

*PH=plant height, NLPP=number of leaves per plant, CV= Coefficient of Variation, p=probability level; ** significantly different at $p<0.05$. Means followed by the same letter in a column are not significantly different at 5 % probability level by DMRT*

Table 4. 7. Mean vegetative parameters as influenced by the interaction effect of lime and Nitrogen fertilizer

Interaction		Growth parameters		
lime	Urea fertilizer rate	Treatments	PH (cm)	NLPP
	N0	T1	251^{g}	9f
L0	N1	T2	264.66^{f}	10.33^{e}
	N2	T3	276.33^{e}	11.33^{d}
	N3	T4	319^{c}	12.33^{c}
	N4	T5	346.33^{ba}	13.33^{b}
L1	N0	T6	249^{g}	10^{e}
	N1	T7	287^{e}	11.33^{d}
	N2	T8	304.33^{d}	13^{b}
	N3	T9	337.66^{b}	14.67^{a}
	N4	T10	352.33^{a}	14.67^{a}
Mean			298.00	12
LSD (0.05)			0.109	0.58
SE±			0.039	0.189
CV			2.14	2.823
p			*	**
R- value			0.983	0.9805

*PH=plant height, NLPP=number of leaves per plant, CV= Coefficient of Variation, p=probability level; ** =highly significantly different at p<0.01, * = significantly different at p<0.05. Means followed by the same letter in a column are not significantly different at 5 % probability level by DMRT*

4.3.3. Effect of Nitrogen fertilizer and lime rates on yield components

4.3.3.1. Number of cobs per plant

Number of cobs per plant was significantly affected ($P \leq 0.01$) by the main effect of N fertilizer and lime. The interaction of N fertilizer and lime had also a significant effect on the number of cobs ($P \leq 0.01$) (Appednix Table 7).

The interaction effect indicated that the maximum (2.93) NCPP was recorded from plots treated with 0.5 t ha^{-1} lime and 400 kg ha^{-1} N while the minimum (1.96) from plots treated with 0.5 t ha^{-1} lime with 100 kg ha^{-1} N (Table 4.9). This might be the result of the synergetic effect of N and Ca. The improvement of soil conditions through lime and urea fertilizer might be responsible for better cob production. This result was in line with Kimiti Winnie (2018) who found improved crop yield of Maize after the combined application of lime, manure and mineral fertilizers as compared with the sole application of mineral fertilizers, lime, and manure. Similarly, Wagh (2002) reported significantly higher cobs of sweet Corn plant after the application of recommended rates of NPK (225:50:50 kg ha^{-1}) with 5 t FYM ha^{-1} and Azotobacter with PSB in India. However, the result was disagreed to Ali *et al.* (2012) that reported insignificant difference in the number of ears per plant of Maize crop after application of compost with N fertilizer at Khyber Pakhtunkhwa Agricultural University Peshawar Pakistan.

The maximum (2.87) mean number of cobs was recorded from plots treated with 400 kg ha^{-1} urea and the minimum (1.37) observed from control (Table 4.8).

The result was in line with the findings of Malaiya *et al.* (2004) who concluded that N fertilizer treatments produced higher cobs. Similar result was also reported by Raisi and Nejad (2012); Shahid *et al.* (2016) and Tesfaye Bayu (2017) who found, higher number of cobs per plant from plots treated with increased N fertilizer rate. Similarly, Yihenew G.Selassie, (2015) indicated increased number of ears per plant of Maize on Alfisols of Northwestern Ethiopia (from 0.993 to 1.077) as N rate increased from 0 kg ha^{-1} to 200 kg ha^{-1}. In addition He reported a significant increase in yield parameters as the rate of application increased to 90 kg N ha^{-1} in Northwestern Ethiopia.

In the sole application of lime, the maximum numbers of cobs (2.327) were recorded from plots treated with 0.5 t ha^{-1} (Table 4.8). This might be due to the involvement Ca supplied in the form of lime in cell growth and division, membrane permeability, enzyme activation protection of cells against toxicity from other elements (Brini *et al.*, 2013).

Figure 4. 1. Partial view of Number of cobs per plant of maize (photo by Birtukan Amare, 2019)

4.3.3.2. Number of grains per cobs

The number grains per cob (NGPC) were significantly affected ($P \leq 0.01$) by the main effect of N and lime (Table 4.8). The interaction of N fertilizer and lime rate had a significant effect on the number of grains per cobs ($P \leq 0.05$) (Table 4.9 and Appendix Table 8).

The ANOVA table indicated that the maximum NGPC (518.1) was recorded from plots treated with 0.5 t ha^{-1} lime and 400 kg ha^{-1} N while the minimum NGPC (496.5) was recorded from plots treated with 0.5 t ha^{-1} lime and 100 kg ha^{-1} urea (Table 4.9). This indicates that treatments with higher N fertilizer applied with 0.5 t ha^{-1} lime supported a significantly higher number of grains per cob as compared to the treatments treated with lower fertilizer and lime rates. This high increase in grain number per cob with the increase of N and lime rate might be due to the synergistic effects of Ca and N fertilizers that improved nutrient use efficiencies and normal development of maize.

This result is consistent with Woubsh Demssie *et al.* (2017) who reported that, higher numbers of kernels per spike (51) of barley were obtained with integrated application of 611kg lime + 5 t compost + 150 kg NPSB + 100 kg KCl +72 kg N ha^{-1} over the control (33). Similarly, Arif *et al.* (2006) reported a significant increase in the number of grains per spike of wheat by applying or manure and mineral fertilizer in combination as compared to inorganic fertilizer alone.

The maximum (517) NGPC was recorded from plots treated with 400 kg N ha^{-1} as compared with the control NGPC (469) (Table 4.8). This might be due to increment of ear length.This is in line with Yihenew G. Selassie (2015) reported that, N fertilizer rates significantly ($P<0.05$) affected grain number per cob and number of cobs per plant.

