RESPONSE OF MAIZE (*ZEA MAYS* L.) TO OMISSION OF NUTRIENTS AT KERSA DISTRICT, JIMMA ZONE, SOUTH WESTERN ETHIOPIA

M.Sc. THESIS

By:-

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October, 2018

Jimma, Ethiopia

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M.Sc. Thesis

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In Partial Fulfillment of the Requirements for the Degree of Master of Science in Soil Science

By

Obsa Atnafu

October, 2018

Jimma, Ethiopia

DEDICATION

This thesis is dedicated to my father Atnafu Wendimu and my mother Magartu Gula who have sown the interest of learning in my mind and wishing me a great career throughout my life.

STATEMENT OF THE AUTHOR

I hereby declare that this thesis entitled; **Response of Maize (*Zea Mays* L.) To Omission of Nutrients at Kersa District, Jimma Zone, South Western Ethiopia** is my original work and has not been submitted in any University and all the sources of materials used for the thesis are properly acknowledged. The thesis is deposed at the Jimma University library to make available to borrowers under the rules of the library.

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ACRONYMS AND ABBREVIATIONS

BD	Bulk Density
DM	Dry Matter
TN	Total Nitrogen
OC	Organic Carbon
OM	Organic Matter
CEC	Cation Exchange Capacity
SSA	Sub-Saharan Africa
TSP	Triple Super Phosphate
NUE	Nutrient Use Efficiency

BIOGRAPHICAL SKETCH

The author, Obsa Atnafu, was born on 09 February 1988 G.C in Jeldu District West Shoa Zone, Oromia National Regional State. He attended his elementary school education at Shukutie Primary School 1996-2003 and Secondary School 2004-2006 at Jeldu Secondary School and Senior Secondary School 2007-2008 at Ginchi Senior Preparatory School. Then he joined Jimma University (2009- 2011) and graduated with B.Sc. degree in Plant science. Then, he was employed by the Agricultural and Rural Development Bureau of Gimbichu District of East Shoa Zone, Oromia regional state in 2012. After he served 2.4 years then he got the chance to joined Ethiopian Institute of Agricultural Research (Jimma Agricultural Research Center) in 2014 as Junior Researcher. In September, 2017 he joined the school of graduate studies of Jimma University, College of Agriculture and Veterinary Medicine to pursue his M.Sc. degree in Agriculture (Soil Science).

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ABSTRACT

Appropriate fertilization practices based on actual limiting nutrient and crop requirement for a given crop is economic and judicious use of fertilizers for sustainable crop production. Balanced nutrition must be achieved to optimize maize productivity. *A field experiment was conducted with an objective to identify which of macronutrients N, P and K are limiting maize grain and yield components in the study area during 2017/18 cropping season. The experiments were laid out in a completely randomized block design with six treatments replicated across six farmers' fields in Kersa district, Jimma zone, south western Ethiopia. The trial consisted of six treatments, which include; control, PK (-N), NK (-P), NP (-K), NPK and NPK+ CaMgSZnB. Among the six treatments, -N, -P, and -K were set to estimate the inherent N, P and K supplying capacity of soil respectively. The yield and soil fertility gap between a full NPK fertilizer plot and a fertilizer omission plot was used as a good diagnostic tool to assess the extent of macronutrient limitations. Average maize yields were the highest in the NPK treatment, followed by those in the NPK+CaMgSZnB plots among all treatments. Maize yield, a significantly increasing trend over time was found in the NPK-treated plots and a decreasing trend in the PK and NK-treated plots. In the absence of N or P, maize yields were significantly lower than those in the NPK treatment. A balanced use of NPK has a remarkable influence on maize growth and yield. Among different treatments NPK combinations, provided the highest grain yield of 9185 kg ha^{-1}andthe lowest (1861.3 kg ha^{-1}) was obtained from control plots. Nitrogen, Phosphorus and Potassium are macronutrients that play a major role in plant growth and crop yields. Yield responses to fertilization were ranked NPK > NPK+CaMgSZnB >NP>PK>NK, illustrating that N deficiency was the most limiting condition in maize production, followed by P and K deficiencies. As compared with the NP treatment, the NPK treatment was significantly increased maize yields by 15.4%. However, maize yields under the NPK treatments were statistically better than those in the NPK+CaMgSZnB treatment. Based on the results, it was concluded that the inherent N, P and K supplying capacity of soil is very low. Therefore, use of appropriate balanced fertilizers should be used for efficient nutrient uptake which ultimately increases maize productivity.*

Keywords*: - maize, Nitrogen, Phosphorus, potassium, limiting nutrients.*

1. INTRODUCTION

Most soils cannot supply all essential plant nutrients in sufficient amounts to support good growth of crops, and hence, the application of fertilizer is one of the most effective means to increase nutrient uptake in crop plants and improve yields (Kumar *et al*., 2012). Nutrient deficiency is one of the most yield constraints in crop production in most of the agro-ecological regions of the world (Neumann *et al*., 2010). Both macro and micro-nutrients play important role in influencing plant growth and hence yields (Haettenschweiler *et al*., 2000). Crop productivity is usually affected by the type as well as amount of fertilizer applied to the plants. Mineral fertilizers are alternative nutrient sources to supply sufficient nutrients in soil as well as to promote better plant productivity.

The overall productivity and sustainability of a given agricultural sector are functions of fertile soils and productive lands. However, soil fertility depletion is the fundamental biophysical cause for declining per capita food production in Sub-Saharan African countries in general (Sanchez *et al.*, 1997, Sanginga and Woomer, 2009). Declining land productivity with negative nutrient balance is the main concerns against the food security problems in Ethiopia. Fertilization is one of the most important notable measures that help to increase agricultural production. So, application of adequate amount of mineral nutrients to crop is one of the important factors in achieving higher productivity. In Ethiopia, agriculture is still characterized by low productivity, a high level of nutrient mining, low use of external inputs, traditional farm management practices and limited capacity to respond to environmental shocks (Amante *et al*., 2014; Agegnehu *et al*., 2016).

Agricultural productivity growth can be a significant instrument for reducing poverty in developing countries (Dethier and Effenberger, 2011). Considering the fact that soil fertility is one of the biggest challenges, an obvious strategy is to increase fertilizer application and promote good agronomic practices to enhance productivity. Nutrients play important role in crop production. In order to increase crop production to feed the ever increasing population, the use of mineral fertilizer needs to be encouraged, especially, among the smallholder farmers who form the larger proportion of farmers to improve soil fertility (Benedicta *et al*., 2016). Declining soil fertility is a serious limitation to crop production in Ethiopia. The primary causes are loss of OM, macro and micronutrient depletion, acidity, topsoil erosion and deterioration of soil physical properties (Zelleke *et al*., 2010). Soil nutrient mining, coupled with low fertilizer use, is the main cause of soil fertility decline in Ethiopia and nutrient balances in the Ethiopian farming systems are generally negative as a result (Abegaz *et al*., 2007; Kraaijvanger and Veldkamp, 2015).

Very low or low soil fertility status of agricultural land of smallholders is mentioned as one of the main constraints of crop yields in Ethiopia. In addition to the very low soil fertility status of Ethiopian soils, partly due to the removal of nutrients through harvested products and losses through erosion and leaching, phosphorus fixation and aluminum toxicity are two major constraints of most Ethiopian soils (Agegnehu *et al*., 2006). This is particularly apparent in soils with pH less than 5.5, the effect being attributed mainly to nutrient deficiency and toxicity. In such soils, phosphate is unavailable to plant roots because of fixation unless it is applied in large amounts (Marschner, 2011). Another challenge of Ethiopian soils is the decline in soil OC and the resultant loss in soil productivity. Many empirical studies (Hailu, 2010; Getachew *et al*., 2012; Bogale, 2014) have documented the problem of low soil nutrient reserves and negative nutrient balances in croplands with few or no external nutrient inputs compared to the nutrient status of forest areas, grazing or well managed lands. Maize is a very nutrient-demanding crop, requiring the intensive application of inorganic or organic fertilizers to produce a high yield (Asadu and Unagwu, 2012). Fertilizers are needed to replenish the nutrients that are detached from the soil when plants are collected and to supplement the soil with more nutrients to increase production (Awotundun, 2005). However, the continuous application of chemical fertilizers may cause a nutrient inequality and reduce the uptake of additional primary nutrients, limiting the growth of this crop. Furthermore, the incessant addition of chemical fertilizers can also affect the soil and plants negatively because most farmers in developing countries apply them without first testing the soil, resulting in the incorrect amounts and types being used.

Nitrogen (N), phosphorus (P) and potassium (K) are macronutrients that play a major role in plant growth and crop yields (Marschner, 2012). In smallholder farming systems, removal of N, P and K from fields through crop harvest and farms often exceeds input via applied fertilizers. Such negative N, P, K balance sheets lead to a gradual and insurmountable decrease in N, P and

K soil fertility status (Roy *et al*., 2003; Smaling, 1993). Restoration of soil fertility status and the provision of crop specific N, P and K recommendations are prerequisites to increase crop yields. The fertilizer N, P, and K nutrients requirement of maize crop are estimated from the difference between the attainable yield, an indicator of the total amount of nutrients that must be taken up by the crop, and the nutrient-limited yield, an indicator of the supply of nutrients from indigenous sources (Witt *et al*.,2009). This difference, also called the yield response, which can be measured with the nutrient omission plot technique. A large variability in soil nutrient supplying capacity exists among field and recommended doses of fertilizer will not be suitable in all fields. The omission plot technique is a useful tool to quantify soil nutrient supply (Regmi *et al*., 2002).

Attainable yield can be estimated from field or station experiments that use crop management practices designed to eliminate yield limiting and yield reducing factors (Yengoh, 2014). Indigenous nutrient supply is defined as the total amount of a particular nutrient that is available to the crop from the soil during a cropping cycle, when other nutrients are non-limiting and can be measured in nutrient omission plots. The yield response is related to indigenous nutrient supply which determines the yield in omission plots (Dobermann, 2003). Yield Response (YR) can be used to evaluate the soil nutrient supply capacity (Xu, 2014). Knowing soil nutrient condition is the premise of the optimized fertilization. Soil indigenous nutrient supply capacity can reflect the soil nutrient condition or soil fertility and can be developed as guidelines for fertilizer recommendation. The higher indigenous nutrient supply means the higher grain yield in the nutrient omission plots (Mueller *et al*., 2012). NUE is a direct measure for the rationality and advancement of fertilization. Some terms were frequently used in agronomic research to assess the efficiency of applied fertilizer, such as apparent recovery efficiency (RE, kg nutrient uptake increase per kg nutrient applied), agronomic efficiency (AE, kg yield increase per kg nutrient applied), partial factor productivity (PFP, kg yield per kg nutrient applied) (Cassman *et al*., 2002; Dobermann, 2007; Liu *et al*.,2011). Nutrient use efficiency is affected by grain yield, soil indigenous nutrient supply, amount of fertilizer application and the overall timeliness of other crop management operations (Dobermann, 2007). Native soil fertility may be determined effectively by the nutrient omission plot technique (Chowdhury *et al*., 2007; Khatun and Saleque, 2010).

Imbalanced fertilizer application during maize cultivation will make depletion of soil nutrients leading to production decline as well as to deterioration of soil physical and chemical properties. The major problems of maize production in southwestern Ethiopia are infertile soils with high soil acidity and low available phosphorus content. Maize grain yields are variable across farmers' fields. This is due to variability in soil condition, crop response to nutrients. Chemical fertilizers play a significant role in yield increment however, the application of higher amount of fertilizers do not always result in increased maize yield (Amujoyegbe *et al*., 2007). Nutrient limitation in soils has led to a drastic decline in maize yields in most smallholder farms. This is caused by decline in soil fertility (Nziguheba *et al*., 2002a, b), which inevitably leads to low agricultural productivity. It is evident that agricultural output is fundamentally affected by productivity status of soil. This decline in soil fertility has decreased farmland productivity in most smallholder farming communities (Amede, 2003). The existing fertilizer recommendation is based on blanket recommendation which assumes that the need of a crop for nutrients is constant over time and large areas. However, the need for supplemental nutrients vary greatly among fields, seasons and years and a blanket dose of fertilizer will not fit to all fields. There is a need to investigate crop response to nutrient application to know the most yield limiting nutrients and limiting nutrients in smallholder fields of Ethiopia have not been established.

Therefore, the **general objective** of this study was to identify which of macronutrients N, P and K are limiting maize grain and yield components in the study area

Specific objectives

- To assess maize responses to (NPK) application in terms of grain yield and yield components through nutrient omission plot techniques
- To assess variability in nutrient use efficiency and nutrient recovery fraction of maize under farmers' field condition

2. LITERATURE REVIEW

2.1. Soil Fertility and Nutrient Use in Ethiopia

Ethiopia is one of the most food insecure countries in Sub-Saharan Africa. Despite the fact that the country has potentially rich land resources, agricultural productivity is low and the nation suffers from recurrent food shortage and hunger. Drought along with low soil fertility due to excessive degradation and nutrient depletion are serious limitations to crop production in Ethiopia (FAO, 1999). The major plant nutrients, N and P, are added to the soil in the form of urea fertilizers and di-ammonium phosphate(DAP), whereas very little attention has been given to other macro and micro-nutrients leading to imbalanced and poor nutrient management and crop quality (Mesfin,1980). Cultivation of improved varieties without balanced nutrient management further aggravated the problem of nutrients to be yield limiting factors (Mesfin, 1998). According to Wondwosen and Sheleme (2011) the biological yields indicated that N and P, in that order, were limiting nutrients to support good crop growth implying that the soil was inherently poor in N and P status and external supply of N and P fertilizers are required to support plant growth and yield. This is in line with the low content of OC, TN and available P of the experimental soil (Wondwosen and Sheleme, 2011). Similar results were reported in Nitisols of Agaro, Metu and Tepi and Acrisols of Haru (Zebene and Wondwosen, 2007).

Maize yields are location and season specific depending upon climate, variety and crop management. The attainable yield for a given location and season is estimated from farmers' fields where good crop management was practiced and nutrients were not limiting yield reported by Witt *et al*. (2009). The amount of nutrients taken up by a maize crop is directly related to yield. The attainable yield level therefore indicates the total amount of nutrients that must be taken up by the crop (Witt *et al*., 2009). Fertilizer N, P and K are applied to supplement the nutrients from indigenous sources and achieve the yield target (attainable yield). The quantity of required fertilizer is determined by the deficit between the crop's total needs for nutrients as determined by the attainable yield level and the supply of these nutrients from indigenous sources as determined by the nutrient-limited yield (Witt *et al*., 2009). According to Witt *et al*. (2009) nutrient limited yields are determined from nutrient omission plots. For example, the N-limited yield is determined in an N omission plot receiving no N fertilizer but sufficient P and K to ensure that the latter nutrients do not limit yield. P and K limited yield are estimated from P and K omission plots, respectively.

Soil infertility has been considered a serious threat to agricultural productivity in Sub-Saharan Africa (SSA). Continuous cultivation of land, rising population and limited use of organic and inorganic fertilizers has led to soil fertility decline in Sub-Saharan Africa (Henao and Baanante, 2006). This situation is manifested by declining crop yields, decreasing vegetation cover, and increasing soil erosion. Consequently, farm productivity and agricultural incomes are falling and migration to urban centers is on the rise, while both household and countrywide food securities are continuously declining (AGRA, 2007).

2.1.1. Crop responses to nutrient omission

Maize requires adequate supply of nutrients particularly nitrogen, phosphorus and potassium for good growth and high yield. Nitrogen and phosphorus are very essential for good vegetative growth and grain development in maize production. The quantity required of these nutrients particularly nitrogen depends on the pre-clearing vegetation, organic matter content, tillage method and light intensity (Kang, 1981). Some of the major causes of low maize yield are declining soil fertility and insufficient use of fertilizers resulting in severe nutrient depletion of soils (Buresh *et al*., 1997).

Nitrogen is a vital plant nutrient and a major yield determining factor required for maize production (Adediran and Banjoko, 1995; Shanti *et al*., 1997). It is very essential for plant growth and makes up 1 to 4 percent of dry matter of the plants (Anonymous, 2000). Nitrogen is a component of protein and nucleic acids and when nitrogen is sub-optimal, growth is reduced (Haque *et al*., 2001). Its availability in sufficient quantity throughout the growing season is essential for optimum maize growth. It is also a characteristic constituent element of proteins and also an integral component of many other compounds essential for plant growth processes including chlorophyll and many enzymes. It also mediates the utilization of phosphorus, potassium and other elements in plants (Brady, 1984). The optimal amounts of these elements in the soil cannot be utilized efficiently if nitrogen is deficient in plants. Therefore, nitrogen deficiency or excess can result in reduces maize yields.

Maize is an exhaustive crop having higher potential than other cereals and absorbs large quantity of nutrients from the soil during different growth stages. Among the essential nutrients, phosphorus is one of the most important nutrients for higher yield in larger quantity (Chen *et al*., 1994) and controls mainly the reproductive growth of plant (Wojnowska *et al*., 1995). Generally, P is the second most crop-limiting nutrient in most soils. It is second only to nitrogen in fertilizer use. Plant growth behavior is influenced by the application of phosphorus (Hajabbasi and Schumacher, 1994; Gill *et al*., 1995; Kaya *et al*., 2001). It is needed for growth, utilization of sugar and starch, photosynthesis, nucleus formation and cell division, fat and albumen formation. Energy from photosynthesis and the metabolism of carbohydrates is stored in phosphate compounds for later use in growth and reproduction (Ayub *et al*., 2002). It is readily translocated within the plants, moving from older to younger tissues as the plant forms cells and develops roots, stems and leaves (Ali *et al*., 2002). Adequate P results in rapid growth and earlier maturity and improves the quality of vegetative growth. Phosphorus deficiency is responsible for crooked and missing rows as kernel twist and produce small ears nubbins in maize. Its deficiency is widespread in 90% of the Pakistani soils and the application of phosphoric fertilizers is considered essential for crop production and its deficiency will slow overall plant growth (Rashid and Memon, 2001). Ali *et al*. (2002) reported significant effect of P application on grain yield; whereas Ayub *et al*. (2002) observed significant effect of P application on dry matter yield and individual plant characteristics like height, number of leaves and leaf area.

The response of maize plant to application of nitrogen and phosphorus fertilizers varies from variety to variety, location to location and also depends on the availability of the nutrients. Research results have shown that various maize cultivars differ markedly in grain yield response to nitrogen fertilization (Bundy and Carter, 1988). Previous findings indicated that the increase in maize grain yield after nitrogen fertilization is largely due to an increase in the number of ears per plant, increase in total dry matter distributed to the grain and increase in average ear weight (Beauchamp *et al*., 1976; Balko and Tussell, 1980; Nxumalo *et al*., 1993). Other studies indicated that maize cultivars differ in grain yield response to nitrogen application (Kamprath *et al*., 1982; Kling *et al*., 1997; Oikeh *et al*., 1997).

