EFFECT OF NITROGEN FERTILIZER ON MAIZE PERFORMANCE, NITROGEN USE EFFICIENCY AND SOIL AVAILABLE NITROGEN CONCENTRATIONS IN SMALLHOLDER FARMS IN RONGO, KENYA

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (INTEGRATED SOIL FERTILITY MANAGEMENT) IN THE SCHOOL OF AGRICULTURE AND ENTERPRISE DEVELOPMENT OF KENYATTA UNIVERSITY

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DECLARATION

I, Desire Nduwimana declare that this thesis is my original work and has not been defended for a degree or any other award in any other University. No part of it should be reproduced without prior authorization of the author and / or Kenyatta University.

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To Almighty God for His love and protection throughout my academic life and to my parents, brothers and sisters for their steady support, love and encouragement.

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ABBREVIATIONS AND ACRONYMS

AE	:	Agronomic Efficiency
N-NH_4	:	Ammonium Nitrogen
ANOVA	:	Analysis of Variance
BD	:	Bulk Density
CAN	:	Calcium Ammonium Nitrate
C.E.C	:	Cation Exchange Capacity
FUE	:	Fertilizer Use Efficiency
INMS	:	International Nitrogen Management System
LSD	:	Least Significant Difference
N−NO_3	:	Nitrate Nitrogen
N	:	Nitrogen
Nt	:	Total nitrogen
NUE	:	Nitrogen Use Efficiency
SOC	:	Soil Organic Carbon
SSA	:	Sub-Sahara Africa
RCBD	:	Randomized Complete Block Design
TSP	:	Triple Superphosphate
WAP	:	Week after Planting

ABSTRACT

Reduced crop productivity among the smallholder farms is the main cause of food insecurity in Sub-Sahara Africa (SSA). Maize is a staple food crop in Kenya and is especially grown in the parts of North Rift and Western Kenya. In the Lake Victoria region and particularly in Rongo sub-county, maize potential production is low ranging between 0.8 to 1.6 tons ha^{-1}. The low soil productivity is due to low soil fertility, low soil nitrogen, inadequate use of inputs such as mineral fertilizers, improved maize seeds, and inadequate agricultural practices to boost production. The purpose of this study was to determine the effect of nitrogen fertilizer on maize yields, nitrogen use efficiency (NUE), its effect on soil properties, and distribution in the soil profile and on soil microbial population. The study was carried out at Kambija and Koderobara in Migori County during the long rainy season from March–July, 2018. The experiment was arranged in a Randomized Complete Block Design with three replications. The treatments of N fertilizer (CAN) were at four levels (0, 25, 50 and 75 kg N ha^{-1}). Tri-Superphosphate (TSP) at 10 kg P ha^{-1} was applied as blanket. Maize variety (Sc Duma 43) was used as a test crop. Data were analyzed with the ANOVA procedure using GenStat statistical software (15^{th} edition) and treatment means separated using least significant difference at ($P \leq 0.05$). Results indicated that treatments with nitrogen fertilizer application significantly increased maize yields ($p=0.001$) at Kambija and ($p=0.01$) at Koderobara. Applied N fertilizer at 50 kg N ha^{-1} exhibited the highest maize yields compared to other treatments at both sites (4.34 t ha^{-1} for Koderobara and 3.41 t ha^{-1} at Kambija). High rates of N fertilizer increase soil acidity and decrease maize yields. Highest nitrogen use efficiency (NUE) was recorded at 25 kg N ha^{-1} with 23.84 at Kambija while at Koderobara was recorded at 50 kg N ha^{-1} with 22.61, in general NUE decreased with increased applied N rates. At Kambija, 75 kg N ha^{-1} had the highest N content in plant tissues with 2.07% in the heading stage while at Koderobara, the highest N content of 1.90% was recorded at 50 kg N ha^{-1}. Due to rainfall variability, mineral N fractions ($N0_3^-$ and NH_4^+) were higher in sub-layers (10-20 cm and 20-30 cm depth) at seedling stages but at heading stages, N mineral concentrations were higher in top-layers (0-10 cm depth) in both sites. Plots fertilized at 50 kg N ha^{-1} recorded highest concentration of available N in the soils in both sites of the experiment. Soil microbial population was slightly increased by N fertilizer application and declined with increased soil depth. Based on the results of this study, application of N fertilizer at 50 kg ha^{-1} can be recommended among the smallholder farms for improvement of maize yield in Rongo-sub County, Migori County, and the catchment of Lake Victoria.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the study