Similarly, Yihenew G.Selassie (2015) reported a significantly higher number of kernels per ear and ears per stand in plots treated with higher fertilizer rates carried as compared to the treatments with lower fertilizer rates. The reports of Abera Kechi (2013) indicated also increased kernel weight in maize after the application of higher rates of N fertilizers. The number of harvestable kernels per ear to be an important contributor to the grain yield potential of maize plant (Neilson, 2003).

In the sole application of lime, the maximum (501.706) NGPC was recorded from plots treated with 0.5 t ha^{-1} lime compared with control (498.7) (Table 4.8). This might be due to involvement of calcium in cell growth and division. This result was agreed with Woubshet

Demssie *et al.* (2017) where he reported increased number of kernels of malt barley after the application of 611 kg ha^{-1} lime on acidic soils of Wolmera District West Showa Ethiopia.

4.3.3.3. Thousands-grain weight

The ANOVA showed that, TGW was significantly affected by urea, lime, and combination of the two factors ($P \leq 0.01$) (Appendix Table 9).

Combined application of lime with urea had a significant effect on TGW (Table 4.9).
The maximum TGW of maize (417.197g) was obtained from plots treated with 0.5 t ha^{-1} lime and 400 kg ha^{-1} urea while the lowest TGW (369.57g) was recorded from the control plots compared to the sole application of lime TGW (385.49g) (Table 4.9). Such higher increase in TGW might be due to the synergistic effects of the combined fertilizers for better growth and grain filling of maize. The lowest TGW could be due to shrunken seeds that have small size which contributed to the less grain weight because of nutrient deficiency.

This was agreed with Anuradha (2003) that reported higher increase in TGW due to the synergistic effects of integrated application of lime and inorganic fertilizer that increased growth and grain filling of maize crop in the Angrau, Hyderbad, India. This result was also in line with Woubshet Demissie *et al.* (2017) that, reported the highest TSW of barley (44g) after the application of lime, compost, NPSB, KCl. Similarly, Mitiku Weldesenbet *et al.* (2014) reported that after the application of 5 t ha^{-1} FYM in combination with 75% recommended rate of inorganic NP, the highest TGW of barely was obtained compared with application of 100% recommended rate of inorganic NP. Likewise, Saidu *et al.* (2012) obtained the highest TGW of wheat grain from the application of 5 t ha^{-1} FYM and 50% inorganic NP, while the lowest TGW was recorded from control.

In sole application of N fertilizer, the maximum TGW (405.36g) was recorded in plots treated with 400 kg N ha^{-1} and the minimum TGW (377.53g) from the control. In the recommended rate of N fertilizer in the study area TGW was 392.06g. This might be due to the better availability of nutrients (Table 4.8) and inorganic fertilizer the accelerated mobility of photosynthesis from the source to the sink as influenced by the growth hormones synthesized after application of mineral fertilizer (Chandraprabha Koshale *et al.*, 2018). Similarly, higher values of 1000 grain weight was found in the Maize crop after the application higher doses of nitrogen in Nigeria reported by Onasanya *et al.*(2009). The same result was reported by

Begizew Golla (2018) where TGW of Maize crop increased from 340.89g to 353.56g as N fertilizer rates were increased from 92 kg ha^{-1} to 115 kg ha^{-1} at Bako, Western Ethiopia.

There was also significant ($P \leq 0.01$) and strong positive correlations between TGW and grain yield, and total above ground dry biomass (Table 4.8 and Table 4.10).

On the other hand lime had also a significant effect on TGW. The maximum mean TGW (402.37 kg ha^{-1}) was recorded from plots treated with 0.5 t ha^{-1} lime than the control TGW (380.95 kg ha^{-1}). This might be due to the positive correlation of Ca^{2+} with TGW ($r=0.952$) (Table 4.8). This is in line with the study of Woubshet Demssie *et al.* (2017) who found the highest TGW of malt barley (36.52g) after the application of 611 kg ha^{-1} lime as compared with control (9.27g).

Table 4. 8. Mean yield components of maize as influenced by main effect of Nitrogen fertilizer and lime

Main effect	NCPP	NGPC	TGW(g)	GY (kg ha^{-1})	AGDB (kg ha^{-1})	HI (%)	STY (kg ha^{-1})
Urea levels (kg ha-1)							
0	1.36^{e}	468.7333^{e}	377.533^{e}	3600.44^{e}	13098.60^{e}	27.50^{e}	9498.5^{d}
100	1.82^{d}	495.8333^{d}	382.1833^{d}	5678.54^{d}	17637.67^{d}	32.33^{d}	11900.3^{c}
200	2.08^{c}	507.8333^{c}	392.0680^{c}	6141.28^{c}	18319.6^{c}	33.5^{c}	12176.8^{b}
300	2.68^{b}	511.4667^{b}	401.1488^{b}	6619.29^{b}	19430.8^{b}	35^{b}	12714.7^{a}
400	2.87^{a}	517.1667^{a}	405.3633^{a}	7281.34^{a}	20498.1^{a}	35.67^{a}	12892.2^{a}
LSD (0.05)	0.173	0.9573	3.61	35.26	349.14	0.0065	221.44
CV	8.308	0.2036	1.008	2.277	2.352	2.6536	2.163
SE±	0.073	0.416	1.613	54.534	170.883	0.004	104.537
p	**	**	**	**	**	**	**
R value	0.934	0.997	0.952	0.9923	0.9818	0.938	0.971
Lime (kg ha^{-1})							
0	2^{b}	498.7067^{b}	380.947^{b}	5502.53^{b}	17109^{b}	32.4^{b}	11508.27^{b}
500	2.327^{a}	501.7067^{a}	402.37^{a}	6225.82^{a}	18484.9^{a}	33.2^{a}	12164.73^{a}
Mean							
LSD (0.05)	0.109	0.605	2.28	22.3	220.8	0.0041	140.05
CV	8.308	0.2036	1.008	2.277	2.352	2.6536	2.163
SE±	0.046	0.2036	1.02	34.490	108.076	0.002	66.115
p	**	**	**	**	**	**	**
R vale	0.934	0.997	0.952	0.9923	0.9818	0.938	0.971

Table 4. 9. Mean yield components of maize as influenced by the interaction effect of lime and Nitrogen fertilizer