Most Ethiopian soils are deficit in macronutrients (N, P, K and, S) and micronutrients (Cu, B and Zn) (EthioSIS, 2014). Fertilizer application has significantly increased yields of crops (Diriba, 2013) and great attention is given to chemical fertilizers and soil fertility to enhancing agricultural productivity (Rasool *et al*., 2007). However, yields have not increased as expected even when recommendation rates of N and P fertilizers applied. This is mainly due to use of two types of fertilizers (DAP and urea) alone and this may cause unbalanced fertilizers use (Demeke *et al*., 1997; Chillot and Hassan, 2010). Fertilizers use has been subjective since it was not based on soil fertility data (Abreha and Yesuf, 2008). However, recent information show that fertilizers application per hectare in Ethiopia has increased five times since the 1980s and is better than the sub-Saharan Africa average but, current production in Ethiopia is small. A nutrients omission trial aims to find out the most limiting nutrients to the growth of a crop plant. If any element is omitted while other elements are applied at suitable rates and plants grow weakly, then the tested element is a limiting factor for crop growth. Conversely, if any element is omitted but plants are healthy, then that element is not a limiting factor for crop production. When a nutrient is deficient in the soil then the growth of a crop plant and ultimately the yield is affected. Literature pertaining to nutrient omission trials is meager.

2.1.2. Effect of nutrient application on plant bio volume

Studies have shown that application of balanced fertilizer accelerate plant growth resulting in taller and greener plants (Zhang *et al*., 2007; 2008a; 2010a, b).According to Fashina *et al.* (2002), the availability of sufficient growth nutrients from inorganic fertilizers leads to improved cell activities, enhanced cell multiplication, enlargement, luxuriant growth, and eventually high yields. This was observed in NPK, NPK + manure, NPK+ CaMgS and NPK + lime and NP treatments. PK and NK achieved low bio volumes across both seasons. This agrees with the observation by Adediran and Banjoko (2003) who indicated that the absence of N and P nutrients resulted in stunted growth and depressed yields. Nitrogen is typically the most limiting nutrient in maize production (Joern and Sawyer, 2006). This observation was confirmed by the poor performance of PK treatment in both seasons. Further, Uyovbisere *et al*. (2001) reported that there was substantial reduction of growth when nitrogen was omitted in smallholder cropping systems of South-western Nigeria. NK, achieved low bio volumes in both cropping seasons. This is enhanced by, Busman *et al*. (2002) and Sahoo and Panda (2001) who indicated that the availability of adequate phosphorous improves plant growth and hastens maturity. This was evident in NPK, NPK + manure, NPK, +CaMgS, NPK + lime and NP treatments which achieved improved bio-volume. Plant growth parameters such as bio-volume increased by application of the phosphorous alone or in combination with the nitrogen (Saeed *et al*., 2001). This observation was further affirmed by Ayub *et al*. (2002), who indicated that growth and yield increased with increase in the rate of phosphorous application. Nitrogen internal efficiency does not only depend on its total amount taken up by the crop, but also on the concomitant supply of secondary nutrients (Jones and Huber, 2007; Potarzycki and Grzebisz, 2009). Although NPK +CaMgS had no significant differences from other full fertilizer treatments; observations show the treatment achieved high bio-volume. Nitrogen metabolism is related to the presence of magnesium in the chlorophyll and its role as a cofactor of the activity of enzymes responsible for the remobilization and transportation of metabolites (nitrogen among others) from the vegetative plant parts to the developing kernels (Rasheed *et al*., 2004). Moreover, since magnesium activates a large number of enzymes in the plant, its simultaneous supply increases the rate of mineral nitrogen transformation into proteins (Pessarakli, 2002).

2.1.3. Effects of nutrient application on grain and stover yields

The average yield findings are in line with the results of Adediran and Banjoko (2003) who reported high yields in treatments with balanced fertilizer treatment. Treatments, NPK, NPK +manure, NPK +CaMgS and, NPK + lime achieved high yields because they had adequate supply of all nutrients. This can be attributed to optimum utilization of solar light, higher assimilates production and its conversion to starches which resulted higher grains number (Derby *et al*., 2004). The results indicate low grain yield was achieved by treatment PK. This is in agreement with Sangoi *et al*. (2007) who found that lack of N before or at sowing results in reduced grain yield in maize. Further, studies conducted by Samira *et al*. (1998) and Torbert *et al.* (2001) found that N application increased yield and yield components of maize. Studies by Jones (2003) indicated that plants suffering from N deficiency mature earlier thus the vegetative growth stage is shortened leading to low grain yields. Further, Malhia *et al*. (2001) and Murshedul *et al.* (2006) reported that treatment NK achieved low yields, this observation was in line with Kogbe and Adediran (2003) who found that the application of inadequate P depressed maize yield. Another study by Grant *et al*. (2001) found that plants require adequate P from the very early stages of growth for optimum crop production. Further studies that corroborate the observations made in this study were done by Tang *et al.* (2007), Blake *et al*. (2000), Krishna (2002), and Bunemann *et al*. (2004) who reported depressed maize yields when P supply was inadequate over the entire maize growth period. Enhanced early-season P nutrition in maize increased the dry matter partitioning to the grain at later development stages (Gavito and Miller, 1998). There exists low biomass production of maize under P deficiency in field conditions since the aboveground biomass accumulation was severely reduced (–60%) during early stages of maize growth (Plénet *et al.,* 2000). The spectacular effect of P deprivation on early reduction in shoot growth is explained by a slight although rapid stimulation of root growth (Mollier and Pellerin, 1999). Phosphorus deficiency results in plants that grow slowly with poorly developed root systems and small leaves of greyish-green color (Plénet *et al*., 2000). Adequate supply of nitrogen leads to a significant increase in grain yield and its components.

2.2. Soil Fertility Variability on Smallholder Farms

Spatial variability of soil properties, within or among agricultural fields is inherent in nature due to geologic and pedologic factors (Deckers, 2002) but variability on soils of similar texture is induced by the diverse management practices unique to each farmer. Normally, fields closest to the homesteads receive comparatively larger nutrient resources leading to the establishment of gradients of decreasing soil fertility from the homestead to distant fields (Carter and Murwira 1995; Tittonell *et al*., 2006; Zingore *et al*., 2007). This is as a result of labour constraints and security considerations which obviously leads farmers to concentrate nutrient resources on fields closest to the homestead. In some places the opposite has been evident whereby nutrient gradients of increasing fertility away from the homestead are evident such as in the central highlands of Ethiopia (Haileslassie *et al*., 2007). The link between socio-economic status and soil fertility has been demonstrated in influencing soil fertility across farms. Studies have consistently shown that when farmers ranked their fields in terms of fertility, the higher resource groups had higher fertility than for the poorer farmers for the same category (Mtambanengwe and Mapfumo, 2005; Tittonell *et al*., 2009). Richer farmers have access to manure as a result of livestock ownership and use more mineral fertilizers than their poor counterparts thus building up fertility on their farms.

2.3. Limiting Nutrients in Smallholder Maize Fields

Soil fertility decline in SSA has contributed to the loss of nitrogen (N), phosphorus (P) and potassium (Amede, 2003). According to Roy *et al*. (2003), negative nutrient balances for nitrogen and phosphorus have been found in smallholder farming systems in SSA. Hennao and Baanante (2006) computed per hectare nitrogen (N), phosphorus (P) and potassium (K) nutrient balances for the whole of Africa for 2002- 2004. They found that the average annual depletion rate of all Sub-Saharan African countries was 54 kg NPK ha^{-1}, ranging from 23 kg $ha^{-1}yr^{-1}$ in South Africa to as much as 88 kg $ha^{-1}yr^{-1}$ for Somalia.

Shepherd *et al*. (1997) observed that nitrogen and phosphorus are the main limiting nutrients in food crop production in western Kenya. Hartemic *et al*. (2000) reported that nitrogen fertilizer input was required in order to sustain high crop yields in intensive crop production system. Further, nitrogen deficiency can be ameliorated through application of inorganic, organic fertilizers and biological nitrogen fixation. According to Lungu and Dynoodt (2008), one of the ways of addressing the impact of soil mining is use of inorganic fertilizers. However, use of these inputs among smallholder farmers is currently very low. Nitrogen is one of the key nutrients for crop production. It is the most mobile, volatile and the most exhausted nutrients due to its ability to exist in different forms and its easy leach ability (Palm *et al*., 1997). Snapp *et al*. (1998) observed that maize removes about 40 kg N ha^{-1} to produce 2 to 2.5 t of grain yield per hectare in the tropics.

According to Kwabiah *et al*. (2003) phosphorus is a limiting nutrient in maize production due to the low native soil P and high P fixation. In addition, Fairhurst *et al*. (1999) observed that phosphorus unlike nitrogen couldn't be replenished through biological fixation. For many cropping systems in the tropics, application of P from organic and inorganic sources is essential to sustain high crop yield. Further, Kwabiah *et al*. (2003) concluded that phosphorus (P) deficiency is a factor limiting crop production in tropical and sub-tropical soils. Correcting P deficiency with application of phosphoric fertilizers is a challenge for most poor smallholder farmers in SSA due to high costs of mineral fertilizers.

2.4. Importance of Nitrogen in Maize Production

Nitrogen (N) is the most important plant nutrient determining the crop production. The doubling of agricultural food production worldwide over the past four decades has been associated with a seven-fold increase in the use of N fertilizers. Nitrogen is one of the basic structural elements and plays significant role in construction of chlorophyll (Brady & Weil, 2014), therefore nitrogen is responsible for vegetative growth as well. According to Jones (2003), nitrogen occurs in soil in organic and inorganic forms. Organic nitrogen originates from living organisms and is a part of the organic compounds remaining after their death and decomposition. Inorganic N in soils refers to all forms of N that have been freed by mineralization from organic compounds including or have been added to the soil in the form of chemical fertilizers (Zhu and Chen, 2002). Tisdale *et al*. (1999) observed that plants absorb nitrogen mainly in the nitrate (NO_3^-) and ammonium (NH_4^+) forms. Mengel and Kirkby (1982) observed uptake of nitrate and ammonium by plants is influenced by soil water availability, microbial activities, and soil chemical reactions. Nitrate uptake is encouraged when soil pH is low and depressed when soil pH is high. This is due to the competitive effect of OH ions, which suppress the NO_3^- uptake and transport. Further, plant uptake of ammonium proceeds best at neutral pH values and is depressed by acidity due to competition between hydrogen (H^+) and ammonium (NH_4^+) on plant roots. According to Splittstoesser (1990), nitrogen is more responsible for variability in plant growth than any other element.

Nitrogen plays a vital role in nutritional and physiological status of maize and promotes changes in mineral composition of the crop (Zhu and Chen, 2002). Malhia *et al*. (2001) and Murshedul *et al*. (2006) reported that increasing nitrogen levels up to 120 kg N ha^{-1} leads to a significant increase in grain yield and its components. However, most plants only utilize less than one-half of fertilizer N applied, and the loss of fertilizer N is high (Zhu, 2000; Zhu and Chen, 2002). Nitrogen management in agro-ecosystems has been extensively studied due to its importance in improving crop yield and quality (Hillin and Hudak, 2003; De Paz and Ramos, 2004; Alam *et* *al*., 2006; Dambreville et *al*., 2008). Nitrogen is a vital plant nutrient and a major yield determining factor required for maize production (Adediran and Banjoko, 1995; Shanti *et al*., 1997). It is very essential for plant growth and makes up 1 to 4 percent of dry matter of the plants (Anonymous, 2000). Nitrogen is a component of protein and nucleic acids and when Nitrogen is sub-optimal, growth is reduced (Haque *et al*., 2001). Its availability in sufficient quantity throughout the growing season is essential for optimum maize growth. It is also a characteristic constituent element of proteins and also an integral component of many other compounds essential for plant growth processes including chlorophyll and many enzymes. It also mediates the utilization of phosphorus, potassium and other elements in plants (Brady, 1984). The optimal amounts of these elements in the soil cannot be utilized efficiently if nitrogen is deficient in plants. Therefore, nitrogen deficiency or excess can result in reduces maize yields.

2.5. Importance of Phosphorus in Maize Production

Phosphorus (P) is by far the most important mineral nutrient for crop production, after nitrogen (N). Compared to other major nutrients, P is the least available to plants due to its high fixation in most soil conditions and slow diffusion (Ramaekers *et al*., 2010; Shen *et al*., 2011). Therefore, P can be a major limiting nutrient for plant growth and development on many soils across the world. Agricultural productivity will be lower without P, and consequently less food will be produced per unit area of land, especially in the least developed and developing countries where access to P fertilizers are restricted due to the rising costs of P fertilizer (Lynch, 2007; Richardson *et al*.,2011; Richardson and Simpson, 2011). Therefore, P is essential for the intensive agricultural production systems and thus contributes significantly to the present and future global food production and security (Richardson *et al*., 2011).

Phosphorus, the second most widely limiting nutrient in soil after nitrogen (Balemi and Negisho 2012), is a critical macronutrient for plant growth; and in tropical agro ecosystems soil, P deficiency is a major limitation to crop production (Mustonen *et al*., 2012). Phosphorous is the precursor for flowering and it plays a significant role for shortening the maturity period (Belay *et al*., 2002). Research report indicates that <1 % of soil P is available for plant uptake (Stewart and Tiessen, 1987) as a result of strong adsorption of phosphate by iron and aluminum oxides

(Xavier *et al*., 2011). According to Sharma *et al*. (2011), phosphorus has a significant role in sustaining and building up soil fertility, especially under intensive system of agriculture. Thus, its deficiency becomes an important chemical factor restricting plant growth in soils. While N is the most limiting nutrient generally in soil, Delve *et al*. (2009) has shown that deficiency of soil P reduces the efficiency of N use by crops.

Jones (2003), described phosphorus (P) has a naturally occurring element that can be found in the earth's crust, water and all living organisms. Powers and McSorley (2000) highlighted that forms in which phosphorus occurs in soils as inorganic phosphorus ions, strongly bound P, organic P in humus and soluble, adsorbed phosphates, including P in solution. These four different forms of soil P are in equilibrium in an aqueous solution, and the predominant form of P depends on the soil pH.

Plants absorb phosphorus largely as primary and secondary orthophosphate ions (H_2PO_4 and HPO_4^-) present in the soil solution (Jones, 2003). Phosphate compounds adenosine di-phosphate (ADP) and adenosine tri-phosphate (ATP) act as energy currency within plants (Wolf, 1999). Good supply of phosphorus increases root development. It is also associated with early maturity and strength of crop tissues, improving quality of final yields (Parker, 2000). Grant *et al*. (2001) found that plants require adequate P from the very early stages of growth for optimum crop production. Yet this element is frequently limited in most Africa soils. According to Tang *et al.* (2007) dynamics of soil P are characterized by interactions between physico-chemical (sorption and desorption) and biological (immobilization and mineralization) processes. The rate and direction of these reactions are influenced by chemical conditions and biophysical dynamics as well as by the agricultural crops adopted (Blake *et al*., 2000; Krishna, 2002; Bunemann *et al*., 2004). Soil P undergoes biological (Hedley *et al*., 1982) and pedological (Smeck, 1985) transformations, which are short- and long-term transformations, respectively.

In highly P fertilized soils, the P concentration in soil solution is high, and the depletion zone is readily replenished. The replenishment is slow when soil solution P is low especially for soil solid phase with a low buffer capacity (Kpongor, 2007). The quantity of P ions in soil solution at any given time generally represents less than 1% of P annually taken up by crops. Approximately, 99% of P taken up by plants is bound to soil constituents before uptake

(Schneider and Morel, 2000). The importance of adequate tissue P concentrations during early-season growth has been reported in many different crop species (Grant *et al*., 2001).

2.6. Importance of Potassium in Maize Production

Next to N and P the third most essential element that plants require in the largest amounts is potassium (Marschner, 1995). It is involved in photosynthesis, sugar transport, and movement of water and nutrient, protein synthesis and starch formation (Zublena, 1997). Soils with greater proportion of clay minerals are high in K; the greater will be the potential K availability in soils (Tisdale *et al.,* 1995). Soil K is mostly occurs in a mineral form and the daily K needs of plants are little affected by organic associated K, except for exchangeable K adsorbed on SOM. Jobbagy and Jackson (2001) reported that nutrients strongly cycled by plants, such as K, were more concentrated in the surface soil than nutrients usually less limiting for the growth of plants. Potassium (K) is another macronutrient required for crop growth. In the soil, K exists in exchangeable and non-exchangeable forms, which are in dynamic equilibrium with each other (Cox *et al*., 1999). Archer (1988) observed that potassium in solution and exchangeable potassium are replenished by non-exchangeable potassium when these forms of K are depleted by plant removal or leaching.

Plants can only absorb potassium as the potassium ion K^+ (Dong *et al*., 2010). He observed potassium (K) plays a particularly critical role in plant growth and metabolism. It contributes greatly to the survival of plants that are under various biotic and abiotic stresses. According to Shaballa and Pottosin (2010), concentration of K^+ in the cytoplasm has consistently been found to be between 100 and 200 mm. Apo plastic K^+ concentration may vary between 10 and 200 or even reach up to 500 mm (White and Karley, 2010).

Potassium plays a vital role as macronutrient in plant growth and sustainable crop production (Bukhsh *et al*., 2012). It maintains turgor pressure of cell which is essential for cell expansion. It helps in osmo-regulation of plant cell, assists in opening and closing of stomata (Mengel and Kirkby, 1987). It plays a key role in activation of more than 60 enzymes (Tisdale *et al*., 1990). Its application has nascent effect on growth and development (Bukhsh *et al*., 2011) and grain yield in maize (Bukhsh *et al*., 2009). It not only affects the transport of assimilates but also regulates the rate of photosynthesis in maize. It is known for its interaction both antagonistic and synergistic with essential macro and micro nutrients (Dibb and Thomson, 1985). K is very important for efficient N utilization and has a consistent effect on lowering tissue concentration of Ca and Mg (Bukhsh, 2010). According to Wolf (1999), K deficiency typically results in stunted plants with weak stalks that lodge easily. When the deficiency is very acute, the leaves show yellow spots followed by necrosis on the tips and edges. K deficiency is common in sandy soils with low exchange capacities and in soils with high potassium fixing capacities. Excess potassium can lead to Ca and /or Mg deficiencies in plants (Sanjuán *et al*., 2003).

2.7. Importance of Secondary and Micronutrients in Maize Growth

Soil nutrient mining remains a challenge in smallholder farmers' fields where secondary nutrients and micronutrients are removed without replacement (Alley and Vanlauwe, 2009). Secondary nutrients play an active role in the plant metabolism process starting from cell wall development to respiration, photosynthesis, chlorophyll formation, enzyme activity and nitrogen fixation (Das, 2000). Micronutrient requirements of the maize crops are relatively small and ranges of their deficiencies and toxicities in plants and soils are rather narrow (Brady and Weil, 2002). Expectation of higher maize productivity using adequate amount of fertilizer nutrients may lead limitation of some micronutrients in the soil (Das, 2000).

The importance of Ca and Mg soils cannot be understated for their role in plant nutrition is crucial since they constitute plants protoplasm (Szulc *et al*., 2008). Calcium is part of every plant cell. Much of the Ca in plants is part of the cell walls in a compound called calcium pectate. Without adequate Ca, cell walls would collapse and plants would not remain upright. Calcium is not mobile in plants therefore it does not easily move from old leaves to young leaves (Fageria *et al*., 2002). Magnesium is an important constituent of chlorophyll, hence vital in photosynthesis (Jones and Huber, 2007). Plants that are deficient in Mg^{2+} have an overall light green color. In maize, the veins are mainly white when concentrations are inadequate. Calcium also has a positive effect on soil properties (Lipinski, 2005).