Low inherent soil fertility is a key constraint of crop production mostly in the farms of the smallhoder farmers in Sub-Saharan Africa (SSA). These farms often realize low crop yields despite the introduction of new technologies in crop production (Altieri, 2018). Food security in Africa has been on the decline for long and particularly in the past three decades contrary to the global tendency (Pellegrini and Fernández. 2018). The cereal outputs' rate has been nearly at 1% whereas the African population growth rate stands at 3% (Havlin *et al.*, 2016). Worldwide, maize crop is estimated to be cultivated at an area of 142 million hectares with potential grain yield of 637 million metric tons, which corresponds to 4.5 tons ha^{-1} (Tilman, *et al*., 2015).

Maize (Zea mays L.) is a basic staple food in Kenya which accounts for between 98 and 100 kg $year^{-1}$ and per capita consumption. This translates to around 2.7 million metric tons annually (Nyoro et.al, 2004). In terms of production, maize grain has been on decline from the last three decades with yields per hectare ranging between 1.6 to 2.2 tons ha^{-1} compared to 4-6 tons ha^{-1} obtained from experimental trials in Kenya (Onono *et al*., 2013). The factors affecting maize production in Kenya are summarized as shrinking land sizes, high cost of inputs especially improved seeds and inorganic fertilizers, low soil fertility, climate change effect, rainfall variability, pre-and post-harvest losses, poor agricultural extension services and limited access to affordable credit (Jama *et al*., 2017).

Smallholder farming is the major actor of maize production which accounts for 70% compared to large scale farmers who contribute 30% of the total maize production in Kenya. Maize production in the Lake Victoria region is even lower than the Country averages (1.6 −2.2 t ha^{-1}) which is reported to range between 0.8 and 1.6 tons ha^{-1} and accounts for 40%−50% of calories to the diet (Wortmann *et al.*, 2001). Despite the agricultural innovations such as use of inorganic fertilizer and selected seeds, only 16% of the small-scale farmers have adopted the application of fertilizers in Rongo (Shiva, 2016). Even though some farmers have tried to implement the use of inorganic fertilizer, most are still facing challenges in terms of fertilizer costs and accessibility. Knowledge of fertilizer use and their management by most small-scale farmers is low and extension services are inadequate to meet the challenges facing farmers in the area (Graeub *et al.*, 2016). Management of N fertilizer as a key factor in boosting maize production is not well understood by many small-scale farmers, hence the need for researchers to work closely with extension officers and the farmers.

1.2 Problem statement

Due to diminishing land sizes, continuous cropping of the land coupled with the inappropriate use of technologies, maize yields for the last three decades has been on the decline. Maize grain yields obtained in farmers-fields have decreased to 2 tons ha^{-1} compared to 4 - 6 tons ha^{-1} usually obtained in research trials (Shiva, 2016). The situation at Rongo sub-county in particular and Lake Victoria region in general is even worse because less than 0.5-1 t ha^{-1} of maize grains per season are realized. The continuous use of land without nutrients replenishment of an equal amount of nutrients removed from the soil, losses through soil erosion and leaching, the soils continue to be degraded and hence less productive (Vanlauwe et al., 2017).

Karuku *et al*. (2016) reported that the results obtained from fertilizer experiments carried out in Rongo area, showed that maize yield under N fertilizers was more responsive (59-68%) than P (7-13%). This implies that N is the most deficient element in the study area. Therefore, more research on N management in the area is a must in order to enhance the agronomic efficiency of applied N, which would improve maize yields and eventually contribute to national food security. This study therefore, was set to come up with the right amounts of nitrogen fertilizers to be applied to maize in order to improve yields, nitrogen use efficiency (NUE) and to reduce excesses and uncalled for losses which have polluted the Lake Victoria waters and underground water (Reis *et al.,* 2016).