Interaction effect		Yield parameters							
Lime	Urea fertilizer rate	Treatments	NCPP	NGPC	TGW(g)	GY (kg ha^{-1})	AGDB (kg ha^{-1})	HI (%)	STY (kg ha^{-1})
L0	N0	T1	1.00^{f}	466.33^{i}	369.577^{f}	3442.47^{j}	12959.2^{h}	28.33^{f}	9333^{g}
	N1	T2	1.66^{e}	495.13^{g}	374.27^{f}	5294.73^{h}	16904.6^{g}	31.67^{e}	11494.7^{e}
	N2	T3	1.93^{d}	506.06^{e}	380.56^{e}	5766.53^{g}	17474.1^{f}	32.67^{d}	11708.67^{e}
	N3	T4	2.60^{b}	509.73^{d}	386.79^{d}	6116.14^{e}	18513.5^{e}	34.33^{c}	12205.33^{d}
	N4	T5	2.8b^{a}	516.26^{b}	393.53^{c}	6892.8^{c}	19693.8^{c}	35^{bc}	12799.7^{bc}
L1	N0	T6	1.73^{ed}	471.13^{h}	385.49d^{e}	3758.42^{i}	13238^{h}	26.67^{g}	9664^{e}
	N1	T7	1.96^{d}	496.53^{f}	390.097^{dc}	6062.35^{f}	18370.8^{e}	33.0^{d}	12306^{d}
	N2	T8	2.23^{c}	509.6^{d}	403.57^{b}	6516.03^{d}	19165.1^{d}	34.33^{c}	12645^{c}
	N3	T9	2.76^{ba}	513.2^{c}	415.504^{a}	7122.44^{b}	20348.1^{b}	35.67^{ba}	13224^{a}
	N4	T10	2.93^{a}	518.067^{a}	417.197^{a}	7669.88^{a}	21302.4^{a}	36.33^{a}	12984.7^{ba}
LSD (0.05)			0.2446	1.3538	5.114	49.87	493.75	0.0092	313.17
SE±			0.080	0.645	1.767	59.739	187.193	0.004	114.515
CV			6.59	0.157	0.761	0.495	1.617	1.628	1.542
p			**	*	**	**	**	**	*
R- value			0.966	0.9987	0.9778	0.9997	0.9926	0.981	0.9878

*NCPP=number of cobs per plant, NGPC=number of grains per cob, AGDB=above ground dry biomass, GY=grain yield, STY=Straw yield, TGW=thousand grain weight, HI= harvest index, LSD= Least significance difference, SE± =Standard error; CV= Coefficient of Variation, p=probability level; ** significantly different at p<0.05. Means followed by the same letters in a column are not significantly different at p<0.05.*

4.3.3.4. Grain yield of maize

Nitrogen fertilizer, lime, and their interaction had a significant ($P \leq 0.01$) effect on grain yield of maize (Appendix Table 10).

The ANOVA result indicated that the maximum grain yield (7,669.88 kg ha^{-1}) was recorded from plots treated with 0.5 t ha^{-1} lime with 400 kg ha^{-1} N while the minimum grain yield (6062.35 kg ha^{-1}) was recorded from plots treated with 0.5 t ha^{-1} lime and 100kg ha^{-1} N (Table 4.9). This might be due to improved soil condition as both Ca and N nutrient was efficiently taken by the plant. This might be due to increased TGW as yield promoting conditions of maize. Since grain yield has strong and positive correlation with lime and urea (r=0.999).

Similarly, Woubshet Demissie *et al.* (2017) reported barley grain yield of 2744 kg ha-1 that made a significant differencedue to the synergistic effect of lime and plant nutrition. Besides, Shiferaw Bokore and Anteneh Fikadu (2014) reported significant increase of barley yield over the control after the application of lime and all combinations of fertilizers, either alone or combined.

The increased rate of urea from 0 kg to 400 kg ha^{-1} had a significant effect on grain yield (i.e it was increased from 3,600.44 kg ha^{-1} to 7,281.34 kg ha^{-1}). This might be due to favorable conditions, where increasing applications of nitrogen fertilizer increases grain yield. On the other hand, the correlation analysis calculated among yield components and grain yield indicated that all the yield components were correlated highly significantly with grain yield (Table 1.10). This result was in line with the finding of Yihenew G.Selassie (2015) where N fertilizer rate had a significant effect on grain, dry stubble and dry aboveground biomass yields of maize. Similarly, Begizew Golla (2018) reported that the application of highest N rate (115 kg N ha^{-1}) at closer plant spacing (20 cm) gave the maximum yield (10,207.8 kg ha^{-1}).

On the other hand, lime had also a significant effect on maize grain yield. The maximum mean grain yield (6,225.82 kg ha^{-1}) was recorded from plots treated with 0.5 t ha^{-1} lime than the control (5,502.53 kg ha^{-1}) (Table 4.8). From the results presented, lime treatments produced more grain yield compared to the control. This shows that lime alone has the capacity to increase yield by facilitation of nutrient availability to the crop by changing the soil pH. Lime raised soil pH that increased availability of soil P by unlocking the soil fixed P into available P for crop use. Liming is likely to have increased the pH to levels conducive for availability of most nutrients and hence its positive effect on maize growth (Peter, 2017). The available P was also low and was likely a limiting factor for maize growth in this soil.

This result was in agreement with Peter *et al*. (2018) who found maximum maize yield (2.35 t ha^{-1}) after the application of 2 t ha^{-1} lime as compared with the control. Similarly, Woubshet Demsie *et al.* (2017) reported 1682.7 kg ha^{-1} grain yield of malt barley in plots treated with 611 kg ha^{-1} lime.

4.3.3.5. Aboveground dry biomass

The analysis of variance showed that urea, lime, and their interaction had a significant effect on AGDB ($P \leq 0.01$) (Appendix Table 11).