2.8. Nutrient Use Efficiency

Nutrient use efficiency is a direct measure for the rationality and advancement of fertilization. Nutrient use efficiency can be expressed as agronomic efficiency (AE) and crop recovery efficiency (RE) (Fixen, 2007). Using AE and RE to evaluate the effect of nutrient omission on nutrient utilization, where AE refers to the crop yield increase per unit nutrient applied, and RE refers to the increase in plant nutrient uptake per unit nutrient applied. Agronomic efficiency or apparent recovery efficiency are appropriate performance indicators, especially in the selection of more efficient genotypes for nutrient uptake or to assess nutrient transfers among soil pools, but both of these measures require a nil fertilizer application treatment to estimate the extra yield due to the added fertilizer(Rob *et al*.,2015). Such measures are normally only available on research plots limiting their usefulness in non-research settings.

Fertilizer use efficiency reflects the recovery of applied fertilizer by the crop, however from the crop perspective, N (or other nutrient) use efficiency is a measure of biomass produced as a function of the N (or other nutrient) available to that crop (Dobermann, 2007; Snyder and Bruulsema, 2007). Canopy architecture, function and longevity determine the production of carbohydrate for grain filling and hence yield. A complication is the need for N by the grain during grain filling, a requirement fulfilled mainly by remobilization from the senescing (and hence decreasingly functionally active) canopy (Abeledo *et al*., 2008).

Soil fertility is multifaceted discipline, cutting across biophysical, climatic, and anthropogenic factors. Despite the massive investment in research and fertilizers, yields in smallholder fields are on a downward trend. The review of literature identified a dearth of critical research on effects of limiting nutrients on the growth and yield of Zea mays. From the published work on research done in other regions of SSA it is evident that deteriorating soil fertility leads to depressed yields among smallholder farmers'.

Although poor maize yields are because of numerous interrelated bottlenecks such as climate change, nutrient mining remains one of the major impediments. It ultimately leads to emergence of limiting nutrients. This problem is further compounded by mismanagement of smallholder fields. Determination of the limiting nutrients to maize growth and yield of maize in Jimma is crucial in helping to develop solutions to arrest the dwindling soil fertility. Further establishment of management practices that influence the variability of nitrogen, phosphorus, and potassium in soils of Jimma is important in developing local solutions.

3. MATERIALS AND METHODS

3.1. General Description of the Study Area

The study was conducted in Kersa district, Jimma Zone, Oromia National Regional State, Southwestern Ethiopia. Kersa is one of the districts in Jimma Zone of Oromia Region. Geographically, the district is located between 7°35′–8°00′N latitudes, 36°46′– 37°14′E longitude and altitude that ranges from 1740 to 2660 m above sea level and consists of 10 percent dega, and 90 percent woinadega, agro ecologies. The main rainy season in Kersa area stretches from March to September and the area receives an average annual rainfall of 900-1300 mm. Temperatures are moderate ranking from 20-28 °C with variations across specific agro-ecologies.

The main language spoken in the study areas is Afan Oromo. Some people also speak Amharic in addition to Afan Oromo. Almost 99 percent of the sample households in the study area are Muslims. The average family size in the study areas is seven persons per household. However, family farmers often face labor shortages, especially during weeding and harvesting seasons. The important sources of energy for family farmers in the study areas are fuel wood and kerosene for light. Fuel wood is collected either from the nearby forests (if available) or crop residues (maize and sorghum Stover) are used as a substitute. The dependence on biomass as source of energy is similar to other parts of the country (Negash & Kelboro, 2014). Access to electricity is limited to urban areas in Kersa district. Maize is the dominant crop produced in the study area. Results of the household survey showed that maize is the most dominant crop in Kersa district covering 74 percent of the total cultivated land of these areas. The second dominant crop is Teff (Eragrostis teff), followed by sorghum, pepper, khat (Catha edulis) and coffee. Livestock such as cattle, sheep, goats, donkey, horses and mules as well as poultry and honey bee are reared in the study areas. The average livestock holding in the study area is 5.7 TLU. Ownership of at least a pair of oxen is a necessary condition for farm traction. However over 16 percent of the households in the study area did not have any ox and they need to look for other options for seedbed preparation and planting.

According to the harmonized soil map of Africa (Dewitte *et al*., 2013), the major reference soil groups of the southwestern highland plateaus are Nitisols, Vertisols, Leptosols, Regosols, Cambisols, and Acrisols. Nitisols are the dominant reference soil groups in coffee-growing areas of southwest Ethiopia. Nitisols have a depth of more than 1.5 m, are clayey and red in colour. They primarily occupy slopes steeper than 5%. These soils are well-drained with good physical properties; they have high water-storage capacity, a deep rooting depth and stable soil aggregate structure. Nevertheless, rates of decomposition of organic matter and leaching of nutrients are extremely fast. Acidity ranges from medium to strong, and pH is generally less than 6 (Feyissa & Mebrate, 1994; Schmitt, 2006).

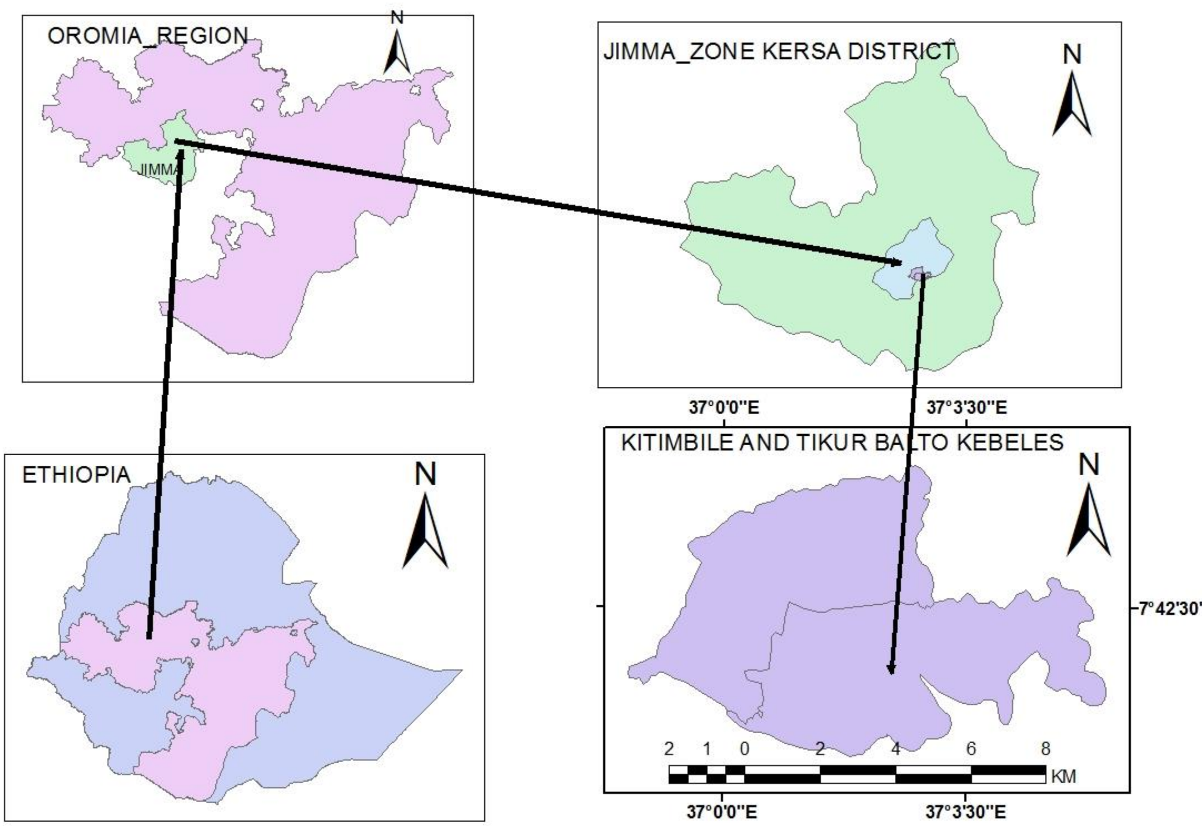

Figure 1. Map of the study area Kersa district -Jimma Zone, Oromia National Regional State.

3.2. Experimental Design and Treatments

The experiment consisted of six treatments, which include; control (no fertilizer input), PK (omission of N), NK (omission P), NP (omission of K), NPK and NPK+ CaMgSZnB. The experiment was conducted during main rainy season in 2017/18 at Kersa district. The treatments were laid out in a Randomized Complete Block Design. The experiment was established on six selected farmers' fields as replications. Choice of the experimental fields was limited to farmer fields currently in crop production. The plot size was 4.5 m x 4.2m. The total area of each site was 10m x 14.6m=146m^2. The six farmers' fields were treated as replications. Land preparation was done by oxen drawn first and at sowing by hand ploughing at a depth of 15-20 cm using hoes. Hybrid maize (BH 661) which is high yielder as compared to other improved maize varieties in the study areas was used as a test crop and that was planted in rows with spacing of 75 cm (inter-row) and 30 cm (intrarow). Planting was done on May 30 and 31; 2017. Two seeds of maize were planted per hill and thinned to one ten days after emergence. Other agronomic management practice was followed appropriately. Straight fertilizers were used to supply N, P, and K. Urea, triple super phosphate (TSP), Murate of potash (MOP), magnesium sulphate (MgSO4), calcium sulphate (CaSO4), zinc sulphate (ZnSO4), and Borax were used as fertilizer sources for N, P, K, Mg, Ca, Zn and B, respectively. The description and rate of nutrient application for each treatment is indicated in Table-1 and 2 respectively.

Treatments

1. Control (no fertilizer input)
2. PK (omission of N)
3. NK (omission of P)
4. NP (omission of K)
5. Ample NPK
6. NPK+secondary & micronutrients (NPK+ Ca + Mg + S +Zn+B)

Table 1. Description of Treatments

Treatments	Description
Control	No fertilizer application. Used to measure grain yield as an indicator of the effective indigenous NPK supply from soil, rain water, crop residue and atmosphere.
PK	N omission plot with sufficient P and K amounts applied. Used to measure grain yield as an indicator of the effective indigenous N supply from soil, rain water, crop residue and atmosphere.
NK	P omission plot with sufficient N and K amounts applied. Used to measure grain yield as an indicator of the effective indigenous P supply from soil, rain water, crop residue and atmosphere.
NP	K omission plot with sufficient N and P amounts applied. Used to measure grain yield as an indicator of the effective indigenous K supply from soil, rain water, crop residue and atmosphere.
NPK	Full NPK input to estimate the nutrient limited yield gap and evaluate agronomic use efficiencies of N, P, and K. Fertilizer N was applied in two splits: 1/2 basal and 1/2 at V10 (approximately 35 DAE).
NPK+Ca+Mg+S+Zn+B	This treatment was used to assess the contribution of secondary and micronutrients to maize productivity.

3.3. Fertilizer (Nutrient) Application Methods

Nutrients were applied based on nutrient requirements to achieve the expected attainable yield without nutrient limitation in each field. Basal fertilizer was applied in the planting holes at sowing time. Half of urea, whole of TSP, Murate of Potash, calcium Sulphate, magnesium Sulphate, Zinc Sulphate and borax were spot applied in the planting holes at planting to maximize the nutrient recovery. The applied fertilizers were covered with some soil before placing the seeds to avoid direct contact of seed with fertilizer. Fertilizers were pre-weighed, using a suitable balance, for each plot before going to the field. The remaining half (1/2) of urea was top dressed by spot-application five weeks after emergence (35DAE) for all plots which requiring N. There were totally seven rows and 14 planting stations (maize) per row in the plot. Table 2 shows the amount of fertilizer required for hectare and then calculated for the plot (4.2 m x 4.5 m) and then per hill.

Table 2. Rate of nutrient application for the different treatments

Treatment	Rate of nutrient application (kg ha^{-1})
Control	No fertilizer inputs
PK	40P+40K
NK	120N+40K
NP	120N+40P
NPK	120N+40P+40K
NPK+ CaMgSZnB	120N+40P+40K+10Ca+10Mg+20S+5Zn+5B

Table 3. Recommended secondary and micro-nutrients application rates

Nutrient	Source	Application rate (kg ha^{-1})	S equivalent application rate (kg ha^{-1})
Zn	Zinc Sulphate	5	2.7
B	Borax	5	0.0
Ca	CaSO4	10	8.0
Mg	MgSO4	10	13.3

3.4. Soil Sampling and Preparation

Soil samples were collected from the experimental fields at the depth of 0-20 cm before planting, prepared and analyzed following standard laboratory procedures for some selected soil physico-chemical properties. Soil samples were taken from each site separately during site selection. From each site, composite soil samples of three topsoil (0 - 20 cm) were taken using a soil auger. The three samples were taken along one of the diagonals of the site by taking one composite sample from the site field of 10 m x 14.6 m trial field. Samples were put in polythene bags labeled with the district, kebele, farmer name, depth and date. The soil samples were air-dried by spreading a sample out as a thin layer on paper sheets. The drying was started immediately as the samples arrive at the station where drying process was done. The collected soil samples were air-dried, ground and passed through a 2 mm sieve for laboratory analysis.

3.5. Land Preparation and Crop management

The experimental fields were prepared using a local plow (maresha) according to farmers' conventional farming practices. The fields were ploughed two times to a depth of 15-20 cm and furrows were constructed by a hand-held hoe. The trials were researcher-designed and managed to ensure uniformity and optimal management. Uniformity in management was ensured and the following standard agronomic practices were followed. Weeds compete for water, nutrients and light with crops. The plots were regularly weeded to minimize any impact of weed pressure on maize performance. Pest infestation and disease symptoms were monitored regularly and controlled appropriately.

3.6. Soil Laboratory Analysis

From the composite soil samples, parameters were analyzed for soil pH, organic carbon, total nitrogen, available phosphorus, exchangeable basic cations (Ca, Mg, Na and K), CEC, particle size and bulk density. Selected soil physical and chemical properties were analyzed at Jimma Agricultural Research Center, Soil and Plant Analysis Laboratory. Bulk density of the soil samples were analyzed on undisturbed soil samples collected using the core sampling method (Sahlemdhin and Taye, 2000). The core samples were oven dried and the bulk density was calculated by dividing the masses of the oven dry soils by their respective volumes as they exist naturally under field conditions. The pH of the composite soil samples was measured potentiometric method in 1:2.5 soil water suspensions (McLean, 1982). Organic carbon content was determined by the wet oxidation method of Walkley and Black (Nelson *et al*., 1982) and total nitrogen by the semi-micro Kjeldahl method (Okalebo *et al*., 1993). Available soil P was determined according to Bray-II method as described by Bray and Kurtz, (1945). Cation exchange capacity of the soils was determined by the neutral ammonium acetate (CH_3COONH_4) saturation method (Rhoades, 1982). The particle size distribution was determined by the hydrometer method (Gee and Bauder, 1986). Soils were analyzed for exchangeable acidity following extraction by 1M potassium chloride and titration of the extract against sodium hydroxide solution following the procedure described by Okalebo *et al*. (2002). The exchangeable bases in the ammonium acetate filtrates collected above was measured by atomic absorption spectrophotometer (Rhoades, 1982)

3.7. Agronomic Data Collection

Relevant plant parameters were recorded from the five central rows (12.6 m^2) out of the seven rows per plot (14.6m^2). Among the measures of plant parameters include plant height, stem girth, ear height, leaf area, stand count, number of cobs per plot, weight of cobs per plot, weight of five cobs for determination of shelling percentage, weight of grain yield, and stover yield.

The height (cm) of five randomly selected plants per plot were measured from ground level to the point where the tassel started branching when 50% of the plants in the plot reached tasselling stage and the mean value was taken as plant height. Stem girth were measured at 50cm from the ground level of five randomly taken plants using caliper. Leaf area Index was determined on five randomly selected plants per plot with the method developed by Mckee (1964).Harvest index was calculated as the ratio of grain yield to above ground biomass yield on dry weight basis (Donald and Hamblin, 1976). Grain and stover yields were determined by harvesting the entire net plot area of (3m x 4.2m=12.6 m^2) and converted into kilogram per hectare. The harvested grain yield was adjusted to 12.5% moisture level (Birru, 1979; Nelson *et al*., 1985). The adjusted seed yield at 12.5% moisture level per plot was converted to grain yield as kilogram per hectare; whereas stover yield was weighed after leaving it in open air for 7 days. The above ground total biomass yield was calculated as the sum of the grain and stover yields.

3.7.1. Analysis of N, P and K contents of stover and grain of maize

Stover and grain samples were collected randomly from the net plot area at harvest from each plot separately for the determination of N, P and K contents. The collected stover and grain samples were prepared following standard procedures and analyzed at Jimma Agricultural Research Center, Soil and Plant Tissue Analysis Research Laboratory. Nitrogen was determined by the modified Kjeldahl method (Van Reeuwijk, 1992), whereas the P content was measured using spectrophotometer by the wet digestion method (Olsen and Dean, 1965) and Atomic Absorption Spectrophotometer (Prasad *et al*., 2005) for K. The total N, P and K uptakes in the plant vegetative parts and the grains were calculated by multiplying N, P and K content with the respective stover and grain yields per hectare, respectively. Total N, P and K uptake by whole plant were calculated by summing up the N, P and K uptake by grains and stover. Apparent N, P and K recovery (AR) in the above ground biomass for each fertilized treatment were calculated as the total uptake (TU) of each fertilized treatment minus TU of control divided by fertilizer applied.

$$ARE = \frac{\text{TU fertilized plot} - \text{TU of controls}}{\text{Fertilizer applied kg/ha}}$$

Agronomic efficiency (AE) of fertilizer N, P and K were calculated as grain yield of each fertilized plot minus grain yield of control divided by the fertilizer applied.

$$AE = \frac{Grain\ yield\ of\ fertilized\ plot - Grain\ yield\ of\ control\ plot}{Fertilizer\ applied\ kg/ha}$$

3.7.2. Harvest grain and crop residue yield

Harvesting was done after the crop has reached physiological maturity and the cobs have dried through monitoring the grain moisture content. First, the number of plants in the net plot were counted and recorded on the harvest form. All the plants in the net-plot were cut at the soil surface and total stover fresh weights determined in the field. The cobs were then harvested in such a way that the husk still remain on the plant. The cobs were counted and the weight of the total number of cobs was determined. Grain and stover yields were determined by harvesting the entire net plot area of 5 rows x 4.2 m (leaving out 2 rows from each end) and converted into kilogram per hectare. Grain yield was adjusted to 12.5% moisture level; whereas stover yield was weighed after leaving it in open air for 7 days. The total dry matter yield, grain yield (at 12.5% moisture content), and harvest index were calculated using the following formulae:

Total dry matter yield (above-ground) = (GY + SY+ CY)

Grain yield (at 12.5% moisture content) = GW x (100 - MCA)/ (100 - MCD)

Harvest Index (HI) = GY/ Total dry matter x 100

Where:

GY, SY and CY are grain, stover, and cob dry matter yields, respectively; GW, MCA and MCD are fresh grain weight, moisture content of fresh grain and moisture content of grains at 12.5% moisture, respectively.