1.3 Justification of the Study

Nitrogen as an important plant nutrient, is reported to be very low in soils of Rongo sub-county and the Lake Victoria region as a whole (Midega *et al*., 2015). This makes nitrogen one of the most limiting factors in maize production in the area and therefore calls for more investigations, not only to boost maize yields but also to increase its management efficiency. The major challenge of nitrogen as a nutrient is on its management due to its high dynamics in soils which have effects on its use efficiency and its enormous losses from the soil ecosystem through leaching (NO_3), Volatilization (NH_3), and denitrification (NO_2, NO, N_2O and N_2) processes. Other pathways of N losses from the soil ecosystem include NH_4-N fixation by clay minerals, run-off water, and soil erosion during heavy rains. With proper use of inputs, especially inorganic fertilizers, maize grain yields have been increased by 40-60% in the Lake Victoria region (Masso *et al*., 2017).

The choice of Rongo sub-county in the Lake Victoria Basin for this study had been influenced by a number of reasons, namely:

- The area has a higher potential for agricultural production compared to other surrounding areas of the Lake,
- Rongo is the most potential area for maize growing in the Lake region but yields are still below the expected level when compared with the neighboring Kisii county,
- Small-scale farming is dominant in the area, which made the area ideal for this study and
- From the fact that not much research on nitrogen management has been carried out in the area since the last fertilizer trials in the 1990s (FURP, 1992).

1.4. Research objectives

1.4.1. Broad objective

The broad objective of this study was to increase maize grain yields and nitrogen use efficiency through application of nitrogen fertilizer, and to determine its effect on N availability in soils and on soil biological (Bacteria and Fungi) and chemical properties in farms of small-scale holders in Rongo, western Kenya.

1.4.2. Specific objectives

To achieve the broad objective, the study focused on the following specific objectives:

i. To determine the response of maize grain yields to nitrogen fertilizer application
ii. To determine nitrogen content in maize crop tissues
iii. To determine the nitrogen use efficiency (NUE) by maize grain
iv. To assess the effect of Nitrogen fertilizer application on changes of available nitrogen concentrations in soil during the maize crop growth period
v. To determine the effect of N fertilizer on biological (Bacteria and Fungi) and chemical properties of the soils

1.5. Research hypotheses

i. Nitrogen fertilizer application significantly improves the production of maize grain yields;
ii. Nitrogen fertilizer significantly increases the performance of maize yields
iii. Nitrogen use efficiency by maize grain in most cases is constant
iv. Nitrogen fertilizer application has effect on mineral nitrogen concentrations in soils during maize crop growth period.
v. Application of N fertilizer in soils has effect on the biological (bacteria and fungi) and chemical properties of soils.

1.6. Conceptual framework

In order to improve the livelihoods of the people and to combat food insecurity in Kenya and the Lake Victoria region at large, it is important to increase the food production even up to three folds in order to meet the demands of the current and future population. The soils in Rongo and the Lake Victoria region as a whole are low in soil fertility,

more especially on nitrogen nutrient which has been reported to be very low in soils and hence the limiting factor of maize crop production in the region. To boost maize crop yields in the area therefore calls for proper management of nitrogen fertilizer in order to avoid the major losses of the nutrient through leaching, denitrification and soil erosion and to increase nitrogen use efficiency. This requires that nitrogen fertilizer to be applied has to be in the right amounts as recommended in the area, at the right time and proper agronomic practices adhered to. Consequently, nutrient use efficiency would be increased and losses through leaching and soil erosion would be reduced

(Fig.1.1).