The ANOVA indicated that, the maximum (21,302 kg ha^{-1}) AGDB was recorded from 0.5 t ha^{-1} lime and 400 kg ha^{-1} N, while the minimum (18,370.8 kg ha^{-1}) AGDB was recorded from 0.5 t ha^{-1} lime with 100 kg ha^{-1} N (Table 4.9). This enable the maize to respond well to urea fertilizer and lime application as a result of its well-developed root system which facilitates absorbtion of the required nutrients for effective dry matter production by the crop and reduction of exchangeable acidity in the soil. The increased AGDB of maize might be an indicator of grain yield improvement as well as straw yield for animal fodder. The increased AGDB yield might be due to the release of unavailable nutrients from highly acidic soil by liming and N fertilizers. This high difference in total AGDB might be due to the synergistic effects of N fertilizer and lime as well as high doses of urea and lime which were well known to increase the vegetative growth of plants, OM, SOC and soil CEC.

This result was in agreement with Woldeyesus Sinebo *et al.* (2004); Getachew *et al.* (2012) and Woubshet Demissie *et al.* (2017) stated that there was significance effect of integrated use of lime and urea fertilizer on AGDB of cereals. Likewise, Woubshet Demissie *et al.* (2017) reported that the maximum (11,500 kg ha^{-1}) biomass data was recorded from plots treated with lime, compost, and NPSB and N fertilizer than the control (3,433 kg ha^{-1}). Similarly, Kibunja *et al.* (2010) reported that total dry matter of maize was higher in treatment combinations of inorganic and organic fertilizers than chemical fertilizers alone. Furthermore, Fageria *et al.* (2011) stated that N availability delayed the vegetative and reproductive stages of phenological development and increase biomass production of maize.

In the sole application of N fertilizeras a main factor, the maximum (20,498.1 kg ha^{-1}) and the minimum (17,637.6 kg ha^{-1}) AGDB was recorded from plots treated with 400 kg ha^{-1} and 100kg ha^{-1} N compared with control (13,098.6 kg ha^{-1}) (Table 4.8). . Soil nutrient might be available to plants. Thus, contribute to increase AGDB of maize.

This result was agreed to Yihenew G.Selassie (2015) that indicated increased AGDB of maize as the rate of urea increased from 0 to 200 kg ha^{-1}. The result of the study also agreed with Barker and Pilbeam (2007) that showed strong interactions and nutritional effects of N fertilizers on crop vegetative growth. Similarly, Tesfaye Bayu (2017) recorded at the highest (14.9 t ha^{-1}) AGDB of maize in plots treated with 10 t ha^{-1} compost and full recommendation of mineral fertilizer.

Regarding with lime effect, the maximum (18,484.9 kg ha^{-1}) AGDB was recorded from plots treated with 0.5 t ha^{-1} while the minimum (17,109 kg ha^{-1}) was recorded from the control (Table 4.8). This might be improved condition of soil by Ca derived from the applied lime. This was in line with Achalu Chimdi *et al. (*2012) who reported increased dry biomass of Barely in the plots treated with lime (2811.4 kg ha^{-1}) than the control (2452.7 kg ha^{-1}).

4.3.3.6. Harvest index of maize

Harvest index is the ratio of economic yield to AGDB yield reported in percent. All treatments as the main effect of lime, N, and their interaction had a significant ($P \leq 0.01$) effect on HI (Appendix Table. 12).

The ANOVA indicated that, the maximum (36.33%) HI was recorded from plots treated with 0.5 t ha^{-1} lime with 400 kg ha^{-1} N. While the minimum (33%) HI was recorded from plots treated with 0.5 t ha^{-1} lime and 100 kg ha^{-1} N (Table 4.9). This might be due to overall improvement of soil by integrated use of lime and N. This indicates that combined use of lime and N fertilizer improve both grain yield and AGDB. From the total AGDB yield 63.67% was straw yield. But HI of 33% revealed that remaining 67% of total AGDB was straw yield.

This was in agreement with Woubshet Demissie *et al.* (2017) reported that the HI of barley was significantly ($P \leq 0.01$) influenced with integrated application of lime and recommended rate of organic and inorganic fertilizers. Likewise, Woubshet Demissie *et al.* (2017) found the highest HI of barley (47%) was obtained with 0.611 t lime ha^{-1}, 5 t compost, 150 kg NPSB, 100 kg KCl and 72 kg N ha^{-1} as compared to other treatments that received less combination of applied lime and fertilizers.

In sole application of N the maximum (35.67%) HI was recorded from plots treated with 400 kg ha^{-1} urea. While the minimum (32.33%) HI was recorded from plots treated with 100 kg ha^{-1} N compared with control HI (27.5%) (Table 4.8). This indicates that how the AGDB of maize is converted into yield. It might be due to the timely availability of N and improvement in soil condition.

The result was in line with Syed *et al.* (2009) who reported that HI was significantly affected by the organic and inorganic source of N. The results were agreed with Shah and Arif (2001), who observed the positive effects of different fertilizers rates on maize HI in maize based cropping system.

Regarding with lime effect, the maximum (33.2%) HI of maize was recorded from plots treated with 0.5 t ha^{-1} lime than control (32.4%) (Table 4.8). This might be due to the increment of grain yield and AGDB because of soil physicochemical improvement.

This result was in line with Tadese Moges *et al.* (2018) lime had a significantly ($p \leq 0.01$) effect on malt barley HI. Similarly, Tadese Moges *et al.* (2018) reported that the maximum HI (27.19%) of malt barley was obtained from plots treated with 4 t ha^{-1} lime than the control HI (24.77%). In contradict with this Woubshet Demissie *et al*. (2017) reported that maximum (38%) HI of barely was obtained from the control plot and the minimum (37%) HI was recorded from plots treated with 611 kg ha^{-1} lime alone.

4.3.3.7. Straw yield of maize

The ANOVA table (Appendix Table 13) showed that, STY was highly significantly ($P \leq 0.01$) affected by main effect of lime and N fertilizer but it was significantly ($P \leq 0.05$) affected by the interaction effect (Table 4.9).