Representative stover was selected randomly, cut into small pieces, well mixed and a subsample was measured. The weight of this fresh sub-sample was recorded. The subsample was bagged and taken to the lab for drying. Five (5) cobs were also randomly selected and fresh weight was determined by ordering the cobs from small to large.

3.8. Statistical Data Analysis

The collected agronomic data were analyzed using statistical analysis software (SAS) 9.3 (SAS, 2012). Analysis of variance (ANOVA) was carried out to determine whether there was a significant difference among treatments on each treatment. Mean separation of significant treatments was carried out using the least significant difference (LSD) test at $P \leq 0.05$ levels. Correlation analysis was done to establish the relationship between yield and yield components.

The statistical model for RCBD experiment is given by: **-**

$$\mathbf{X_{ij} = \mu + \tau_i + \beta_j + E_{ij}}$$

Where χ_{ij} = observation of the ith treatment in the jth block.

μ = overall mean

τ_i = ith treatment effect ($\mu_i - \mu$)

B_j = jth block effect ($\mu_j - \mu$)

E_{ij} = effect of the ith treatment in the

jth block ($\chi_{ij} - \mu_i - \mu_j + \mu$)

i = 1,.......t.

j = 1,....... r

4. RESULTS AND DISCUSSION

4.1. Soil Physico-Chemical Properties before Planting

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

4.1.1. Pre- treatment soil characteristics

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

The analyzed soil characteristics included soil particle size distribution (texture), Bulk density, soil pH, soil organic C, total N, available P, CEC and exchangeable bases (Ca, Mg, Na and K) which were determined from the composite surface (0-20 cm) soil samples collected from the experimental plots before fertilizer application were presented in Table 4.

4.1.1.1. Soil texture

The results revealed that the surface soil of the field before application of fertilizer is sandy clay loam in texture. As indicated in Table 3, the clay content varied from 22.0 to 34.0 % (with the mean value of 27.7%). The sand fraction ranged from 54.0 to 64.0 % (with a mean of 58.2 %) while the silt fraction varied from 6.0 to 24% (with the mean value of 14 %). The silt to clay ratio of the soil of the study area before treatment was 0.51. This ratio is one of the indices used to assess the rate of weathering and determine the relative stage of development of a given soil. According to Young (1976), a ratio of silt to clay <0.15 is considered as low and indicative of an advanced stage of weathering and/or soil development while >0.15 indicates that the soil is young contains easily weatherable minerals. Hence, the soil of the study area is young that contain easily weatherable minerals. Soil texture is an important soil characteristic that drives crop production and field management. It influences the drainage, water holding capacity, aeration, susceptibility to erosion, organic matter content, cation exchange capacity (CEC), pH buffering capacity and tilth of a soil. Posadas *et al*. (2001) stated that particle size distribution reflects the relative balance of weathering and pedogenetic processes.

4.1.1.2. Bulk density

The bulk density of the field soil before treatments varied from 1.02 to 1.17 g cm^{-3}(with the mean value of 1.09 g cm^{-3}). According to the rate established by Landon (1991), this range falls within the category of dense to very dense status. The BD of soils from all the experimental fields had average below 1.6 g cm^{-3}, which is considered as best for root growth due to proper aeration owing to larger sand fraction relative to clay and silt (Arshad *et al*., 1996). It is desirable to have soil with a low BD (<1.5 g cm^{-3}) (Hunt and Gilkes, 1992) for optimum movement of air and water through the soil. Also White (1997) stated that values of BD ranges from < 1 g cm^{-3} for soils high in organic manure, 1.0 to 1.4 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.

4.1.1.3. Soil reaction (pH)

The soil pH ranged from 4.54 to 5.14 which were classified as very strongly acidic to moderately acidic (Landon, 1991; FAO, 1990) and ideal for the production of most field crops. The main cause of acidity is the loss of exchangeable bases through leaching from the top soil and is replaced with Al ions (Lechisa *et al*., 2014). Therefore, under very acidic conditions, the soil solution is occupied mostly by Al and H ions. This has a direct effect on maize growth by suppressing the root development and reducing availability of macronutrients to plants especially phosphorus, which is readily available under medium pH range (Paulos, 1997; Brady and Weil, 2008).

4.1.1.4. Soil organic Carbon

The soil organic carbon content of the field before the application of treatment ranged from 1.6 to 2.5 % (with the mean of 2.04 %). Therefore, according to Landon (1991) the soil organic carbon content of the soil of the trial plots could be classified as low to medium range (Table 4). Similarly (Bogale, 2014) also reported that the soil organic carbon status of the study area was within the range of very low.

4.1.1.5. Total Nitrogen

The total N contents of the soil varied from 0.104 % to 0.207 % (with mean value of 0.165 %) found in very low or medium range (Landon, 1991; FAO, 1990 and Bruce and Rayment, 1982) as presented in Table 4. Similar findings by Bogale (2014) indicated that the study area has total nitrogen within the range of low. Thus, the soil of the trial plots before application falls under the low N fertility class of Landon (1991) and Tekalign *et al*. (1991).

4.1.1.6. Available Phosphorus

The soil of the trial plots contained available P ranging from 0.88 mg kg^{-1} to 7.25 mg kg^{-1} (with the mean value of 3.13 mg kg^{-1}). Thus, the available P of the trial plots before application of fertilizer falls below the critical level (8 mg kg^{-1}) for most crop plants, as established by Tadesse *et al*. (1991) for some Ethiopian soils respectively (Table 4). This could be attributed to the uptake or utilization by crops due to continuous cultivation, low input of amendment and generally poor management practices. Also, Marschner (1995) stated in most cases, soils with pH values less than 5.5 are deficient in P.

4.1.1.7. Cation Exchange Capacity

According to the rating suggested by Landon (1991) and FAO (2006), the CEC values of the soil fall under low to medium rate. As indicated in Table 4, the CEC value ranged from 12.44 cmol (+) kg^{-1} to 36.9 cmol (+) kg^{-1} with the mean value of 15.87 cmol (+) kg^{-1}. Thus, the CEC of the trial plots falls within low to medium classification rate of both Landon (1991) and FAO (2006). According to Horneck *et al*. (2011) soils with high clay and/or OM content have high CEC. CEC is a measure of a soil's capacity to retain and release elements such as K, Ca, Mg, and Na (Horneck *et al*., 2011). It relates information on a soils ability to sustain plant growth, retain nutrients, buffer acid deposition or sequester toxic heavy metals. Therefore, the CEC of a soil is a good indicator of soil productivity, fertility, the amount of clay and organic matter present in the soil, acidity treatment and is useful for making recommendations of phosphorus, potassium, and magnesium for soils of different textural classes.

4.1.1.8. Basic Exchangeable Cations

Exchangeable K followed by Ca and Mg was the predominant cation in the exchange site (Table 4). The mean exchangeable Ca and Mg contents of the experimental plots before the application of soil fertility treatments were 2.69 and 1.35 cmol (+) kg^{-1} while that of exchangeable Na and K were 0.01 and 588.2 mg kg^{-1}, respectively. According to rate established by FAO (2006), exchangeable Ca of the trial plots falls under low classification rate and Mg falls under low to medium rates while Na falls under very low rates and K falls under high to very high rates (Table 4). As indicated in Table 4, the proportions of the cations of the trial plots were in the order of K > Ca > Mg > Na. This might be related to the parent material from which the soils have been developed i.e. basalt rock and their differential attraction to the soils' exchange complex which is approximately in that order. Generally, exchangeable Na contributed very small proportion to the CEC (Table 4).

Table 4. Selected physicochemical properties of soil before planting maize on farmer’s field in 2017

Treatments	Farm-1	Farm-2	Farm-3	Farm-4	Farm-5	Farm-6
Sand (%)	54.00	56.00	64.00	58.00	54.00	64.00
Silt (%)	12.00	10.00	12.00	20.00	24.00	6.000
Clay (%)	34.00	34.00	24.00	22.00	22.00	30.00
Textural class	SCL	SCL	SCL	SCL	SCL	SCL
BD(g/cm^3)	1.060	1.020	1.160	1.170	1.120	1.020
pH-H_2O(1:2.5)	4.990	4.890	4.540	4.770	5.100	5.140
OC (%)	2.180	1.995	2.293	2.500	1.595	1.687
Total N (%)	0.165	0.151	0.190	0.207	0.174	0.104
Av.P B II(mg/kg)	0.957	0.878	2.761	3.388	3.545	7.251
Ex. Ca (cmol(+) kg^{-1})	3.114	2.630	2.123	2.423	2.585	3.259
Ex. Mg (cmol(+) kg^{-1})	2.045	1.273	0.692	1.032	1.274	1.771
Ex. K. (mg/kg)	480.04	306.18	558.81	382.77	625.41	1176
Ex.Na(cmol(+)kg^{-1}	0.013	0.011	0.014	0.010	0.007	0.007
CEC(cmol(+) kg^{-1}	12.44	15.92	15.98	17.10	13.60	20.16
Ex.A(meq/100g)	1.610	1.620	1.860	1.520	1.080	1.016

SCL=Sandy Clay Loam

4.2. Maize Growth Responses to Different Nutrient Treatments

4.2.1. Plant height

Plant height reflects the vegetative growth behavior of crop plants to applied inputs. Plant height of maize was significantly affected ($p<0.05$) by nutrient treatments. Significantly the longest plant height (296.5cm) was obtained with the application of NPK+CaMgSZnB and NPK (285.5cm) treatments compared to all the other treatments, while significantly the shortest plant height was recorded for the control treatment (228.4cm), N-omitted (245.5cm) and P omitted (266cm) treatments. The extent of plant height reduction due to nutrient omission was in the order of N omission>P omission>K omission. The increment in plant height might be due to increase in cell elongation and more vegetative growth attributed to the balanced application, especially of primary nutrients N, P and K. On the other hand, the shortest plant height in unfertilized plots might have been due to low soil fertility level in the study area. In conformity with the results obtained from this study, plant growth and development may be retarded significantly if any of nutrient elements is less than its threshold value in the soil or not adequately balanced with other nutrient elements (Landon, 1991). Thus, the results indicated that balanced nutrient application has enhanced the maize vegetative growth.

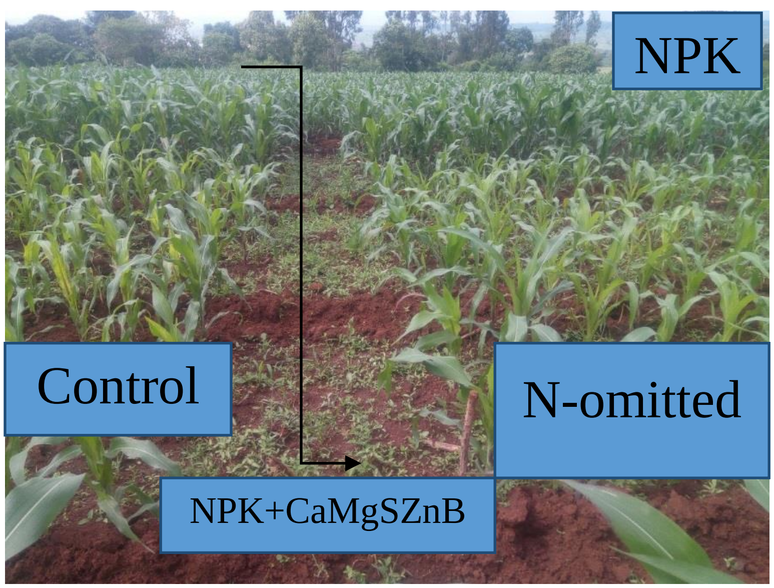

Figure 2. Vegetative growth of maize as affected by nutrient omission.

The increase in plant height with the application of balanced NPK fertilizer could be due to their synergistic effects and the fact that N is considered as one of the major limiting nutrients in plant growth and adequate supply of it promotes the formation of chlorophyll which in turn resulted in higher photosynthetic activity, vigorous vegetative growth and taller plants. Phosphorus is required for shoot and root development where metabolism is high and cell division is rapid.

This results in line with the findings of Adekayode and Ogunkoya (2010) who reported that there was very high significant difference in maize plant height in plots treated with balanced fertilizers compared to nil application. Also Kumar *et al*. (2005) reported that growth and yield of maize plants in terms of plant height varied significantly due to various fertility levels.

Table 5. Mean of plant height and leaf area index of maize as affected by NOT

Treatments	Plant height(cm)	Leaf Area Index	Stem Girth(cm)
Control	228.37d	2.15d	2.03c
PK(-N)	245.50cd	2.48d	2.20bc
NK(-P)	266.00bc	2.98c	2.27b
NP(-K)	281.70ab	3.51b	2.30b
NPK	285.50ab	3.92a	2.54a
NPK+CaMgSZnB	296.50a	3.69ab	2.71a
Mean	267.26	3.12	2.34
LSD(0.05)	24.85	0.32	0.19
CV (%)	7.82	8.71	6.80

4.2.2. Leaf area index

Leaf Area Index of maize was significantly affected ($P < 0.05$) by fertilizer treatments (Table 5). Significantly the highest leaf area index (3.92) was obtained with the application of balanced NPK, NPK+CaMgSZnB (3.69) which was at par. The lowest LAI (2.15) and (2.48) were obtained from the control and N-omitted treatments respectively (Table 5). The LAI increased by 63.3% due to application of NPK when compared to N omitted treatment and this increase was attributed to only N effect, while LAI increased by 76% P effect due to NPK application compared to the P omitted treatment.

The leaf area index was increased with increased balanced NPK fertilizer because of vigorous growth of the crop and leaf expansion in length and width. Leaf area index has primary importance in increasing the yield of crop. The reason for an increase of leaf area index could be attributed to development of more above ground biomass with expanded leaves produced in response to nitrogen. Phosphorous also promotes rapid canopy development and contributing to root cell division. Leaf expansion was improved in plants by giving chemical fertilizers and was illustrated in terms of leaf length and width (Valero *et al*., 2005). Kumar *et al*. (2005) reported that growth and yield of maize plants in terms of leaf area index varied significantly due to various nutrient application. He also reported that having maximum leaf area index, from application of NPK was superior over remaining treatments. Greater LAI in NPK treatment was attributed to production of new leaves and also increase in size of the existing leaves (Bandyopadhyay *et al*., 2010).

4.2.3. Stem girth

Stem girth of maize was significantly affected ($p<0.05$) by fertilizer treatments (Table 5). Stem girth of maize significantly differed among the fertilizer treatments. Significantly the highest stem girth (2.71cm) was recorded from the application of NPK+ CaMgSZnB fertilizer compared to all other treatments, which was also at par with the NPK treatment (2.54cm), while the lowest stem girth was recorded from the control (2.03cm). The significant difference among treatments might be attributed to application of balanced nutrients which enhanced vegetative growth of maize crop and have positive effect on maize stem girth.

The girth of the plant is an important criterion, which determines its strength and ability to resist lodging. Potassium application favorably influenced the girth of maize plants, the greatest girth being observed with the application of NPK (Table 5). The increase in stem girth of maize under balanced fertilization may be due to cell expansion, which induces sturdiness and healthiness of plants, including better root development (Walker and Parks, 1969; Singh and Tripathi, 1979; Ahmed, 1992). In plots without K application, strong winds caused the crop to lodge but no lodging took place in the NPK treated plots because of the increased stem strength and root development enhanced by balanced nutrition with potassium.

4.3. Yield and Yield Components

4.3.1. Effect of nutrient omission on yield of maize

The Nutrient Omission Trials showed significant effects on yields of maize (Table 6). The average yield findings are in line with the results of Adediran and Banjoko (2003) who reported high yields in treatments with balanced fertilizer treatment. Treatments, NP, NPK, and NPK +CaMgSZnB achieved high yields because they had adequate supply of all nutrients. This can be attributed to optimum utilization of solar light, higher assimilates production and its conversion to starches which resulted higher grains number (Derby *et al*., 2004). The results indicate low grain yield was achieved by treatment PK. This is in agreement with Sangoi *et al*. (2007) who found that lack of N before or at sowing results in reduced grain yield in maize. Further, studies conducted by Samira *et al*. (1998) and Torbert *et al*. (2001) found that N application increased yield and yield components of maize. Studies by Jones (2003) indicated that plants suffering from N deficiency mature earlier thus the vegetative growth stage is shortened leading to low grain yields. Further, Malhia *et al*. (2001) and Murshedul *et al*. (2006) reported that adequate supply of nitrogen leads to a significant increase in grain yield and its components.

Treatment NK achieved low yields, this observation was in line with Kogbe and Adediran (2003) who found that the application of inadequate P depressed maize yield. Another study by Grant *et al*. (2001) found that plants require adequate P from the very early stages of growth for optimum crop production. Further studies that corroborate the observations made in this study were done by Tang *et al*. (2007), Blake *et al*. (2000), Krishna (2002), and Bunemann *et al*. (2004) who reported depressed maize yields when P supply was inadequate over the entire maize growth period. Studies in Ontario have shown that maize grain yield was strongly affected by P supply and tissue P concentration in the V4 to V5 stage, rather than by P concentration later in growth (Barry and Miller, 1989; Lauzon and Miller, 1997). Enhanced early-season P nutrition in maize increased the dry matter partitioning to the grain at later development stages (Gavito and Miller, 1998). There exists low biomass production of maize under P deficiency in field conditions since the aboveground biomass accumulation was severely reduced (–60%) during early stages of maize growth (Plénet *et al*., 2000). The spectacular effect of P deprivation on early reduction in shoot growth is explained by a slight although rapid stimulation of root growth

(Mollier and Pellerin, 1999). Phosphorus deficiency results in plants that grow slowly with poorly developed root systems and small leaves of greyish-green color (Plénet *et al*., 2000).

Nitrogen was the most grain yield limiting nutrient but the omission of both P and K reduced the yield significantly in all the maize cropping system ($p < 0.05$). Plant height, leaf area index, harvest index, grain yield, and stover yield differed statistically among the treatments showing low (0N and control) and high productive (ample NPK and NPK+secondary +micronutrients) distinctive groups. Nitrogen has a major effect on growth of maize plant among the major nutrients needed by plants (especially the three elements of N, P, and K) (Ciampitti and Vyn, 2012).Casta *et al*. (2002) and Bundy *et al*. (1993) reported that maize crop response to nitrogen is different due to weather conditions, soil type and maize rotation. The omission of P (-P) similarly led to a drastic reduction in maize grain yield relative to the NPK fertilizer treatment. P is the next most important yield-limiting nutrient after N.