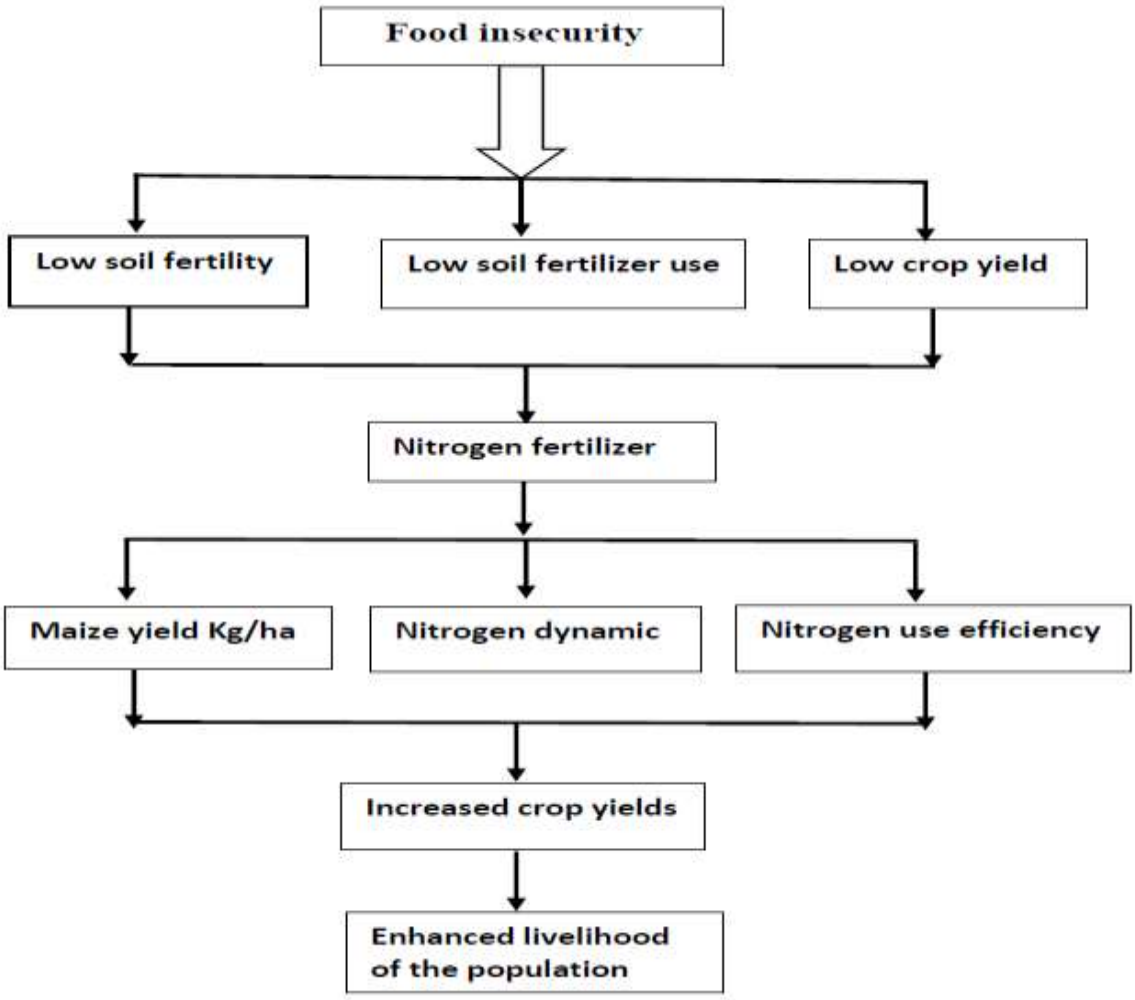

Figure 1.1: Conceptual framework on effect of nitrogen fertilizer application

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 General introduction

Food insecurity remains a big problem in many developing countries even today when there are advanced agricultural science practices. In Sub Saharan Africa (SSA), agricultural productivity has registered far lower productions of food crops than other countries in the world (Monfreda *et al*., 2008). Karaya *et al*. (2012) reported that declining of maize production in western Kenya was mainly linked to poor soil fertility and weeds-spread land infestation. According to Mugwe *et al*. (2008), maize production was estimated at less than 1 t ha^{-1} in western Kenya.

In the region, the main soil types reported include the Acrisols **(**Ultisols: US Soil Taxonomy) Nitisols and Ferralsols (Oxisols: US Soil Taxonomy) (Jaetzold *et al.*, 2006). The distinction was based on their physical and chemical characteristics, which are important factors influencing the effectiveness of organic or inorganic fertilizer responses in the region. According to Tittonell *et al*. (2005), it was reported that the soil quality between 'poor' and 'rich' farmlands was quite different. Also, Vanlauwe *et al*. (2016), reported that differences of soil fertility in the same farm depended on the quantity and access of inputs used by the farmers. In the same region, improving maize grain yields was correlated to the nitrogen fertilizer application and its management system. In fact, nitrogen fertilizer is among the right option to increase maize production in the area when used judiciously.