The interaction effect indicated that, the minimum (9,333 kg ha^{-1}) straw yield was recorded from control plot while the maximum STY was recorded from plots treated with 0.5 t ha^{-1} lime combined with 300 kg ha^{-1} N (13,224 kg ha^{-1}) followed by STY (12,984.67 kg ha^{-1}) obtained from plots treated with the combined use of 0.5 kg ha^{-1} lime and 400 kg ha^{-1} N (Table 4.9).This might be due to adequate supply of nutrients to the crop helps in the synthesis of carbohydrates, which are required for the formation of protoplasm, thus resulting in higher cell division and cell elongation. Thus, an increase in straw yield might have been on account of overall improvement in the vegetative growth of the plant due to the application of lime in combination with urea.

This result was in line with Woubshet Demissie *et al.* (2017) the mean straw yield of Barley (6114 kg ha^{-1}) were obtained with 611 kg lime ha^{-1}, 5 t compost,150 kg NPSB, 100 kg KCl,72 kg N ha^{-1} as compared to control for straw yield (2115 kg ha^{-1}). Similar results were obtained by Makinde and Ayoola (2010) who reported that integrated application of organic, lime and N fertilizers is effective for the growth of maize and improving straw yields.

In sole application of N the maximum (12,892.2 kg ha^{-1}) STY was recorded from plots treated with 400 kg ha^{-1} N but statically same with plots treated with 300 kg ha^{-1} urea straw yield (12,714 kg ha^{-1}) (Table 4.8). While the minimum (11,900.3 kg ha^{-1}) STY was recorded from plots treated with 100 kg ha^{-1} N. This result might be due to N availability of in the soil and improved AGDB. The rise of soil pH and improved soil conditions might be enables synergetic effect of soil nutrients. This was agreed with Tesfaye Bayu (2017) found that STY was increased from 1.64 t ha^{-1} to 7.51 t ha^{-1} as 0 kg N and 0 kg NPSZnB fertilizer to 75 kg N and 100 kg NPSZnB fertilizer.

Regarding with sole application of lime, STY was increased from 11,508.27 kg ha^{-1} to 12,164.7 kg ha^{-1} as lime was increased from 0 to 0.5 t ha^{-1} (Table 4.8). The application of lime is a prerequisite to achieve good straw yields on acid soils. This result was agreed with Woubshet Demissie *et al.* (2017) who reported that STY of barely was increased from 2116 kg ha^{-1} to 2801 kg ha^{-1} as lime was applied 0 to 611 kg lime ha^{-1}.

4.4. Correlation of Maize Yield and Yield Components

A simple correlation analysis was done to evaluate the association of various agronomic parameters of maize (Table 4.10). The correlation study indicate that, STY was highly and positively correlated with AGDB(r=0.987) and HI (r=0.959), PH (r=0.857), NLPP (r=0.886), DM (r=0.915), NCPP (r=0. 841), TGW(r=0.743) and NGPC (r=0.954). This indicates that the effect of lime and urea fertilizer showed positive increment. When the rate increased the STY increased as well as all the above parameters also increased. But DS (r=-0.887) and DT (r=-0.927) were highly and negatively correlated with STY (Table 4.10). This indicate that the effect of lime and urea (i.e when the rate increased the STY increased while DS and DT decreased.

Similarly, grain yield was highly and positively correlated with AGDB (r=0.996), HI(r=0.987), STY (r=0.977), NGPC (r=0.966),DM (r=0.931), NLPP (r=0.0.923),PH (r=0.909), NCPP (r=0.885) and TGW (r=0.797), and This indicate that the effect of lime and urea fertilizer (i.e when the rate increased the GY increased as well as all the above parameters also increased. It was also highly and negatively correlated with DT (r=-0.957) and DS (r=-0.925). This indicate that the effect of lime and urea (i.e when lime and urea fertilizer rate increased the grain yield increased while DT and DS decreased (Table 4.10). This revealed that grain yield was highly significantly increases with an increase of grain yield per cobs, number of cobs per plant and plant height. In general all of the parameters (growth parameters and yield components) were positively and significantly correlated with GY except that of DT and DS.

This result was in line with Yihenew G. Selassie (2015); Habtamu Admas *et al*. (2015) and Tesfaye Bayu (2017) that grain yield of maize were positively and significantly correlated with yield components.

Table 4. 10. Pearson’s simple correlation coefficient among yield and yield components of maize

Correlations	DT	DS	DM	PH	NLPP	NCPP	NGPC	TGW	GY	AGDB	HI	STY
DTAS	1											
DSILK	.950**	1										
DM	-.853**	-.803**	1									
PH	-.888**	-.889**	.873**	1								
NLPP	-.904**	-.929**	.833**	.925**	1							
NCPP	-.936**	-.901**	.789**	.908**	.890**	1						
NGPC	-.936**	-.863**	.915**	.871**	.868**	.870**	1					
TGW	-.803**	-.887**	.658**	.792**	.905**	.794**	.676**	1				
GY	-.957**	-.925**	.931**	.909**	.923**	.885**	.966**	.797**	1			
AGDB	-.944**	-.906**	.942**	.897**	.912**	.865**	.962**	.779**	.996**	1		
HI	-.890**	-.856**	.961**	.899**	.888**	.821**	.955**	.710**	.987**	.974**	1	
STY	-.927**	-.887**	.915**	.857**	.886**	.841**	.954**	.743**	.977**	.987**	.959**	1

**=Correlation is significant at the 0.01 level (1-tailed).

HI= harvest index, STY=straw yield, GYPC=Grain yield per cob, GY=Grain yield, AGDB=above ground dry biomass, PH=plant height, NCPP=number of cobs per plant, DM= Date of 90% maturity, DS= Date of 50% silking and DTAS=Date of 50% tasseling

4.5. Economic Feasibility Analysis of Maize

As shown in Appendix Table 14, total variable costs which are responsible for yield increase in each treatment were listed.

During the 2018/2019 rainy season the market price of Maize taken at Burie District was 10 Ethiopian Birr per kilogram (ETB kg^{-1}). Field prices for NPS, urea, and lime were taken as 10.40, 12.00 and 1.35 ETB kg^{-1}, respectively. The cost of labour for harvesting and bagging were taken at 28 ETB 100 kg^{-1}, the cost of labour for incorporation and transportation of lime was taken at 25 ETB 100 kg^{-1}, the cost of application and transport for fertilizer during planting was 1000 ETB kg^{-1} considering that 10 laborers can apply fertilizer on a hectare of land in 1 day (daily wage of one laborer is 100 Birr). The same amount of money would be required for side dressing. So it should be 1000 ETB for urea treated plot and daily wage of one labor was 100ETB.