Table 6. Effect of nutrient omission on Maize grain, stover and total biomass yields in 2017

Treatments	Grain Yield (kg/ha)	Stover yield (kg/ha)	Total Biomass yield (kg/ha)
Control	1861.3f	3786.6f	5647.9f
PK(-N)	2680.6e	5297.2e	7977.8e
NK(-P)	4270.4d	6465.6d	10736.0d
NP(-K)	7959.0c	8483.8c	16442.8c
NPK	9185.1a	10307.8a	19492.8a
NPK+ CaMgSZnB	8362.1b	9299.9b	17662.0b
Mean	5719.732	7273.493	12993.22
LSD(0.05)	389.69	606.45	757.48
CV (%)	5.73	7.01	4.90

Table 7. Grain yield response due to each nutrient application in the NOTs in 2017

Grain yield (kg ha^{-1}) increase due to nutrients			
N	P	K	(S, Mg, Ca, B, Zn)
6504	4915	1226	823

4.3.1.1. Grain yield

Grain, stover and bio-mass yield of maize was significantly affected ($P<0.05$) by the fertilizer treatments (Table 6). Grain yield is the end result of many complex morphological and physiological processes occurring during the growth and development of crop (Khan *et al.*, 2008). Grain yield of maize significantly differed for all fertilizer treatments. Significantly the highest grain yield (9185 kg ha^{-1}) was obtained with the balanced application of NPK fertilizer compared to all the other treatments followed by the application of NPK+ CaMgSZnB (8362.1 kg ha^{-1}), while the lowest grain yield was recorded for the control treatment (1861.3 kg ha^{-1}) and N-omitted(2680.6 kg ha^{-1}). Maize has a strong exhausting effect on the soil and it is generally observed that maize fails to produce good grain yield in plots without fertilizer application (Kumar, 1993). In most experiments, maize response to N is very significant. The present result agrees with the finding of Tesfaye *et al*. (2018) who also observed the highest maize grain yield was obtained from the NPK treatments than the other treatments both in Bako Tibe and four districts of Jimma Zones. The fact that the highest maize grain yield was recorded for the NPK treated plots compared to the rests of the treatments has the implication that the current blended fertilizer should contain potassium both to enhance maize productivity as well as to safeguard further depletion of soil K. Among all treatments, NPK fertilization produced the highest yield. This high yield was due to the balanced supply of NPK important nutrients to the plants. Other treatments, such as NP, NK and PK, were lacking at least one major nutrient, i.e., N, P or K, and thus may induce a specific nutrient deficiency stress and retard overall growth of maize with a concomitant reduction in yield. Nevertheless, the contributions of chemical fertilizers were diverse. These results were in agreement with previous studies (Zhang *et al*.,2003 and Pan *et al*.,2012) reported that yield components were affected by the fertilizations, and consequently, crop yields were usually greater depending on the soil fertility (Hossain *et al*.,2005). Results showed that yield increase due to nitrogen application was 6,504.5 kg ha^{-1}. Likewise, yield increase due to P application was 4914.7 kg ha^{-1}. The yield increase due to K application was 1,226.1 kg ha^{-1}. The yield response to K fertilizer was much lower than that to N or P fertilizer (Table 7), most likely due to the high inherent soil K levels, which were in excess of the crop K demands. On the other hand, yield increase due to supplementing NPK with secondary and micronutrients was, 823 kg ha^{-1}. The result suggests that supplementing N and P fertilizers with K is more useful than supplementing with secondary and micronutrients, since the yield increase due to the later was lower by half. The impact of secondary and micronutrient on maize yield was also small in the study area. Therefore, application of fertilizer containing secondary and micronutrient is not an urgent matter in major maize production areas of Ethiopia. However, balanced application of N, P and K fertilizers is quite important since such application significantly improved recovery efficiency, regardless of the current study area.

Grain yield of maize involves the cumulative effect of a large number of components and metabolic processes that act with varying intensity throughout the plant's life cycle (Gungula *et al*., 2007). The highest grain yield in ample NPK plot could be due to highest final plant height (285.5cm), leaf area index (3.92), and harvest index (47.15%) respectively, suggesting that the improvement in the yield attributes might have increased the grain yield. This could be justified by the positive linear correlation between grain yield and plant height (0.701**), and stem girth (0.552**), and biomass yield (0.992**) (Table 9).

Further, highest stover yield could also be another reason for the highest yield of maize under NPK fertilization plot. This has also been verified from the strong positive correlation between grain yield and stover yield (0.962**) (Table 9). Lemcoff and Loomis (1986) also reported that application of balanced amount of nutrient increases nutrient uptake which facilitates more photosynthetic activity and more partitioning of dry matter to the ears, consequently increase in yield components and grain yield. This forms the basis for high yield under high nutrient availability.

The lowest grain yield among PK (-N) and control, where PK was applied but lowest in 0N plot indicates N application cannot be substituted and has highest contribution in maize yield. It could be due to high effect of N on chlorophyll formation, photosynthesis and assimilate production because nitrogen stress reduces crop photosynthesis by reducing leaf area development and leaf photosynthesis rate by accelerating the leaf senescence (Diallo *et al*., 1996). Moreover, under N deficiencies, a considerably large proportion of dry matter is partitioned to roots than shoots, leading to reduced shoot/root dry weight ratio (Rufty *et al*., 1988) and consequently the grain yield. Another strong reason might be due to low indigenous N supply capacity, as the soil of sloppy land is prone to soil and nutrient erosion.

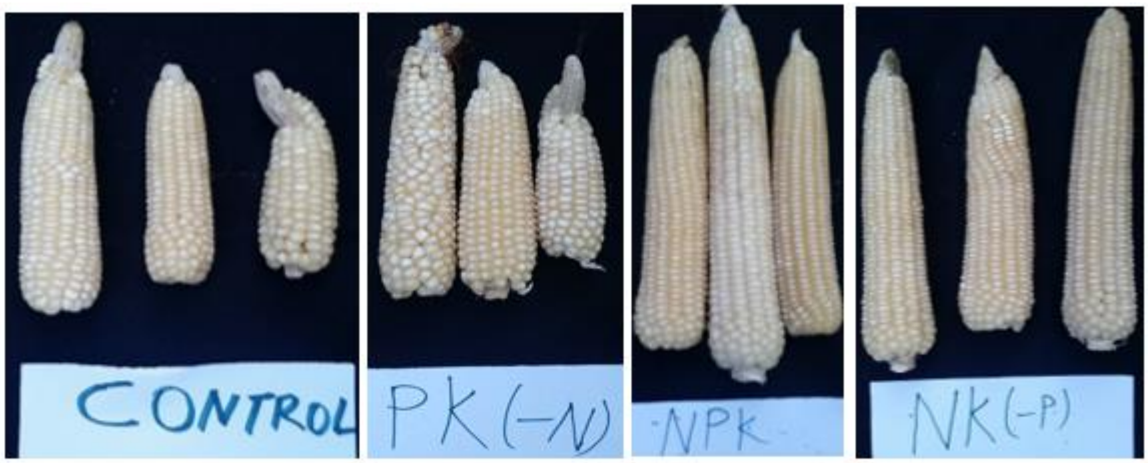

Figure 3. Ear performance of under different nutrient fertilization.

Among the chemical fertilizer, nitrogen is also considered one of the most important factors affecting crop morphology, physiological traits and grain yield (Khan *et al*., 2008). The main role of N in the plant is its presence in the structure of protein, the most important building substances from which the living material or protoplasm of every cell is made. In addition, nitrogen is also found in chlorophyll, the green colouring matter of leaves. Chlorophyll enables the plant to transfer energy from sunlight by photosynthesis. Therefore, the nitrogen supply to the plant will influence the amount of protein, protoplasm and chlorophyll formed. In turn, this influences cell size, leaf area and photosynthetic activity. Maize is very sensitive to insufficient nitrogen and very responsive to nitrogen fertilization. Insufficient N availability to maize plants results in low yields and significantly reduced profits compared to a properly fertilized crop (Singh *et al.*, 2003).

The nitrogen nutrient has synergistic effect on growth and yield attributes resulting in greater translocation of photosynthesis from source to sink, beneficial effect on physiological process, plant metabolism, growth and the major ingredient of proteins, enzymes, amino acids, amides and nucleic acids (Yayock *et al*.,1988) and there by leading to higher grain yield. The P supply is particularly important for stimulating early root formation and growth, functions in plant macromolecular structures as a component of nucleic acids and phospholipids, with crucial roles in energy metabolism, participation in signal transduction path ways via phosphorylation and controlling key enzyme reactions (Marschner, 2012). Application of potassium fertilizer in adequate amount is essential for obtaining optimal crop yields. Many other researchers also have reported that the application of potassium fertilizer along with N and P fertilizers increased maize grain yield (Grunes *et al*., 1998; Fageria *et al.*, 2010). Generally, the application of balanced N, P and K nutrient is useful to enhance crop productivity and nutrient use efficiencies.

4.3.1.2. Stover yield

The highest stover yield was obtained with the application of NPK fertilizer, while the lowest stover yield was obtained from the control. N, P and K omission significantly reduced stover yield over NPK application. The omission of N, P and K suppressed stover yield (Table 6). However, the stover yield from the control and N omitted treatments were significantly lower as compared to any of the other treatments (Table 6). Stover yield is strongly correlated with K supply and was reduced significantly due to its omission by 21.5% in comparison to NPK. Omission of secondary and micronutrients had comparatively smaller effect on stover production. It might be due to progressive depletion of N, P and K in the respective omission plots could not meet the higher requirements of N, P and K for maize and therefore, resulted in reduction of yield attributes and yield of maize. This result was in accordance with the findings of Rawal *et al*. (2017).

4.3.1.3. Total biomass yield

The effect of omitted nutrients on yield attributes was reflected directly in the grain and straw yields of maize. The total biomass yield was significantly higher for the NPK treatment, but was significantly lower for the control. N omission reduced total biomass yield more than P and K omission. The total biomass yield was significantly higher for NP, NPK and NPK+ CaMgSZnB treatments than for the rest of the treatments. Significantly the lowest total biomass was recorded for the control and N omitted treatments. The total biomass was much more reduced by N omission than P omission, but was much more reduced by P omission compared to K omission, implying that the importance of each of the primary nutrient in enhancing total biomass was in the order of N>P>K.

The result showed that above ground biomass yield was increased by balanced fertilizers is due to high grain yield, LAI, stem girth, plant height and stover yield. An increase in leaf area index, may have promoted photosynthetic production to enhance high biomass yield in balanced application of nutrients. 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 elongation. Thus an increase in biomass yield might have been on account of overall improvement in the vegetative growth of plant due to the application of balanced nutrients (NPK).

The effect of omitted nutrients on yield attributes was reflected directly in the grain and straw yields of maize. Both grain and straw yields under NPK approach were significantly superior to all other treatments and were higher than NP treatment (Table 6). Omission of P to maize crops resulted in significant reduction in bio-mass yield by 81.56% compared to the treatment where NPK was applied and other all nutrients were omitted. Similarly, the sustained omission of K in the system significantly influenced total biomass yield of maize which was reduced by 18.55 when compared to balanced NPK fertilizers (Table 6). The biomass yield reduction was slightly lower with secondary and micronutrient omission (10.4%).

4.3.1.4. Harvest index

Harvest index was computed as the ratio of grain yield to the total above ground dry biomass yield. Harvest Index of maize was significantly affected ($p<0.05$) by the fertilizer treatments (Table 8). Harvest Index significantly differed for all fertilizer treatments. Significantly the highest harvest index (47.36%) was obtained by the application of NPK+ CaMgSZnB treatment compared to all the other treatments followed by the application of NPK (47.15%), while the lowest harvest index was recorded from the control (33%) and N-omitted treatment (34%).This phenomenon has been summarized by Sinclair (1998) that harvest index for crops had increased with grain production dramatically increasing in the twentieth century. Previous studies indicated that harvest index is already close to the practical maximum value around 50% (Mann, 1990; Katsura *et al*. 2008); even 55% has been achieved under high-yielding cultivars (Yang *et al*., 2007; Katsura *et al*., 2008). Similarly, (Hay and Gilbert, 2001) reported that harvest index of maize to be 50% for most tropical maize crops. However, in all treatments, the harvest index values recorded were below (50). Low harvest index values can be attributable to late sowing, low plant population, diseases and unavailability of water at the critical growth stage of the crop (Ahmad *et al*., 2007).

Table 8.Harvest index of Maize as affected by nutrient omission in 2017

Treatments	Harvest Index (%)
Control	32.97d
PK(-N)	33.56d
NK(-P)	39.79c
NP(-K)	44.27b
NPK	47.15ab
NPK+	47.36a
Mean	40.85
LSD(0.05)	3.02
CV (%)	6.21

The production of photo-syntheses via photosynthetic activity in the leaf is ultimately the driver of crop yield and is dependent on leaf area. Any treatment increasing leaf area is thus likely to contribute towards raising crop yield. In this respect, leaf area was found to increase with the addition of balanced fertilizers (Table 5). On average, maximum leaf area index was observed when balanced NPK was applied. As well as its effect in promoting photosynthetic activity, potassium also increases cell expansion by regulating solute potential that may increase the rate of leaf expansion and the leaf area (Rao and Madhava, 1983; Yahiya *et al.*, 1996).

The physiological efficiency of maize in converting the photosynthesis into grain yield is measured in the form of harvest index. Grain filling is an important stage in the phonology of maize crops. Any stress due to insufficient moisture or nutrients at this time will adversely affect this process. The harvest index (HI), defined as the ratio of economic yield to biological yield is used to describe the accumulation and redistribution of assimilates to achieve final yield (Healey *et al*., 1998). In addition, harvest index (HI) shows the physiological efficiency of plants to convert the fraction of photo-assimilates to grain yield. According to Echarte and Andrade (2003), the vital determinants of crop yields are the harvest index value and its stability.

The treatments that promoted better growth of the maize crop had a positive influence on HI, presumably due to faster growth and partitioning of more carbohydrates into the grain. All treatments had higher HI compared to the control, reflecting poor plant growth in the control. The results suggest that an application of NPK supply is essential for optimized partitioning of DM between grain and other parts of the maize plant.

4.4. Correlation among Grain Yield and Yield Components of Maize

All the independent variables showed a significant positive and linear relationship with grain yield (Table 9) suggesting an increment in grain yield of maize with increase NPK fertilizers. The correlation analyses revealed that, there was a significant ($P < 0.001$) and positive correlation between grain yield and yield related agronomic parameters of maize. Grain production showed significantly positive correlation to yield components and growth parameters. Grain yield was significantly and positively correlated with biomass yield ($r=0.992^{**}$, $p<0.01$), leaf area index ($r = 0.871^{**}$), stover yield ($r = 0.962^{**}$) and harvest index ($r = 0.931^{**}$). Straw and total biomass yield were positively correlated with almost all agronomic parameters of maize crop. This indicates increasing grain yield could increase yield components of maize and vise verse. This pattern agrees with the findings that most of the variation in grain yield could be explained by above-ground DM (Haefele *et al*., 2003; Katsura *et al*., 2008). All these indicate that the improvement in above-ground plant biomass with maintenance of high harvest index could be of great benefit for an additional increase in maize grain yield. Similar findings were reported by Yihenew (2015) and Habtamu *et al*. (2015) that grain yield of maize were positively and significantly correlated with yield components. Generally, Pearson's moment correlation coefficients between grain yield and six other agronomic traits considered in the study area.

Table 9.Correlation among growth parameters, yield traits and grain yield of Maize at Kersa in 2017

Variables	GY	SY	BM	HI	PHT	Stem girth	LAI
GY	1.00	0.962**	0.992**	0.931**	0.701**	0.552**	0.871**
SY		1.00	0.988**	0.818**	0.697**	0.521*	0.875**
BM			1.00	0.889**	0.706**	0.544*	0.881**
HI				1.00	0.651*	0.549*	0.777**
PHT					1.00	0.739*	0.873**
Stem girth						1.00	0.678*
LAI							1.00

GY= Grain Yield; BMY= Biomass Yield; HI= Harvest Index; LAI=Leaf Area Index; PH= Plant Height; ** and * indicate significant at $P < 0.001$ and $P < 0.05$ level, respectively.

4.5. Maize Nutrient Uptake

Total mineral nutrient uptake is the sum of nutrient contents in the stover and grain estimates that total quantity of a mineral nutrient required producing a crop. Total N, P and K uptake in aboveground plant parts of maize under different fertilization treatments are shown in Table 10. Total N, P and K uptake of maize were highly significantly ($p<0.01$) influenced by nutrient omission. There was a progressive and significant increase in NPK uptake with increase balanced nutrient. Significantly higher NPK uptake was found with the application of balanced fertilizer treatment (NPK). Total N uptake was enhanced under NPK fertilization compared with control, PK and NK treatments. The total N uptake by maize varied from 4.23 to 17.37 kg ha^{-1}. The total N uptake during cropping season was higher for the NPK treatment than for the PK treatment. The maximum total N-uptake (17.37kg ha-1) was recorded from balanced NPK fertilization while the minimum total N uptake was obtained from the control (4.23kg ha-1) and N-omitted (5.11 kg ha-1) treatment. The total N-uptake was increased by 54.54 and 29.4% when compared to control and N-omitted (PK) treatment respectively. The N uptake in maize grain and straw at harvest, with some deviation depending on the absence or supply of N, indicating the ability of the plant to translocate nutrients to grain and straw at the expense of the vegetative part of the plant.

The total maize P-uptake was significantly ($p<0.01$) affected by nutrient fertilization. Phosphorus uptake in maize was greater under NPK fertilization compared with NK treatment. The total P uptake varied from 27.20 to 120.6 kg ha^{-1} under different treatment fertilization. The maximum total P-uptake was obtained from the application of balanced NPK (120.59) fertilizer, while the minimum was recorded from control (no fertilizer input) (27.2).The total P-uptake was increased by 63.2 and 53.45% when compared to control and P-omitted treatment respectively. The results clearly showed that there was a positive effects P on maize grain and straw yields and the improvement of grain and straw P contents by application of balanced (NPK) fertilizers.

Compared with NK treatment, potassium uptake was enhanced under NPK fertilization. Finally, the total K uptake of maize ranged from 40.20 to 100.53 kg ha^{-1} for maize under different fertilization. Furthermore, the highest N, P and K uptake was observed at NPK fertilization followed by NPK+. This illustrated that NPK fertilization treatment was better than the other treatments for improving the N, P and K accumulation of maize productivity (Table 10).

Table 10. Total above ground N, P and K uptake of maize (kg/ha) as influenced by different nutrient omission in 2017

Treatments	Total Nutrient uptake(kg/ha)		
	N	P	K
Control	4.23d	27.20f	40.20f
PK(-N)	5.11d	46.55e	59.32e
NK(-P)	7.40c	64.46d	71.40d
NP(-K)	12.46b	87.73c	79.52c
NPK	17.37a	120.59a	100.53a
NPK+	12.99b	104.49b	93.87b
Mean	9.92	75.17	74.14
LSD(0.05)	1.22	5.39	3.75
CV (%)	10.37	6.03	4.26

According to Mengel and Kirkby (1987) the nutrient content of plant tissue reflects soil availability. The low P uptake and concentrations in plant materials of the control might therefore be attributed to low P availability in the experimental soil; as was also confirmed by soil analysis before planting (Table 4). Additionally, phosphorus availability to plants is determined by the chemical characteristics of the soil and the P fertilizer source (Havlin, 1999; Kirsten, 2014).

The efficiency of nutrients absorption often determined as the ability of the plants to absorb a certain element at low level of soil stocks or the nutrient medium (Dawson *et al*., 2008). Usually however the selection of the cultures was performed in agrochemical conditions not limited their growth and productivity (Abeledo *et al*., 2008).

4.6. Nutrient Use Efficiency

Nutrient use efficiency is also called nutrient to grain ratio. The major macronutrients (N, P and K) use efficiency was significantly influenced by different nutrient omission trial. The treatments showed that highest FUE was observed in NPK fertilizer treatment. The agronomic efficiency (AE), uptake/recovery efficiency (UEN), of maize as influenced by different nutrient omission trial.