Overloading of N in agroecosystems can increase the rate of $N{-}NO_3$ losses into the groundwater and rivers which lead to water mass plant growth (e.g. hyacinth), death of fish and also become harmful to human health (Howarth *et al*., 2002; Galloway *et al*., 2003). On the other hand, when large amounts of $N{-}NO_3^-$ are available in the soil, they are taken up by the crop luxuriously, thus causing the nitrate ions to accumulate in plant tissues which become toxic and dangerous for human and animals healthy (Kumar, 2019).

2.2. Factors affecting maize productivity in western Kenya

2.2.1. Soil fertility management in western Kenya

Soil nutrients depletion is the most limiting factor of crop productivity for a number of farmers in Africa (Sanchez *et al*., 1997). The low soil fertility and the continued deterioration of soils as a result of poor land and nutrients management, if not arrested, will continue to produce low crop yields (Günal *et al*., 2015). Different soil fertility status, that is, at regional, community and farming fields have been generally influenced by biophysical and socio-economic factors. In western Kenya, the highlands are densely populated, the land is intensively cultivated, thus rendering the soils infertile, or of low productivity. The farmers of the region do not have enough resources to replenish nutrients lost from the soils (Félix et al., 2018). It has been indicated that N and P are the main nutrients in short supply in soils for crop production in Kenya (Shepherd *et al*., 1997). Turmel *et al*. (2015) reported that low concentrations of nutrients in soils, especially N and P, are the first biochemical limiting factors that bring about the low crop productivity in African soils.

Therefore, because of the shortage of arable lands for cultivation and the rapid population increase for food demands in Kenya, good land management systems are key options for agro-ecological sustainability and soil productivity (McKenzie *et al*., 2015). The smallholder farmers should be encouraged to adopt the innovative soil management technologies. Also, Agricultural extension services should participate actively in integrating and extending the innovative knowledge to the farmers to enhance their management skills in crop production.

2.2.2. Constraints affecting maize productivity

Nitrogen fertilizers, mainly those containing ammonium ions (NH_4^+) have an effect in generating acidity as shown in the following bio-chemical reaction equation:

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + [2H^+] + H_2O \quad (1)$$

Transformation of $NH4^+$ to NO_3^- releases two molecules of hydrogen $[2H^+]$ ions making the soil more acidic. In fact, the poor soil quality and low crop yields are often attributed to soil acidification and high concentrations of Al^{3+} in soil solution (Graham *et al*., 2002). The low soil organic carbon (SOC) and nitrogen content levels in soils are also the major signs of soil degradation in SSA (Gelaw et al., 2014).

2.3. Soil nitrogen content

Nitrogen (N) in soils is predominantly in organic form (>95%). Other forms include mineral forms: the ammonium (NH_4) and nitrates (NO_3) found in soil solution (< 1%), and NH_4^+ fixed in clay mineral lattices (Karuku and Mochoge, 2016). For nitrogen in organic form to be made available in soil for plant use, a complex mixture of chemical and biological transformations must take place (Porder, 2019).

The transformation of organic N into ammonium is known as mineralization or ammonification process and that one to nitrates as nitrification process as shown in the equation (2):

$$\text{Organic-N} \xrightarrow{\text{Mineralization}} NH_4^+ \xrightarrow{\text{Nitrification}} NO3^- \quad (2)$$

Although organic matter generally is the capital supplier of carbon and nitrogen in soils, its supply level, however, depends on the rate at which organic matter is decomposed. The decomposition rate of organic matter, among other factors, depends on the C/N ratios of the substrates. Segura *et al*. (2009) indicated that C:N ratio of organic substrates lying below 20:1 accelerated organic matter decomposition with the positive release of available N (net mineralization) into soil while organic substrates with more than 30:1 C/N ratios, exhibit slow decomposition leading to net immobilization of available N forms in soils. Segura *et al*. (2009) also reported that in western Kenya, where the incorporated residues had narrow C: N ratios that is between 12 and 17, net nitrogen mineralization was recorded in soils. Therefore, if the microbial processing of organic N gives a reduction of inorganic N in the soil, then mineralization is said to be "net-immobilization". This means that plant available N declines in soil and is said to be "tied-up" or immobilized by microbes.