The marginal and dominances analysis of maize in T2, T7, T9 and T8 had greater than 100% in MRR (Table 4.11 and Table 4.12). The maximum net benefit (58,891.47 Ethiopian Birr) with MRR value of (805.24%) was obtained from T9-lime (0.5 t ha^{-1}) + 300 kg ha^{-1} urea) as compared to T8-lime (0.5 t ha^{-1}) + urea (200kg ha^{-1}) NB (47,701.04 ETB) with MRR (203.59%) (Table 4.11). This means for T9 on average for each 1 Birr ha^{-1} invested, the return was 1 birr, plus 8.05 Birr ha^{-1} in the net benefit which is economically feasible as compared to T8 that showed 1Birr recovery plus 2.04 Birr ha^{-1} net benefit. The MRR analysis of treatment 2, 7, 8 and 9 was more than 100% but T9 is economically feasible to recommend for the farmers.

This study suggests that it could be advisable for farmers in the study area to apply integrated lime at 0.5 t ha^{-1} plus 300 kg ha^{-1} urea to enhance maize grain yield and ensuring maximum economic return.This recommendation is also supported by CIMMYT (1988) which stated that farmers should be willing to change from one treatment to another if the marginal rate of return of that change is greater than the minimum acceptable rate of return.

This result was in line with Woubshet Demelash *et al.* (2017) who reported that integrated use of lime, compost, recommended NPS, KCl and urea fertilizer gave the highest grain yield net benefit and MRR on Barley production. Similarly, Trinh *et al.* (2008) reported that higher grain yield and higher net benefit was recorded from higher planting density with higher NPK rate of site specific nutrient management (SSNM).

Table 4. 11. Dominances analysis of Maize

Treatments	TVC(ETB ha^{-1})	Net benefit (ETB ha^{-1})	Dominance
T1	5928.92	25842.43	Non-dominated
T6	6689.272	26356.478	Non-dominated
T2	8599.701	39052.869	Non-dominated
T7	9598.291	44962.859	Non-dominated
T3	9899.129	41999.641	Dominated
T8	10943.23	47701.04	Non-dominated
T4	11281.57	43763.69	Dominated
T9	12332.93	58891.47	Non-dominated
T5	12630.82	51769.03	Dominated
T10	13667.99	55360.93	Dominated

Treatment 3=with 200kg ha^{-1} urea alone, T4=with 300kg ha^{-1} urea alone and T5= with 400kg $ha^{-}1$ urea, treatment 10=with 0.5 t ha^{-1} lime and 400 kg ha^{-1} urea were dominated treatments. Hence, these are rejected from further consideration in marginal analysis. Based on this treatment 3, 4, 5 and 10 are rejected because they are dominated by other treatments.

Table 4. 12. Marginal analysis of Maize

Treatments	Grain Yield (kg ha^{-1})	Adjusted yield (-10%) (kg ha^{-1})	Gross return (ETB ha^{-1})	TVC(ETB ha^{-1})	Net benefit (ETB ha^{-1})	MRR (%)
T1	3530.15	3177.135	31771. 35	5928.92	25842.43	---
T6	3671.75	3304.575	33045.75	6689.272	26356.478	67.6
T2	5294.73	4765.257	47652.57	8599.701	39052.869	664.5
T7	6062.35	5456.115	54561.15	9598.291	44962.859	591.8
T3	5766.53	5189.877	51898.77	9899.129	41999.7 **D**	---
T8	6516.03	5864.427	58644.27	10943.23	47701.04	203.59
T4	6116.14	5504.526	55045.26	11281.57	43763.69 **D**	---
T9	7122.44	6410.196	64101.96	12332.93	58891.47	805.24
T5	6892.8	6203.52	62035.2	12630.82	51769.03 **D**	---
T10	7669.88	6902.892	69028.92	13667.99	55360.93**D**	-----

D=dominated treatment

4.6. Agronomic Use Efficiency

Agronomic use efficiency reflects the direct production impact of an applied fertilizer and relates directly to economic return. As shown in Table 4.13 the nutrient use efficiency (NUE) was good for those plots treated with 100 kg ha^{-1} urea and has the highest NUE which is 5.88%. This was due to the fact urea fertilizers were known in releasing nutrients immediately to the soil and crop which account in yield increase. The maximum (5.88%) AUE was recorded from plots treated with 100 kg ha^{-1} urea while the lowest AUE (0.202%) was recorded from plots treated with 0.5 t ha^{-1} lime alone. This confirms that, inorganic fertilizer release nutrients immediately while lime does not release nutrients immediately for maize. The remaining might be lost through erosion, leaching, dinitrification and changed to organic stock.

The result was similar with Tesfaye Bayu (2017) who reported that, the highest agronomic use efficiency (16.14%) of maize was obtained from plots treated with mineral fertilizer only (75 kg ha^{-1} N fertilizer plus 100 kg ha^{-1} NPSZnB fertilizer and lowest NUE (0.04%) was obtained from plots treated with compost only (5000 kg ha^{-1}).

Similarly, William and Gordon (1999) who reported low nitrogen use efficiency in cereal production due to dinitrifecation. Plots treated with lime alone or in combination with urea fertilizer were low in their NUE. This is due to the fact that lime is not providing nutrients to the soil and crops immediately. William *et al.* (2012) found the effect of N fertilizer rate on agronomic use efficiency.