Table 11. Agronomic and Apparent Recovery efficiency of N, P and K as affected by nutrients in 2017

Treatments	Agronomic Efficiency (kg grain kg^{-1} Nutrient applied)			Apparent Recovery Fraction (kg N,P,K taken up kg^{-1} of N,P,K applied)		
	AEN	AEP	AEK	ARN	ARP	ARK
Control	-	-	-	-	-	
PK(-N)	-	11.13c	17.25d	-	21.03d	39.85d
NK(-P)	20.08d	-	50.02c	2.11c	-	65.01c
NP(-K)	50.81c	55.48b	-	6.13b	52.63c	-
NPK	61.03a	68.81a	152.58a	10.37a	88.35a	125.71a
NPK+	54.17b	64.78a	135.43b	6.62b	77.61b	111.82b
Mean	46.52	50.05	88.83	6.31	59.91	85.60
LSD(0.05)	2.74	6.36	6.76	0.908	4.61	9.02
CV (%)	4.78	10.32	6.18	11.70	6.26	8.56

4.6.1. Agronomic efficiency of nutrients

Agronomic Efficiency of N, P and K was significantly affected ($p<0.05$) by nutrient omission (Table 10). The agronomic efficiency of N, P and K varied between treatments. The AEN ranged from 20.08 (for NK treatment) to 61.03 kg grain kg^{-1} of applied N (for NPK treatment). The highest AEN was obtained from the application of NPK (61.03 kg of grain kg^{-1} N applied) fertilizer treatment, while the lowest AEN was recorded from the application of NK (20.08 kg/kg). Dobermann (2007) reported that the AEN for cereals in developing countries could reach >30 kg/kg in a well-managed system. The AEP ranged from 11.13(for PK treatment) to 68.81(for NPK treatment) kg of grain kg^{-1} applied P. The highest AEP was obtained from the application of NPK (68.81kg grain kg^{-1} applied P) plot; while the lowest AEP was recorded from the treatment PK (11.13 kg grain kg^{-1} applied P). Omission of N (i.e. PK treatment) extraordinarily reduced AEP, suggesting that P application in the absence of N cannot improve the agronomic efficiency of P. The AEK ranged from 17.25(for PK treatment) to 152.58(for NPK treatment) kg of grain kg^{-1} K. The highest AEK was obtained from the application of NPK

(152.58 kg grain kg^{-1} K) plot, while the lowest AEK was recorded from the treatment PK (17.25 kg grain kg^{-1} K).

Likewise, Xu *et al*. (2014) obtained higher AE of NPK with lower doses. Initially the agronomic efficiency for a nutrient increased with yield response increasing, but the amount of increase became smaller as the yield response became larger. NPK balanced fertilizer improved N use efficiency by 83.25% as compared to recommended NP fertilizers. Similarly, the same trend was observed with P and K use efficiencies. High agronomic efficiency would be obtained if the yield increment per unit applied is high (Obreza and Rhoads, 1988). A lower yield response indicates higher soil indigenous nutrient supply or higher soil fertility, resulting in lower agronomic efficiency. In contrast, a larger yield response means lower soil nutrient supply and relatively higher agronomic efficiency.

4.6.2. Apparent recovery efficiency of nutrients

The recovery of any nutrient applied shows the soil supplying capacity and the inherent capacity of the plant to utilize nutrient. The recovery of N fertilizer from total N uptake by the total biomass at harvest varied among fertilizers types. Accordingly, the highest value of N recovery was recorded from balanced NPK fertilizer and followed by balanced NPK+ fertilizer, whereas the least value was for NK fertilizer. Application of NPK balanced fertilizer improved N recovery by 20.35% as compared to NK fertilizer. This showed that nitrogen application could be efficiently taken up by maize and would not decrease N uptake from the soil. Similarly, the maximum values of P and K recovery were recorded from NPK balanced fertilizer and followed by NPK+ balanced fertilizer, whereas the least were for PK fertilizer treatment. Application of NPK balanced fertilizer improved N recovery by 59.11% as compared to recommended NP fertilizers. In agreement with the present study, nitrogen applied at anthesis increased N recovery (Wuest and Cassman, 1992). They showed that split N application could be efficiently taken up by maize and would not decrease N uptake from the soil.

Phosphorous ARE is in line with the findings indicated that the level of nutrient fertilization affects the nutrient availability in soil, and at high contents of soil nutrients and their availability more nutrients might be taken up by plants (Salam *et al*.,2014; Sandana,2016; Trehan,2009).

5. SUMMARY AND CONCLUSION

Nutrient availability is the most yield-limiting factor to produce higher yields. The ability to better identify crop response to the application of fertilizers, soil indigenous nutrient supply capability, and the maintenance of soil fertility over time are crucial to the development of improved nutrient management practices. Soil analysis before sowing indicated that the major nutrients (N, P) were found at low levels. The ability to better identify crop response to the application of fertilizers, soil indigenous nutrient supply capability, and the maintenance of soil fertility over time are crucial to the development of improved nutrient management practices. All the studied nutrient omission effects on maize yield and yield components showed that the balanced fertilizers would be promising to grow maize in the study area, whereas maize productivity for the previously existing NP fertilizers in the country was low as compared to the balanced fertilizers (NPK); which indicated that maize productivity in the study area was reduced due to high demand for external nutrient inputs rather than NP fertilizers. The higher mean grain yield (9185.1 kg ha^{-1}), stover yield (10307.8 kg ha^{-1}) and total biomass yield (19492.8 kg ha^{-1}) were recorded from balanced fertilizers (NPK), whereas the lowest were recorded from the control and N-omitted treatment. Plots that were treated with the combined NPK application had significantly higher maize yields than plots with no NPK treatment at experimental site. The lowest yields were observed in the control and no-N plots (PK), which indicated that N deficiency was the most yield limiting condition for maize production. The yield response to K fertilizer was much lower than that to N or P fertilizer, most likely due to the high inherent soil K levels, which were in excess of the crop K demands. The results revealed that the addition of P and K fertilizer had a considerably positive effect on crop productivity when they were balanced with N. A similar trend was observed for P and K accumulation by aboveground parts of maize, indicating that it is possible to enhance P and K accumulation when they are applied in combination with N fertilizer. Balanced fertilizers had improved grain nutrient uptake and agronomic efficiency of maize. It was also apparent that much of the nutrients applied were assimilated by the grain than that achieved by the stover. To improve the current unbalanced fertilizer application and soil mining of the study area, precautionary actions such as adopting sustainable soil fertility replenishment strategy, soil conservation practices and avoiding unbalanced fertilizers can help to rebuild the soil conditions to increase crop productivity.

In summary, balanced fertilizer application is not only essential for producing top quality crops in high yields but also for environmental sustainability. Nutrients needed in high quantities (N, P, and K) or which have high harvest index (HI) values (N, P, K), are expected to be key nutrients for high-yield maize production. High total nutrient uptake necessitates accurate fertilization rates made at the right time and place. Nutrients with high HI values remove more of that nutrient from the field than nutrients with low HI values and suggest a looming soil fertility crisis if adequate adjustments are not made in usage of balanced nutrients as productivity increases.

A high degree of variability in crop response to nutrients and amendments is observed in major cereal growing areas in Ethiopia. This is mainly associated with variability in soil characteristics within and between farmers' fields. Fertilizer trials are key for yield gap assessment and provide data and information relevant to developing strategies and identifying possible solutions to improve crop productivity. The analyses of response patterns of crops to the various treatments in different fields can enable grouping of fields into response classes.

Consequently, maize showed a large degree of variation in yield response to nutrient applications at the studied area. Nitrogen and phosphorus were generally the most limiting nutrients for maize production in the study area. However, maize yield responded significantly to Potassium fertilizer as well. Overall, the maize yield response to secondary and micronutrients was small at studied area suggesting that only small amounts of secondary and micronutrients are required for maximizing maize production as well as for soil fertility maintenance to minimize depletion of secondary and micronutrients reserves and sustain maize productivity in the long-term.

Furthermore the following points are suggested as future line of works, based on the findings of this study;

- Further researches are required on N, P and K fertilizer distribution for maize production to address the most limiting nutrients around the study area.
- In addition to Nitrogen and phosphorus, potassium inadequacy needs to be addressed in Jimma, since potassium is the nutrients limiting maize growth and yields.
- There is need for a further study to understand the impact of each of the secondary and micro-nutrients on maize productivity in Ethiopia.

6. REFERENCES

Abegaz Assefa, H. van Keulen, Haile Mitiku and S.J. Oosting, 2007. Nutrient dynamics on smallholder farms in Teghane, Northern Highlands of Ethiopia. In *Advances in integrated soil fertility management in sub-Saharan Africa: Challenges and opportunities* (pp. 365-378). Springer, Dordrecht.

Abeledo, L.G., D.F. Calderini and G.A. Slafer, 2008. Nitrogen economy in old and modern malting barleys. *Field Crops Research*, **106**:171-178.

Adediran, J.A. and V.A. Banjoko, 1995. Response of Maize to Nitrogen, Phosphorus and Potassium fertilizers in the savanna zone of Nigeria. Commun. Soil Sci. Plant Anal., 26:593-606.

Adediran, J.A., and V.A. Banjoko, 2003. Comparative effectiveness of some compost fertilizer formulations for maize in Nigeria. Nig. J. Soil Sci. **13:** 42-48.

Admas Habtamu, Heluf Gebrekidan, Bobe Bedadi and Enyew Adgo, 2015. Effects of Organic and Inorganic Fertilizers on Yield and Yield Components of Maize at Wujiraba Watershed, North-western Highlands of Ethiopia. American Journal of Plant Nutrition and Fertilization Technology, **5:** 1-15.

AGRA, 2007. Alliance for a Green Revolution in Africa: AGRA at work. Retrieved 13th March, 2008 from www.agra-alliance.org/work/Agric Ecosyst Environ **71**:185-202.

Alam, M.M., J.K. Ladha, Z. Rahman, S.R. Khan, A.H. Khan and R.J. Buresh, 2006. Nutrient management for increased productivity of rice–wheat cropping system in Bangladesh. *Field crops research*, ***96*****:**374-386.

Ali, J., J. Bakht, M. Shafi, S. Khan and W.A. Shah. 2002. Uptake of nitrogen as affected by various combinations of nitrogen and phosphorus. Asian J. Pl. Sci. **1:** 367-369.

Alley, M.M., and B. Vanlauwe, 2009. The role of fertilizers in Integrated Plant Nutrient Management, First edition, IFA, Paris, France. TSBF-CIAT, Nairobi, p 59.

Amante Daniel J., T.P. Hogan, S.L. Pagoto and T.M. English, 2014. A systematic review of electronic portal usage among patients with diabetes. *Diabetes technology & therapeutics*, ***16*****:**84-793.

Amede Tilahun, 2003. Opportunities and Challenges in Reversing Land degradation: The Regional Experience. In: Amede, T (ed), Natural resource degradation and environmental concerns in the Amhara National Regional State: Impact on Food Security. Ethiopian Soils Sci. Soc. pp. 173-183.

Amujoyegbe, B. J., J. T.Opabode, and A. Olayinka, 2007. Effect of organic and inorganic fertilizer on yield and chlorophyll content of maize (Zea mays L.) and sorghum (Sorghum bicolor (L.) Moench). African Journal of Biotechnology, **6:**1869-1873.

Archer, J., 1988. Crop nutrition and fertilizer use. 2nd ed. Ipswich, England: Farming Press Ltd.

Arshad, M.A., B.Lowery, and B. Grossman, 1996. Physical tests for monitoring soil quality. Methods for assessing soil quality, (methodsforasses), pp.123-141.

Asadu, C.L.A. and B.O. Unagwu, 2012. Effect of combined poultry manure and inorganic fertilizer on maize performance in an ultisol of Southeastern Nigeria. Niger. J. Soil Sci., **22:**79-87.

Awotundun, J.S., 2005. Comparative effects of organic and inorganic fertilizer on the yield of pop-corn. Proceedings of the 29th Annual Conference of the Soil Science Society of Nigeria, December 6-10, 2004, University of Agriculture Abeokuta, Nigeria, pp: 175-179.

Ayub, M., M.A. Nadeem, M.S. Sharar, and N. Mahmood, 2002. Response of maize (Zea mays L.) fodder to different levels of nitrogen and phosphorus. Asian Journal of Plant Sciences, **1:**352-354.

Bandyopadhyay, K.K., A.K. Misra, P.K. Ghosh, and K.M. Hati, 2010. Effect of integrated use of farmyard manure and chemical fertilizers on soil physical properties and productivity of soybean. Soil and Tillage Research, **110:**115-125.

Blake L. S., M. Merciks, S. Koerschen, P. R. Moskal, K. W. T. Poulton, A. Goulding, D. Weige and S. Powlson, 2000. Phosphorus content in soil, uptake by plants and balance in three European long - term field experiments, Nutr. Cycle, Agro-ecosyst. **56:**263-275.

Bogale Gelena, 2014. Resource and Nutrient Flows in Smallholders Farming Systems of Kumbursa Village, Ada'a district of Central Ethiopia. MA thesis paper presented for Addis Ababa University, Ethiopia, Addis Ababa.

Brady N C. and R. Weil, 2002. Micronutrient and other trace elements. The Nature and Property of Soil (13th ed.). Pearson Education Publisher, Singhapur. pp. 638- 668.

Brady, N.C. and Weil, R.R., 1984. Nature and properties of soils, Macmillan Publishers Co. *INC, New York*.

Brady, N.C. and Weil, R.R., 2008. Soil colloids: seat of soil chemical and physical acidity. The Nature and Properties of Soils, pp.311-358.

Brady, N.C., and R.R. Weil, 2014. The Nature and Properties of Soils, (14th ed., pp. 567, 615, and 671). New Delhi, India: Pearson Education.

Bray, R.H. and L.T. Kurtz, 1945. Determination of total organic and available forms of phosphorous in soils. *Soil Science*, **63**: 370 – 379.

Bruce, R.C. and G.E. Rayment, 1982. *Analytical methods and interpretations used by the Agricultural Chemistry Branch for soil and land use surveys*. Queens land Department of Primary Industries.

Bukhsh, M. A. A. H. A., A. Riaz, R. Ahmad, M. Ishaque and M. Asmatullah, 2009. Response of maize hybrids to varying potassium application in Pakistan. Pakistan J. Agri. Sci.

Bukhsh, M. A. A. H. A., R. Ahmad, R., Iqbal, M. Maqbool, A. Ali, M. Ishaque, and S. Hussain, 2012. Nutritional and physiological significance of potassium application in maize hybrid crop production. Pakistan J. Nutri., **11**:187-202.

Bundy LG, TW Andraski and RP Wolkowski, 1993. Nitrogen credits in soybean corn corps: sequences on three soils. Agron **85**: 1061-1067.

Bunemann E.K., F. Steinebrunner, P.C. Smithson, E. Frossand and A. Oberson, 2004. Phosphorus dynamics in a highly weathered soil as revealed by isotopic labeling techniques. Soil Sci. Soc. **125:** 49-54.

Busman, L., J. Lamb, G. Randall, G. Rehm, and M. Schmitt, 2002. The nature of phosphorus in soils. University of Minnesota.

Carter, S.E. and H.K. Murwira, 1995. Spatial variability in soil fertility management and crop response in Mutoko communal area, Zimbabwe. Ambio, **24:**77–84.

Cassman, K.G., A. Dobermann and D.T. Walters, 2002. Agro ecosystems, nitrogen-use efficiency, and nitrogen management. AMBIO: - A Journal of the Human Environment, **31:**132-140.

Casta C, L. Dwyer, MDW. Stewart and DL. Smith, 2002. Nitrogen effects on grain yield and yield components of leafy and non-leafy maize genotypes. Crop Sci **42**: 1556-1563.

Charman, P.E.V. and M.M. Roper, 2007. Soil organic matter. In 'Soils–their properties and management'. 3rd edn. (Eds PEV Charman and BW Murphy.) pp. 276–285.

Chen, M.L., X.L. Jiang, B.Y. Zoov and Z.Y. Zheri, 1994. Mathematical models and best combination of high yield cultivation technique for rapeseed variety Zhenyouyoum. Acta Agric Zhejiiangenesis. **6:**22-26.

Chowdhury T., G.P. Ayam, S.B. Gupta, G.K. Das and M.K. Pradhan, 2007. Internal nutrient supply capacity of Vertisols for rice in Chhattisgarh agro-climatic conditions of India, Bangladesh J. Agril. Res., **32:** 501-507.

Ciampitti IA., and TJ Vyn, 2012. Physiological perspectives of changes over time in maize yield dependency on nitrogen uptake and associated nitrogen efficiencies: A review. Field Crops Research **133**: 48-67.

Cox, A.E., B.C. Joern, S.M. Brouder and D.GAO, 1999. Plant available potassium assessment with modified sodium tetra phenyl boron method. Soil Science Society of America Journal, **63:** 902-911.

Da Xavier FAS, EF Almeida, IM Cardoso and ES. Mendonça, 2011. Soil phosphorus distribution in sequentially extracted fractions in tropical agro ecosystems in the Atlantic forest biome, southeastern Brazil. Nutr Cycl Agro-ecosyst. **89**:31–44.

Dambreville, C., T. Morvan and J.C. Germon, 2008. N_2O emission in maize-crops fertilized with pig slurry, matured pig manure or ammonium nitrate in Brittany. Agr. Ecosyst. Environ**. 123**: 201-210.

Dawson, J.C., D.R. Huggins and S.S. Jones, 2008. Characterizing nitrogen use efficiency in natural and agricultural ecosystems to improve the performance of cereal crops in low-input and organic agricultural systems. *Field Crops Research*, **107**:89-101.

De Paz, J.M., and C. Ramos, 2004. Simulation of nitrate leaching for different nitrogen fertilization rates in a region of Valencia (Spain) using a GISGLEAMS system. Agr. Ecosyst. Environ. **103**: 59-73.

Deckers, J., 2002. A systems approach to Target Balanced Nutrient Management in soils capes of Sub-Saharan Africa. In: Integrated Plant Nutrient Management in Sub- Saharan Africa. Vanlauwe, B J. Diels, N. Sanginga and R Merckx (Eds) CAB International, Wallingford.

Delve RJ, ME. Probert, JG. Cobo, J. Ricaurte, M. Rivera, E. Barrios and IM. Rao, 2009. Simulating phosphorus response in annual crop using APSIM; model evaluation on contrasting soil types. Nutr Cycl Agro-ecosyst, **84**:293–306.

Derby, N.E., F.X. Casey, R.E. Knighton, and D.D. Steele, 2004. Midseason nitrogen fertility management for corn based on weather and yield prediction. *Agronomy journal*, ***96*****:**494-501.

Dethier, J.J. and A. Effenberger, 2011. *Agriculture and development: a brief review of the literature*. The World Bank.

Dewitte, O., A. Jones, O. Spaargaren, H. Breuning-Madsen, M. Brossard, A. Dampha, J. Deckers, T. Gallali, S. Hallett, R. Jones and M. Kilasara, 2013. Harmonization of the soil map of Africa at the continental scale. Geoderma, **211:**138-153.

Dibb, D. W. and W. R. Thomson, 1985. Interaction of potassium with other nutrients. In potassium in Agriculture. Soil Science Society of America Madison, WI. USA. pp. 515-532.

Dobermann, A., 2007. Nutrient use efficiency–measurement and management. Fertilizer best management practices, 1.

Dobermann, A., C. Witt, S. Abdulrachman, H.C. Gines, R. Nagarajan, T.T. Son, P.S. Tan, G.H. Wang, N.V. Chien, V.T.K. Thoa and C.V. Phung, 2003. Soil fertility and indigenous nutrient supply in irrigated rice domains of Asia. *Agronomy Journal, **95***:913-923.

Donald, C.M. and J. Hamblin, 1976. The biological yield and harvest index of cereals as agronomic and plant breeding criteria. In Advances in agronomy, pp. 361-405. Academic Press.

Dong, H., X. Kong, W. Li, W. Tang and D. Zhang, 2010. Effects of plant density and nitrogen and potassium fertilization on cotton yield and uptake of major nutrients in two fields with varying fertility. Field Crop Res., **119:**106–113.

Driessen, P., J. Deckers, O. Spaargaren and F. Nachtergaele, 2000. *Lecture notes on the major soils of the world* (No. 94). Food and Agriculture Organization (FAO).

Echarte, L. and F.H. Andrade, 2003. Harvest index stability of Argentinean maize hybrids released between 1965 and 1993. Field Crops Research, **82:**1-12.

Fageria, N.K., V.C. Baligar and C.A. Jones, 2010. Growth and mineral nutrition of field crops. CRC Press.

Fairhurst, T., R. Lefroy, E. Mutert and N. Batjes, 1999. The importance, distribution and causes of phosphorus deficiency as a constraint to crop production in the tropics. Agroforest for **9**:2-8.

Farouque, M.G. and H. Tekeya, 2008. Farmers' Use of Integrated Soil Fertility and Nutrient Management Practices for Sustainable Crop Production: A Field-level Study in Bangladesh. American Journal of Agricultural and Biological Sciences. **3**: 716-723.

Fashina A. S., K. A. Olatunji and K. O. Alasiri, 2002. Effects of different plant population and poultry manure on yield of Ugu (Telfairia occidentalis) in Lagos State, Nigeria in Proceedings of the annual Conference of Horticultural Society of Nigeria (HORTON). pp. 123-127.

Feyissa A. and M. Mebrate, 1994. Provenance trial of Cordia Africana. In: Provenance trials of some exotic and indigenous tree species. Research Note No. 3, Forestry Research Centre, Addis Abeba: 81-96.

Gavito M.E. and M.H. Miller, 1998b. Early phosphorus nutrition, mycorrhizae development, dry matter partitioning and yield of maize. Plant and Soil. **199:** 177-186.

Gavito, M.E. and M.H. Miller, 1998a. Early phosphorus nutrition, mycorrhizae development, dry matter partitioning and yield of maize. *Plant and soil*, ***199*****:**177-186.

Gee, G.W. and J.W. Bauder, 1986. *Particle-size analysis 1* (No. methodsofsoilan1, pp. 383-411). Soil Science Society of America, American Society of Agronomy.

Getachew Agegnehu, Amare Ghizaw and Woldeyesus Sinebo, 2006. Yield performance and land-use efficiency of barley and faba bean mixed cropping in Ethiopian highlands. European Journal of Agronomy, **25**:202-207.

Getachew Agegnehu, Angaw Tsigie and Tesfaye Agajie, 2012. Evaluation of crop residue retention, compost and inorganic fertilizer application on barley productivity and soil chemical properties in the central Ethiopian highlands. Ethiopian Journal of Agricultural Sciences, **22:** 45-61.

Getachew Agegnehu, P.N. Nelson and M.I. Bird, 2016. Crop yield, plant nutrient uptake and soil physicochemical properties under organic soil amendments and nitrogen fertilization on Nitisols. Soil and Tillage Research, **160**:1-13.

Giller, K.E., M. Corbeels, J. Nyamangara, B. Triomphe, F. Affholder, E. Scopel, and P. Tittonell, 2011. A research agenda to explore the role of conservation agriculture in African smallholder farming systems. Field crops research, **124**:468-472.

Girma Taye, 2017. *Potato Productivity, Nutrient Uptake and Use Efficiency as Influenced by Organic and Inorganic Amendments in Arbegona district, Southern Ethiopia* (Doctoral dissertation, Hawassa University).

Grant C. A., D. N. Flaten, D. J. Tomasiewicz and S. C. Sheppard, 2001. The importance of earl season P nutrition. Can. J. Plant Sci. **81:** 211-224.

Grunes, A., M. Alpaslan and A. Inal, 1998. Critical nutrient concentrations and antagonistic and synergistic relationships among the nutrients of NFT-grown young tomato plants. Plant Nutr. J. **21**: 2035–2047.

Haefele, S.M., M.C.S. Wopereis, M.K. Ndiaye, S.E. Barro and M.O. Isselmou, 2003. Internal nutrient efficiencies, fertilizer recovery rates and indigenous nutrient supply of irrigated lowland rice in Sahelian West Africa. *Field Crops Research*, **80**:19-32.

Haileslassie Amare, J. A. Preiss, E. Veldkamp and J. P. Lesschen, 2007. Nutrient flows and balance at the field and farm scale: exploring effects of land use strategies and access to resources. Agricultural Systems, **56**:459-470.

Haque, M.M., A. Hamid and N.I. Bhuiyan, 2001. "Nutrient uptake and productivity as affected by nitrogen and potassium application levels n maize/sweet potato intercropping system". Korean J. Crop Sci., **46:** 1-5.

Hartemink, R.J., P.M. Buresh, A.R. van Bodegom, C. Braun, B.I. Jama, and B.H. Janssen, 2000. Inorganic nitrogen dynamics in fallows and maize on an Oxisol and Alfisol in the highlands of Kenya. Geordama **98:**11-33.

Havlin J., S. Tisdale, W. Nelson and J. Beaton, 1999. Soil fertility and fertilizers. An introduction to nutrient management. 503 p.

Hay, R.K.M. and R.A. Gilbert, 2001. Variation in the harvest index of tropical maize: evaluation of recent evidence from Mexico and Malawi. Annals of Applied Biology, **138:**103.

Healey, K.D., G.L. Hammer, K.G. Rickert and M.P. Bange, 1998. Radiation use efficiency increases when the diffuse component of incident radiation is enhanced under shade. Australian Journal of Agricultural Research, **49:**665-672.

Hedley, M.J., J.W.B. Stewart, and B.S. Chauhan, 1982. Changes in organic and organic fractions induced by cultivation practices and by laboratory incubations. Soil Sci. Soc. Am. J. **46:** 970-976.

Heisey, P.W., and W. Mwangi, 1996. Fertilizer use and maize production in sub-Saharan Africa. Economics Working Paper 96–01.pp 34. Mexico, D.F.: CIMMYT.

Henao, J. and C. Baanante, 2006. Agricultural production and soil nutrient mining in Africa: Implications for resource conservation and policy development.

Hillin, C.K. and P.F. Hudak, 2003. Nitrate contamination in the Seymour aquifer, north central texas, USA. Bull. Enviro.Contam.Tox. **70**: 674-679.

Hossain, M.F., S.K. White, S.F. Elahi, N. Sultana, M.H.K. Choudhury, Q.K. Alam, J.A. Rother and J.L. Gaunt, 2005. The efficiency of nitrogen fertilizer for rice in Bangladeshi farmers' fields. *Field Crops Research*, ***93*****:**94-107.

Hunt, N. and B. Gilkes, 1992. Farm monitoring handbook. University of Western Australia.

Hurni H. and M. Bruno, 1990. Degradation and conservation of the soil resources in the Ethiopian highlands. African Mountains and Highlands: Problems and Perspectives, USA, pp. 51-64.

Jobbagy, E.G. and R.B. Jackson, 2001. The distribution of soil nutrients with depth: global patterns and the imprint of plants. Biogeochemistry, **53**:51-77.

Jones (Jr) J.B. 2003. Agronomic handbook: management of crops, soils, and their fertility. New York, USA: CRC Press.

Jones J. and D. Huber, 2007. Magnesium and plant disease. In. Datnoff, L., Elmer, W., Huber, D. (Eds.): Mineral nutrition and plant disease. APS Press, St. Paul, USA. pp. 95-100.

Katsura K, S. Maeda, I. Lubis, T. Horie, W. Cao and T. Shiraiwa, 2008. The high yield of irrigated rice in Yunnan, China. Field Crops Research, **107:** 1-11.

Kazombo-Phiri, S.F., 2005. Main causes of declining soil productivity in Malawi: Effects on agriculture and management technologies employed to alleviate the problems. *Sustainable Agriculture Systems for the Dry lands*, p.59.

Khatun, A. and M.A. Saleque, 2010. Farmers' participator field specific nutrient management in tidal flooded soil for HYV AUS rice. Bangladesh Journal of Scientific Research, **23:**73-80.

Kirsten A., 2014. The Agronomy Guide: Penn State College of Agricultural Sciences, pp: 41-58.

Kogbe J.O S. and J.A. Adediran, 2003. Influence of Nigeria, Phosphorus and Potassium application on the yield of maize in the savannah zone of Nigeria. Africa Academic. **2:** 345-349.

Kpongor, D.S., 2007. Spatially explicit modeling of sorghum (Sorghum bicolor (L.)Moench) production on complex terrain of a semi-arid region in Ghana using APSIM. Ecology and Development Series No 51.PhD Dissertation. Pp. 78 – 104.

Kraaijvanger, R. and T. Veldkamp, 2015. Grain productivity, fertilizer response and nutrient balance of farming systems in Tigray, Ethiopia: A multi-perspective view in relation to soil fertility degradation. *Land Degradation & Development*, ***26*****:**701-710.

Krishna K.R. 2002. Soil phosphorus, its transformation, and their relevance to crop productivity. In: Krishna Enfield (NH), USA, Plymouth, UK. pp. 109-140.

Kumar, K., S.C. Gupta, S.K. Baidoo, Y. Chander and C.J. Rosen, 2005. Antibiotic uptake by plants from soil fertilized with animal manure. Journal of environmental quality, **34:**2082-2085.

Kumar, M., L.K. Baishaya, D.C. Ghosh, V.K. Gupta, S.K. Dubey, A. Das, and D.P. Patel, 2012. Productivity and soil health of potato (Solanum tuberosum L.) field as influenced by organic manures, inorganic fertilizers and bio fertilizers under high altitudes of eastern Himalayas. *Journal of Agricultural Science*, ***4*:**223.

Kwabiah, A.B., N.C. Stoskopf, C.A. Palm, R.P. Voroney, M.R. Rao, and E. Gacheru, 2003. Phosphorus availability and maize response to organic and inorganic fertilizer inputs in a short term study in Western Kenya. Agric Ecosyst Environ **95**:49-59.

Ladha J.K., K.S. Fisher, M. Hussain, Hobbs P.R. and B. Harry, 2000. Improving the productivity and sustainability of rice-wheat cropping systems of the Indo-Gangetic plains: a synthesis of NARS-IRRI partnership research, IRRI.Discussion Paper Series, 40.

Landon, J. R., 1991. Booker tropical soil manual: A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics. Longman Scientific and Technical, Essex, New York. 474p.

Landon, J.R., 2014. *Booker tropical soil manual: a handbook for soil survey and agricultural land evaluation in the tropics and subtropics*. Routledge.

Lechisa Takele, Achalu Chimdi and Alemayehu Abebaw, 2014. Impact of land use on selected soil physicochemical properties of soils of Gindeberet Area, Western Oromia, Ethiopia. Sci. Technol. Arts Res. J, **3:**36-41.

Liu, M., Z.P. Li, T.L. Zhang, C.Y. Jiang and Y.P. Che, 2011. Discrepancy in response of rice yield and soil fertility to long-term chemical fertilization and organic amendments in paddy soils cultivated from infertile upland in subtropical China. Agric. Sci. China. **10**:259–266.

Lungu, O.I. and R.F. Dynoodt, 2008. Acidification from long-term use of urea and its effect on selected soil properties. African Journal of Food, Agriculture, Nutrition and Development, **8:**63-76.

Malhia, S.S., C.A. Grant, A.M. Johnston and K.S. Gill, 2001. Nitrogen fertilization management for no-till cereal production in the Canadian Great Plains: a review. Soil Till. Res. **60:** 101-122.

Marschner, H., 1995. The soil root interface (rhizosphere) in relation to mineral nutrition. Mineral nutrition of higher plants.

Marschner, H., 2011. Mineral Nutrition of Higher Plants (Academic, London).

Marschner, P. and Z. Rengel, 2012. Nutrient availability in soils. In Marschner's Mineral Nutrition of Higher Plants (Third Edition) (pp. 315-330).

McLean, E.O., 1982. Soil pH and lime requirement: In: Methods of soil analysis part 2 (edited by AI Page; RH Miller and DR Keeney) Amer Soc of Agron Soil Sci Amer Inc. *Madison, Wisconsin*, pp.191-224.

Mengel, K. and E.A. Kirkby, 1982. Principles of Plant Nutrition 3rd edition International Potash Institute. *Warblaufen-Bern Switzerland*.

Mengel, K., and E. A. Kirkby, 1987. Principles of Plant Nutrition, 4th edn. International Potash Institute, Horgen, Switzerland.

Mesfin Abebe, 1998. "Nature and management of Ethiopian soils." *Alemaya University of Agriculture, Ethiopia* 272.

Mesfin, Abebe, 1980. State of Soil Science Development for Agriculture in Ethiopia. Ethiopian Journal of Agricultural Sciences.

Mollier A. and S. Pellerin, 1999. Maize root system growth and development as influenced by phosphorus deficiency. J. Exp. Bot. **50:** 487-497.

Mtambanengwe, F., and P. Mapfumo, 2005. Nutrient Cycling in Agro ecosystems **73**:227–243.

Mueller ND, JS. Gerber, M. Johnston, DK. Ray, N. Ramankutty and JA. Foley, 2012. Closing yield gaps through nutrient and water management. Nature. **490**:254–257.

Mueller, L., U. Schindler, W. Mirschel, T.G. Shepherd, B.C. Ball, K. Helming, J. Rogasik, F. Eulenstein, and H. Wiggering, 2010. Assessing the productivity function of soils. A review. *Agronomy for Sustainable Development*, ***30*****:**601-614.

Murwira, H.K., 2003. Managing Africa soils: approaches and challenges .In: Gichuru MP ,Bationo A ,Bekunda,M.A,Goma, P.C,Mafongoya, P.L,Mugendi, D.N, Murwira,H.M. Nandwa,S.M, Nyathi P,Swift, M.J (eds) Soil fertility management in Africa: a regional perspective .Academy Science Publishers Nairobi Kenya.

Mustonen PJ, M. Oelbermann and DCL. Kass, 2012. Using Tithonia diversifolia (Hemsl.) Gray, in a short fallow system to increase soil phosphorus avail‑ability on a Costa Rican Andosol. J Agric Sci **4**:91–100.

Nandwa, S.M., 2001. Soil organic carbon (SOC) management for sustainable productivity of cropping and agro forestry systems in eastern and southern Africa. Nutr Cycling Agr ecosyst, **61**:143-158.

Negash Mesele and Girma Kelboro, 2014. "Effects of Socio-Economic Status and Food Consumption Pattern on Household Energy uses: Implications for Forest Resource Degradation and Reforestation around Wondo Genet Catchments, South-Central Ethiopia." *Eastern Africa Social Science Research Review* **30:** 27-46.

Nelson, D.W. and L.E. Sommers, 1996. Total carbon, organic carbon, and organic matter. Methods of soil analysis part 3-chemical methods, (methodsofsoilan3), pp. 961-1010.

Neumann, K., P.H. Verburg, E. Stehfest and C. Müller, 2010. The yield gap of global grain production: A spatial analysis. Agricultural systems, **103:**316-326.

Nziguheba, G., Merckx, R., and C. A. Palm, 2002a. Soil phosphorus dynamics and maize response to different rates of phosphorus fertilizer applied to an Acrisols in western Kenya. Plant Soil **243**: 1–10.

Nziguheba, G., R. Merckx, C. A. Palm and P. Mutuo, 2002b. Combining Tithonia diversifolia and fertilizers for maize production in a phosphorus deficient soil in Kenya. Agroforest. Syst. **55**: 165-174.

Obreza, T.A. and F.M. Rhoads, 1988. Irrigated corn response to soil-test indices and fertilizer nitrogen, phosphorous, potassium, and magnesium. Soil Science Society of America Journal, **52**:701-706.

Palm, C.A., R.J. Myers and S.M. Nandwa, 1997. Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. *Replenishing soil fertility in Africa*, (replenishingsoi), pp.193-217.

PAN, S.G., S.Q. HUANG, Z. Jing, J.P. WANG, C.G. CAO, M.L. CAI, Z.H.A.N. Ming and X.R. TANG, 2012. Effects of N management on yield and N uptake of rice in central China. *Journal of Integrative Agriculture*, ***11*:**1993-2000.

Pearl, K., 2012. Evaluation of newly released maize varieties in Ghana for yield and stability under three nitrogen application rates in two agro-ecological zones (Doctoral dissertation).

Plénet D., A. Mollier and S. Pellerin, 2000. Growth analysis of maize field crops under phosphorus deficiency. II. Radiation use efficiency, biomass accumulation and yield components. Plant Soil. **224:** 259-272.

Potarzycki, J. and Grzebisz, W., 2009. Effect of zinc foliar application on grain yield of maize and its yielding components. *Plant Soil Environ*, ***55*:**519-527.

Powers, L. E., and R. McSorley, 2000. Ecological Principles of Agriculture Albany, NY: Delmar Thomson Learning.

Prasad, R., Y.S. Shivay, D. Kumar and S.N. Sharma, 2006. Learning by Doing Exercises in Soil Fertility (A practical manual for soil fertility), Division of Agronomy, Indian Agricultural Research Institute, New Delhi, India. 68 p.

Rasheed M., T. Mahmood, M.S. Nazir, W.A. Bhutta, A. Ghaffar, 2004. Nutrient Efficiency and Economics of Hybrid Maize Under Different Planting Methods and Nutrient Levels. Int. J. Agri. Biol. **6:** 922-925.

Rashid, A. and K.S. Memon. 2001. Soil and fertilizer phosphorus. Soil Sci. B. Elena and R. Bantel (Eds). National Book Foundation, Islamabad, Pakistan. pp. 300-302.

Rawlins, B.G., S.P. McGrath, A.J. Scheib, N. Breward, M. Cave, T.R. Lister, M. Ingham, C. Gowing and S. Carter, 2012. The advanced soil geochemical atlas of England and Wales.

Regmi A.P., J.K. Ladha, H. Pathak, H.E. Pashuquin, C. Bueno, D. Dawe, P.R. Hobbs, D. Joshy, S.L. Maskey and S.P. Pandey, 2002. Yield and soil fertility trends in a 20-year rice-rice wheat experiment in Nepal, Soil. Sci. Soc. Am. J., **66**: 857-867.