Table 4. 13. Agronomic use efficiency for maize

Treatments	lime(kg/ha)	N fertilizer (kg/ha)	NPS fertilizer (kg/ha)	Total nutrient added	Grain yield of (kg/ha)	AUE
L0N0	--	--	200	200	3530.15	--
L0N1	--	100	200	300	5294.73	**5.88**
L0N2	--	200	200	400	5766.53	5.59
L0N3	--	300	200	500	6116.14	5.17
L0N4	--	400	200	600	6892.8	5.604
L1N0	500	--	200	700	3671.75	**0.202**
L1N1	500	100	200	800	6062.35	3.16
L1N2	500	200	200	900	6516.03	3.32
L1N3	500	300	200	1000	7122.44	3.59
L1N4	500	400	200	1100	7669.88	3.76

V. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

From the result of the study, the following can be concluded; Inherent physicochemical properties of the study area soil including; Bd was higher than the critical value, pH value was low, and the experimental site soils were under the critical value in SOC, OM, TN, available P and CEC.

Soil physicochemical properties were improved after harvesting of maize by combined use of lime and N fertilizers.

Integrated use of lime and N fertilizer was found economically feasible for maize production. The optimum rate of lime and N fertilizer for yield increment, soil fertility improvement and maximum economic benefit was 0.5 t ha^{-1} lime and 300 kg ha^{-1} urea with full recommendation of NPS. Application ofN fertilizer had good agronomic use efficiency than lime.

5.2. Recommendations

To increase crop yield and improve soil fertility at Burie District on a sustainable way, the following recommendations are suggested based on the result of the study.

- Farmers should use 0.5 t ha^{-1} lime and 300 kg ha^{-1} urea with full recommendation NPS.
- The government should supply lime ($CaCO_3$) and urea for the farmers.
- Further study should be done in the residual effect of lime for further growing seasons, with organic and inorganic fertilizers as well as economic feasibility.
- Further study should be done in the effect of lime and N fertilizer in long rainy seasons.

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APPENDICES

Appendix Table 1. Critical level used for classifying soil fertility parameters analysis result

Soil parameters	Status	Critical level	Reference	Soil parameters	Status	Critical levels	Reference
Soil pH(water)	Strongly acidic	<5.5	ETHoSIS,2014	Available P mg/kg	Very low	0-15	ETHoSIS,2014
	Moderately acidic	5.6-6.5			low	15-30	
	Neutral	6.6-7.3			Optimum	30-80	
	Moderately alkaline	7.3-8.4			High	80-150	
	Strongly alkaline	>8.4			Very high	>150	
EC(dS/m)	Salt free	< 2	Landon,1991	Organic matter (%)	Very low	<0.2	Landon,1991
	Very slightly	2-4			Low	2.0-3.0	
	Saline	4-8			Optimum	3.0-7.0	
	Slightly saline	8-16			High	7.0-8.0	
	Moderately saline	> 16			Very high	> 8.0	
Total N (%)	Very low	< 0.1	ETHoSIS,2014	CEC(cmol/kg)	Very low	<0.2	Landon,1991
	Low	0.1-0.5			Low	5-15	
	Optimum	0.15-0.3			Medium	15.25	
	High	0.3–0.5			High	25-40	
	Very high	> 0.5			Very high	>40	

Appendix Table 2. ANOVA table for days to 50% tasseling

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Urea	4	111.66	27.91	279.17	<.0001
Lime	1	14.70	14.70	147.00	<.0001
Rep	2	0.86	0.43	4.33	0.0531
Urea*lime	4	1.80	0.45	4.50	0.0338
Rep*urea	8	2.133	0.26	2.67	0935
Rep*lime	2	0.200	0.10	1.00	0.4096

Appendix Table 3. ANOVA table for days to 50% silking

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Urea	4	153.20	38.30	287.25	<.0001
Lime	1	50.70	50.70	380.25	<.0001
Rep	2	0.466	0.233	1.75	0.2342
Urea*lime	4	4.133	1.033	7.75	0.0074
Rep*urea	8	1.200	0.150	1.13	0.4359
Rep*lime	2	0.60	0.33	2.25	0.1678

Appendix Table 4. ANOVA table for Days to 90% physiological maturity

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Urea	4	101.466	25.366	179.06	<.0001
Lime	1	0.833	0.833	5.88	0.0415
Rep	2	0.466	0.233	1.65	0.2517
Urea*lime	4	6.667	1.667	11.76	0.0020
Rep*urea	8	0.533	0.441	3.12	0.0642
Rep*lime	2	0.866	0.433	3.06	0.1031

Appendix Table 5. ANOVA table for plant height

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Urea	4	3.84385333	0.96096333	243.85	<.0001
Lime	1	0.15987000	0.15987000	40.57	0.0002
Rep	2	0.00748667	0.00374333	0.95	0.4264
Urea*lime	4	0.09081333	0.02270333	5.76	0.0175
Rep*urea	8	0.03364667	0.00420583	1.07	0.4645
Rep*lime	2	0.00854000	0.00427000	1.08	0.3833

Appendix Table 6. ANOVA table for the Number of leaves per plant

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Urea	4	83.33	20.83	312.50	<.0001
Lime	1	16.13	16.13	242.00	<.0001
Rep	2	2.60	1.30	19.50	0.2301
Urea*lime	4	2.60	0.47	7.00	0.0100
Rep*urea	8	1.87	0.13	2.00	0.1733
Rep*lime	2	0.47	0.23	3.500	0.0809

Appendix Table 7. ANOVA table for the number of cobs per plant

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Urea	4	9.1580	2.28	249.76	<.0001
lime	1	0.800	0.80	87.31	<.0001
Rep	2	0.200	0.100	10.95	0.114
urea*lime	4	0.344	0086	9.40	0.0041
Rep*urea	8	0.276	0.0345	3.76	0.0394
Rep*lime	2	0.0167	0.0083	0.91	0.4408

Appendix Table 8. ANOVA table for the number of grains per cobs

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Urea	4	8893.752000	2223.438000	4092.22	<.0001
Lime	1	67.500000	67.500000	124.23	<.0001
Rep	2	3.082667	1.541333	2.84	0.1172
Urea*lime	4	11.613333	2.903333	5.34	0.0215
Rep*urea	8	4.464000	0.558000	1.03	0.4854
Rep*lime	2	2.400000	1.200000	2.21	0.1723