Rhoades, J.D., 1982. Cation exchange capacity. In: Methods of soil analysis. Part 2. Chemical and Microbiological Properties (A.L. Page, R.H. Miller and D.R. Keeney), (Eds.) American

Society of Agronomy, Inc. Soil Science Society of America. Inc. Madison, Wisconsin, pp. 149-157.

Roberts R.K., J.T. Walters, A. Larson, B.C. English and D.D. Howard, 2004. Effects of disease, nitrogen source, and risk on optional nitrogen fertilization timing in winter wheat production. Agronomy Journal, **96:** 792-799.

Roy, R.N., R.V. Misra, J.P. Lesschen and E.M.A. Smaling, 2003. *Assessment of soil nutrient balance: approaches and methodologies* (No. 14). Food & Agriculture Org.

Saeed I. M., Abbasi R., Abbasi and Kazim M. Kazim. 2001. Response of maize (Zea mays) to nitrogen and phosphorus fertilization under agro-climatic condition of Rawalokol, Azad Jammu and Kaslim and Kashmir, Pak. J. Biological Sci. **4:** 949-952.

Sahlemedhin, S. and Taye Bekele, 2000. Procedures for soil and plant analysis. Technical paper 74. National soil research center, Ethiopian Agricultural Research Organization, Addis Ababa, Ethiopia.

Sahoo S.C., and Panda M. 2001. Effect of phosphorus and de-tasseling on yield of baby-corn. Indian J. Agric. Sci. **71:** 21-22.

Saikh, H., C. Varadachari and K. Ghosh, 1998. Changes in carbon, nitrogen and phosphorus levels due to deforestation and cultivation: a case study in Simlipal National Park, India. Plant and Soil, **198**:137-145.

Salam, M.A., A.R.M. Solaiman, A.J.M.S. Karim and M.A. Saleque, 2014. System productivity, nutrient use efficiency and apparent nutrient balance in rice-based cropping systems. *Archives of Agronomy and Soil Science*, **60**:747-764.

Samira M., M.A. Hussein, M. Haikel and M.A. El-Masry, 1998. Effect of some preceding crops, hill spacing and nitrogen fertilization on yield attributes and grain yield of maize under reclaimed sandy soil conditions in East Delta. Proc. 8thConf. Agron, Suez Canal Univ., Ismailia, Egypt, 28-29 November. pp. 174-181.

Sanchez, P.A., C.A. Palm and S.W. Buol, 2003. Fertility capability soil classification: a tool to help assess soil quality in the tropics. *Geoderma*, ***114*:**157-185.

Sanchez, P.A., K.D. Shepherd, M.J. Soule, F.M. Place, R.J. Buresh, A.M.N. Izac, A.U. Mokwunye, F.R. Kwesiga, C.G. Ndiritu and P.L. Woomer, 1997. Soil fertility replenishment in Africa: an investment in natural resource capital. *Replenishing soil fertility in Africa*, (replenishing), pp.1-46.

Sandana, P., 2016. Phosphorus uptake and utilization efficiency in response to potato genotype and phosphorus availability. *European journal of agronomy*, ***76*:**95-106.

Sanders, J.H., S. Ramaswamy and B.I. Shapiro, 1996. The Economics of Agricultural Technology in Semi-Arid Sub-Saharan Africa. Johns Hopkins Press, Baltimore, MD.

Sanginga, N. and P.L. Woomer, 2009. Integrated soil fertility management in Africa: Principles, practices and developmental process. Tropical Soil and Fertility Institute of the International Centre for Tropical agriculture. Nairobi. pp 263.

Sangoi L., P. Rernani and P. R.F. Silva, 2007. Maize response to nitrogen fertilization timing in two tillage systems in a soil with high organic matter content. Rev. Bras. Ciênc. Solo. Vol. **31:** 507-517.

SAS Institute Inc. 2012. SAS® 9.3 Macro Language: Reference. Cary, NC: SAS Institute Inc.

Schmitt CB. 2006. Montane rainforest with wild Coffea arabica in the Bonga region, South West Ethiopia: Plant diversity, wild coffee management and implications for conservation. Doctoral Thesis. ZEF-Ecology and Development Series No. 47. University of Bonn, Germany.

Schneider, A. and C. Morel, 2000. Relationship between the isotopically exchangeable and resin-extractable phosphate of deficient to heavily fertilized soil. Eur. J. Soil Sci. **51**: 709–715.

Selassie, Yihenew G, 2015. "The effect of N fertilizer rates on agronomic parameters, yield components and yields of maize grown on Alfisols of North-western Ethiopia." *Environmental Systems Research* **4:** 21.

Shabala, S. and I.I. Pottosin, 2010. Potassium and potassium-permeable channels in plant salt tolerance. In *Ion Channels and Plant Stress Responses* (pp. 87-110). Springer, Berlin, Heidelberg.

Shanti, K.V.P., M.R. Rao, M.S. Reddy and R.S. Sarma, 1997. Response of maize (Zea mays) hybrid and composite to different levels of nitrogen. Indian J. Agric. Sci., **67**: 424-425.

Sharma, A., U.S. Rawat, and B.K. Yadav, 2012. Influence of phosphorus levels and phosphorus solubilizing fungi on yield and nutrient uptake by wheat under sub-humid region of Rajasthan, India. *ISRN Agronomy*, *2012*.

Shepherd, K.D., J.K. Ndufa, E. Ohlsson, H. Sjogren, and R. Swinkels, 1997. Adoption potential of hedgerow intercropping in maize-based cropping systems in the highlands of western Kenya. I. Background and agronomic evaluation. Exp. Agric. **33**: 197-223.

Sinclair T R., 1998. Historical changes in harvest index and crop nitrogen accumulation. Crop Science, **38:** 638-643.

Smeck, N.E., 1985. Phosphorus dynamics in soils and landscapes. Geoderma **58:** 185- 189.

Snapp, S.S., P.L. Mafongoya and S. Waddington, 1998. Organic matter technologies for integrated nutrient management in smallholder cropping systems of southern Africa. Agriculture, ecosystems & environment, **71**:185-200.

Splittstoesser, W.E., 1990. Vegetable Growing Handbook: Organic and Traditional. *Methods*, ***3*:**167-171.

Stewart JWB and H. Tiessen, 1987. Dynamics of soil organic phosphorus. Biogeo-chemistry **41:**41–60

Tang D.T., T. Vu and R.D. Amstron, 2007. Changes and availability of P fraction following 65 years' application to a calcareous soil in a Mediterranean climate. Plant soil. **304:** 21-33.

Tekalign Tadesse, I. Haque, and E. A. Aduayi, 1991. "Soil, plant, water, fertilizer, animal manure and compost analysis manual."

Tesfahunegn GB, L. Tamene and PLG.Vlek, 2011. Catchment-scale spatial variability of soil properties and implications on site-specific soil management in northern Ethiopia. Soil and Tillage Research **117**: 124-139.

Tesfaye Balemi and L. Negisho, 2012. Management of soil phosphorus and plant adaptation mechanisms to phosphorus stress for sustainable crop production: a review. J Soil Sci Plant Nutr **12**:547–562.

Thiffault, E., K.D. Hannam, D. Paré, B.D. Titus, P.W. Hazlett, D.G. Maynard and S. Brais, 2011. Effects of forest biomass harvesting on soil productivity in boreal and temperate forests a review. *Environmental Reviews*, ***19*****:**278-309.

Tisdale, S. L., W. L. Nelson and J. D. Beaton, 1990. Soil fertility and fertilizer. Elements required in plant nutrition. 4th Ed. Maxwell McMillan Publishing, Singapore. pp. 52-92.

Tittonell, P., A. Muriuki, C.J. Klapwijk, K.D. Shepherd, R. Coe and B. Vanlauwe, 2013. Soil heterogeneity and soil fertility gradients in smallholder farms of the East African highlands. Soil Science Society of America Journal, **77:**525-538.

Tittonell, P., Muriuki, A., Mugendi, D., Kaizzi, K. C. and Okeyo, J., 2009. The diversity of rural livelihoods and their influence on soil fertility in agricultural systems of East Africa -A typology of smallholder farms. Agricultural Systems, **72**:83-97.

Tittonell, P., P. A. Leffelaar, B. Vanlauwe, M. T. van Wijk and K. E. Giller, 2006. Exploring diversity of crop and soil management within smallholder African farms: A dynamic model for simulation of N balances and use efficiencies at field scale. Agricultural Systems, **91**:71-101.

Torbert H.A., K.N. Potter and J.E. Morrison, 2001. Tillage system, fertilizer nitrogen rate and timing effect on corn yields in the Texas Black land prairie. Agron. J. **93:** 1119-1124.

Trehan, S.P., 2009. Improving nutrient use efficiency by exploiting genetic diversity of potato. *Potato Journal*, **36:**121-135.

Twomlow, S.J., J.C. Urolov, M. Jenrich, and B. Oldrieve, 2008. Lessons from the field–Zimbabwe's conservation agriculture task force. Journal of SAT Agricultural Research, **6:**1-11.

Van Reeuwijk, L.P., 1992. Procedures for soil analysis. 3rd Edition. International Soil Reference and Information Centre Wageningen (ISRIC). The Netherlands. Wageningen.

Vimpany, I.A. and G.G. Johns, 1999. Interaction of pH amendment and potassium fertilizer on soil chemistry and banana plant growth. Australian journal of agricultural research, **50**:199-210.

Walker, W.M. and W.L. Parks, 1969. Effect of Soil Potassium, Potassium Fertilizer, and Method of Placement upon Lodging in Corn (Zea mays L.) 1. Soil Science Society of America Journal, **33**:909-912.

White, P., and A. Karley, 2010 .Potassium: In Cell Biology of Metals and Nutrients; Hell, R., Mendel, R.R., Eds.; Springer: Berlin/Heidelberg, Germany, pp. 199–224.

White, R.E., 2013. Principles and practice of soil science: the soil as a natural resource. John Wiley & Sons.

Wojnowska, T., H. Panak and S. Seikiewiez. 1995. Reaction of winter oilseed rape to increasing levels of nitrogen fertilizer application under condition of Ketizyn Chernozem. Rosling Oleiste. **16:**173-180.

Wolf, B., 1999. The fertile triangle: the interrelationship of air, water, and nutrients in maximizing soil productivity. New York, USA: Food Products Press.

Wondwosen Tena and Sheleme Beyene, 2011. "Identification of growth limiting nutrient (s) in Alfisols: Soil physico-chemical properties, nutrient concentrations and biomass yield of maize." *American journal of plant nutrition and fertilization technology* **1:** 23-35.

Wuest, S.B. and K.G. Cassman, 1992. Fertilizer-nitrogen use efficiency of irrigated wheat: II. Partitioning efficiency of pre-plant versus late-season application. Agronomy Journal, **84**:689-694.

Xu X.P., P. He, M.F. Pampolino, A.M. Johnston, S.J. Qiu and S.C. Zhao, 2014. Fertilizer recommendation for maize in China based on yield response and agronomic efficiency, Field Crops Res., **157**: 27–34.

Yahiya, M., M. Samiullah, T. Khan and S. Hayat, 1996. Influence of potassium on growth and yield of pigeon pea (Cajanus Cajan). Indian Journal of Agronomy, **41**:416-419.

Yengoh G.T. and J. Ardo, 2014. Crop yield gaps in Cameroon, Ambio, **43**: 175–190.

Zelleke Gete, Getachew Agegnehu, Dejene Abera, and Shahid Rashid, 2010. "Fertilizer and Soil Fertility Potential in Ethiopia." *Constraints and opportunities for enhancing the system. International Food Policy Research Institute, sustainable solution for ending hunger*.

Zhang J., A.M. Blackmer, J.W. Ellsworth and K.J. Koehler, 2008a. Sensitivity of chlorophyll meters for diagnosing nitrogen deficiencies of corn in production agriculture. Agron. J. **100:** 543-55.

Zhang J., A.M. Blackmer, T.M. Blackmer and P.M Kyveryga, 2010b. Fertilizer bands affect early growth of corn. Commun. Soil Sci. Plant Anal. **41:**1306–1314.

Zhang J., A.M. Blackmer, T.M. Blackmer and P.M. Kyveryga, 2010a. Fertilizer bands and dual effects of nitrogen on young corn plants. Better Crops. **94:**17-19.

Zhang, H.C., X.Q. Wang, Q.G. Dai, Z.Y. HUO and K. XU, 2003. Effects of N-application rate on yield, quality and characters of nitrogen uptake of hybrid rice variety liangyoupeijiu [J]. *Scientia Agricultural Sinica*, ***7*:**011.

Zhang, J., A.M. Blackmer, T.M. Blackmer, P.M. Kyveryga and J.W. Ellsworth, 2007. Nitrogen deficiency and recovery in sustainable corn production as revealed by leaf chlorophyll measurements. *Agronomy for sustainable development*, ***27*:**313-319.

Zhu, Z.L., 2002. Loss of fertilizer N from plants soil system and the strategies and techniques for its reduction. Soil Environ. Sci. **9:** 1-6.

Zhu, Z.L., and D.L. Chen, 2002. Nitrogen fertilizer use in China-contributions to food production, impacts on the environment and best management strategies. Nutr.Cycl.Agroecosys. **63:** 117-127.

Zingore, S., H. K. Murwira, R. J. Delve and K. E. Giller, 2007. Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe. Agriculture Ecosystems & Environment **119**:112- 126.

Zublena, J.P., J.C. Barker and T.A. Carter, 1990. Poultry manure as a fertilizer source. AG-North Carolina Agricultural Extension Service, North Carolina State University (USA).

7. APPENDIXES

Appendix Table 1. Meteorological data during crop growth period at Jimma in 2017

Month	Rainfall (mm)	Min. Temp. (^oC)	Max. Temp. (^oC)	Mean Temp. (^oC)
January	88.2	11.5	26.7	19.1
February	83.8	9.9	26.0	18.0
March	87.2	10.3	24.7	17.5
April	76.6	10.4	25.6	18.0
May	281.3	10.4	25.6	18.0
June	158.4	10.2	26.6	18.4
July	187.3	10.7	24.6	17.7
August	99.6	11.5	28.0	19.8
September	350.0	11.2	26.8	19.0
October	262.0	10.8	26.6	18.7
November	53.0	10.2	28.3	19.3
December	20.0	9.4	28.2	18.8
Mean		10.5	26.5	18.5

Source: Jimma Agricultural research center meteorology department, Melko.

Appendix Table 2. Analysis of variance of Agronomic efficiency of Nitrogen at Kersa

Source	DF	SS	MS	F-value	P-value
Replication	5	190.97	38.19	7.73	0.1209
Treatment	3	5921.60	1973.87	399.37	.0001
Error	15	74.14	4.94		
Total	23	6186.70			

Appendix Table 3. Analysis of variance among Agronomic Efficiency of Phosphorus at Kersa

Source	DF	SS	MS	F-value	P-value
Replication	5	405.40	81.10	3.04	0.0532
Treatment	3	12678.78	4226.26	158.38	.0001
Error	15	400.27	26.68		
Total	23	13484.45			

Appendix Table 4. Analysis of variance among Agronomic Efficiency of Potassium at Kersa

Source	DF	SS	MS	F-value	P-value
Replication	5	233.36	46.67	1.55	0.23
Treatment	3	77189.38	25729.79	852.91	.0001
Error	15	452.50	30.17		
Total	23	77875.25			

Appendix Table 5. Analysis of Variance among total Biomass yield at Kersa in 2017

Source	DF	SS	MS	F-value	P-value
Replication	5	2505887.1	501177.4	1.24	0.32
Treatment	5	960875548.5	192175109.7	473.56	.0001
Error	25	10145163.4	405806.5		
Total	35	973526599.0			

Appendix Table 6. Analysis of Variance among grain yield at Kersa

Source	DF	SS	MS	F-value	P-value
Replication	5	887874.9	177575.0	1.65	0.1828
Treatment	5	301377797.4	60275559.5	561.19	.0001
Error	25	2685151.1	107406.0		
Total	35	304950823.5			

Appendix Table 7. Analysis of Variance among stover yield at Kersa

Source	DF	SS	MS	F-value	P-value
Replication	5	1615758.0	323151.6	1.24	0.3193
Treatment	5	188969304.6	37793860.9	145.30	.0001
Error	25	6502944.4	260117.8		
Total	35	197088007.0			

Appendix Table 8. Analysis of Variance among Harvest Index at Kersa

Source	DF	SS	MS	F-value	P-value
Replication	5	62.40	12.48	1.94	0.12
Treatment	5	1260.83	252.17	39.19	.0001
Error	25	160.86	6.43		
Total	35	1484.08			

Appendix Table 9. Analysis of Variance among Stem girth of maize plant

Source	DF	SS	MS	F-value	P-value
Replication	5	2.55	0.51	20.08	0.2101
Treatment	5	1.80	0.36	14.19	.0001
Error	25	0.63	0.025		
Total	35	4.99			

Appendix Table 10. Analysis of Variance among plant height at Kersa

Source	DF	SS	MS	F-value	P-value
Replication	5	8473.91	1694.78244	3.88	0.197
Treatment	5	20303.79	4060.75844	9.30	.0001
Error	25	10917.40	436.70		
Total	35	39695.11			

Appendix Table 11. Analysis of Variance among leaf area index at Kersa

Source	DF	SS	MS	F-value	P-value
Replication	5	3.11	0.62	8.44	.0001
Treatment	5	14.82	2.96	40.18	.0001
Error	25	1.844	0.074		
Total	35	19.78			

Appendix Table 12. Analysis of Variance among phosphorus uptake at Kersa

Source	DF	SS	MS	F-value	P-value
Replication	5	1272.28	254.46	12.40	.051
Treatment	5	37892.93	7578.59	369.42	.0001
Error	25	512.87	20.51		
Total	35	39678.08			

Appendix Table 13. Analysis of Variance among Nitrogen uptake at Kersa

Source	DF	SS	MS	F-value	P-value
Replication	5	17.25	3.45	3.26	0.0212
Treatment	5	800.15	160.03	151.03	.0001
Error	25	26.49	1.06		
Total	35	843.89			

Appendix Table 14. Analysis of Variance among Potassium uptake at Kersa

Source	DF	SS	MS	F-value	P-value
Replication	5	466.69	93.34	9.37	.0601
Treatment	5	14963.94	2992.79	300.45	.0001
Error	25	249.02	9.96		
Total	35	15679.65			

Appendix Table 15. Analysis of Variance among Apparent Recovery Efficiency of N

Source	DF	SS	MS	F-value	P-value
Replication	5	2.82	0.56	1.04	0.4327
Treatment	3	205.43	68.48	125.76	.0001
Error	15	8.17	0.54		
Total	23	216.41			

Appendix Table 16. Analysis of Variance among Apparent Recovery Efficiency of P

Source	DF	SS	MS	F-value	P-value
Replication	5	153.35	30.67	2.18	0.1107
Treatment	3	16119.87	5373.29	382.63	.0001
Error	15	210.65	14.043		
Total	23	16483.88			

Appendix Table 17. Analysis of Variance among Apparent Recovery Efficiency of K

Source	DF	SS	MS	F-value	P-value
Replication	5	507.50725	101.50145	1.89	0.1562
Treatment	3	28878.87802	9626.29267	179.11	<.0001
Error	15	806.18118	53.74541		
Total	23	30192.56645			


NP(-k)


NPK+Ca+Mg+S+Zn+B