Appendix Table 9. ANOVA table for1000 seed weight of maize

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Urea	4	3404.134120	851.033530	161.83	<.0001
lime	1	3442.858239	3442.858239	654.68	<.0001
Rep	2	40.663398	20.331699	3.87	0.0669
Urea*lime	4	183.511173	45.877793	8.72	0.0051
Rep*urea	8	98.668231	12.333529	2.35	0.1246
Rep*lime	2	19.214743	9.607372	1.83	0.2221

Appendix Table 10. ANOVA table for Grain yield of maize

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Urea	4	46885701.17	11721425.29	13769.9	<.0001
Lime	1	3923591.48	3923591.48	4609.30	<.0001
Rep	2	1977.34	988.67	1.16	0.3607
Urea*lime	4	377347.59	94336.90	110.82	<.0001
Rep*urea	8	6808.13	851.02	1.00	0.5001
Rep*lime	2	1595.84	797.92	0.94	0.4308

Appendix Table 11. ANOVA table for above ground dry biomass of maize

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Urea	4	194031964.4	48507991.1	580.09	<.0001
lime	1	14197334.2	14197334.2	169.78	<.0001
Rep	2	170256.6	85128.3	1.02	0.4037
Urea*lime	4	2363235.1	590808.8	7.07	0.0098
Rep*urea	8	659186.5	82398.3	0.99	0.5081
Rep*lime	2	163140.9	81570.5	0.98	0.4177

Appendix Table 12. ANOVA table for harvest index of maize

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Urea	4	0.02511333	0.00627833	163.78	<.0001
Lime	1	0.00048000	0.00627833	12.52	0.0076
Rep	2	0.00002000	0.00001000	0.26	0.7767
Urea*Lime	4	0.00115333	0.00028833	7.52	0.0081
Rep*Urea	8	0.00014667	0.00048000	0.48	0.8414
Rep*Lime	2	0.00006000		0.78	0.4893

Appendix Table 13. ANOVA table for the Straw yield of maize

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Urea	4	44830525.67	11207631.42	336.65	<.0001
Lime	1	3232113.63	3232113.63	97.08	<.0001
Rep	2	66734.60	33367.30	1.00	0.4089
Urea*Lime	4	842560.87	210640.22	6.33	0.0134
Rep*Urea	8	266601.73	33325.22	1.00	0.4995
Rep*Lime	2	67000.47	33500.23	1.01	0.4076

Appendix Table 14. Partial budget analysis of lime and N fertilizer rates applied for maize in Burie District

Items	Treatments									
	1	2	3	4	5	6	7	8	9	10
GY (kg/ha)	3530.15	5294.73	5766.53	6116.14	6892.8	3671.75	6062.35	6516.03	7122.44	7669.88
GB (ETB/ha)	35301.5	52947.3	57665.3	64461.4	68928	36717.5	60623.5	65160.3	71224.4	76698.8
Cost of BH661/ha	520.83	520.83	520.83	520.83	520.83	520.83	520.83	520.83	520.83	520.83
Cost of NPS fertilizer/ha	2080	2080	2080	2080	2080	2080	2080	2080	2080	2080
Cost of lime	0	0	0	0	0	675	675	675	675	675
Cost of urea	0	1200	2400	3600	4800	0	1200	2400	3600	4800
Cost of urea fertilizer application	0	1000	1000	1000	1000	0	1000	1000	1000	1000
Cost of NPS application	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Cost of lime application	0	0	0	0	0	125	125	125	125	125
Cost of weeding and cultivation	1300	1300	1300	1300	1300	1300	1300	1300	1300	1300
Cost of harvesting and bagging	1028.09	1498.87	1598.298	1780.744	1929.98	988.442	1697.46	1842.40	2032.097	2167.1636
TVC	5928.9	8599.701	9899.129	11281.57	12630.82	6689.272	9598.291	10943.23	12332.93	13667.99
NB (ETB/ha)	29,372.5	44,347.59	47,766.2	53,179.83	56,297.18	30,028.2.	51,025.21	54,217.07	58,891.5	63,030.81

GY=grain yield, GB=gross benefit, TVC=total variable cost, NB=net benefit

Appendix Table 15. Summary of 10 years (2010-2019) mean rainfall and temperature data of study area

Climate data	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total RF
						Average Rain fall (mm)							
RF(mm)	7.2	7.8	46.2	52.6	194.0	242.8	313.1	201.3	144.0	84.8	71.9	10.0	1375.8
			Mean Monthly Temperature(^{0}C)								Mean Temperature		
MinT.(^{0}C)	10.37	11.19	12.65	12.59	14.01	14.4	12.53	13.80	12.40	12.19	11.81	9.67	12.31
Max.T.(^{0}C)	27.81	28.71	29.25	28.74	24.69	24.92	23.10	22.33	24.28	25.70	24.85	26.81	25.93
MeanT.(^{0}C)	19.09	19.95	20.95	20.66	19.35	19.70	17.82	18.06	18.34	18.94	18.33	18.24,	19.12

APPENDEX FIGURES

Appendix Figure 1. Partial view of ten treatments with three replication and yield

AUTHOR'S BIOGRAPHY

The author, Birtukan Amare Kebede was born on 3 March 1981 E.C in Guagusa Shikudad District, Awi Administrative Zone, Amhara Regional State, Ethiopia.

She attended elementary education (grade 1-8) at Tillili Aguta Elementary School from 1989 -1996 E.C. After completing elementary education, she was enrolled at Tillili Secondary School from 1997-1998 E.C (grade 9-10) and then she was enrolled Enjibara Preparatory School at Enjibara town from 1999-2000 E. C (grade 11-12). She then joined Debre Markos University college of Agriculture and Natural resource in October 2001 E.C and graduated with Bachelor of Science degree on Natural Resource Management in July 2003 E. C.

Following her graduation, she was a Soil and water conservation expert at Guagusa Shikudad District in Land administration and environmental protection office from October (2004-2006 E.C) and then from 2007 E.C still now she is employed by Burie Poly Technic College as Trainer in Natural resources and plant science Department. Then after, in July 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 summer program as a candidate for Master of Science degree in Watershed management, soil and water conservation.