This " tie-up " of nitrogen happens when organic materials are added in the soils with high quantities of carbon (C) and low N contents. When microbial processing of organic N in soils gives an increase of inorganic N release to the soil, then mineralization is said to be "net-mineralization".

That is to say, there is release of mineral N into soil for plant use. Approximately, around 2 to 4% of soil organic matter in soils can be degraded yearly accounting for 50% or more of the added crop residue (Paustian *et al*., 2016).

However, Halvorson *et al*. (2018) reported that the soil organic matter in form of humus is more difficult for microbes to degrade than newly added crop residues. Therefore, mineralization-immobilization process is a concept of soil microbiology in which mineralization and immobilization of nutrients proceed concurrently, a sign of continual biological turnover cycles in soils.

2.4 The behavior of available nitrogen in soils

Nitrogen is an essential plant nutrient which is taken up in large quantities by most plants. Its main function in plants is to encourage vegetative growth, hence, it is known as a vegetative plant nutrient. The available forms of nitrogen in soils for plant uptake are NH_4^+ and NO_3^- ions which account for less than 1% of the total nitrogen in soils. NH_4^+ can be held at the exchangeable cation sites on negative charges of the soil complex or can be found in soil solution (Yin *et al*., 2017).

Under aerobic and warm conditions in soils, NH_4 is fast nitrified to NO_3 with the help of autotrophic bacteria, (nitrosomonas and nitrobacter) which nitrify NH_4 first to nitrite (NO_2) and then to nitrate (NO_3), respectively. N-NH_4 can also be fixed in clay mineral lattices of 2:1 clay mineral types or be lost from soil ecosystem in form of NH_3 gas in soils with high pH (>8.0) through a process called volatilization (Delville et al., 2018). Nitrogen in form of Nitrates (NO_3) is very mobile in soil and readily leached to groundwater or rivers (Jacobson, 2017, Mochoge, 1989). Under anaerobic conditions in soils, nitrates (NO_3) are denitrified into gaseous forms which are easily lost to the atmosphere (equation 3).

The process is a bio-chemical reaction where denitrifying bacteria (Thiobacillus denitrificans) are involved. In the absence of O_2 in soil, the T.denitrificans use O_2 on the nitrate (NO_3) to survive.

$$NO_3 \text{----------} \rightarrow NO_2 \text{…….>} NO \text{ ……..>} N_2O \text{……>} N_2 \qquad (3)$$

A good understanding of Nitrogen dynamics in soils is therefore necessary for the proper management of N fertilizers especially in increasing N-use efficiency by plants and reduction of uncalled for losses.

2.5. Crop nutrient uptake and nutrient use efficiency

2.5.1. Nutrient uptake by crops

Plants take up nutrients in ionic forms from the soil solution. Nutrients are absorbed by plants from soil a process which is dynamic and complex (Yadav and Sidhu, 2016). Nutrients are transported to the roots by mass flow, diffusion and root interception (Fang et al., 2019). In the tropical region, plant nutrients uptake is more influenced by the edapho-climatic conditions (Carmeis Filho *et al.*, 2017). Moreover, soil compaction, lack of aeration, high soil moisture, and type of land management decrease plant nutrients uptake (Abuarab et al. 2019). Having knowledge of the roles of nutrients and their interactions, is a relevant point to enhance crop NUE and adequate management of crop nutrients supply by growers. Jones *et al.* (2011) observed that the high quantity of nutrients uptake was required particularly before maximum crop growth period. They also reported that low nutrients absorption in the early stages of plant growth could affect crop performance /yield and quality.

Nevertheless, maximum nutrients uptake varies among crops and from one crop stage to another with generally maximum uptake occurring during flowering and maize-milk stages for maize growth (Kitonyo *et al*., 2018). Jones *et al*. (2011) reported that the timing of nutrient application should coincide with its availability for the crop prior to the peak demand of the nutrient by the crop. For example, at flowering stage, maize takes up roughly 63% of nitrogen demand for the season, then the remaining is taken up during the grain-fill time (Malathesh *et al*., 2005). The absorption of nutrient varies with both the capacity of the roots, their locations and concentration in the soil (Jones, 2001).

Nitrogen fertilizer is largely used in crop production to improve yields. Maize crop in particular relies on applied fertilizer, although the dosage of fertilizer used by small-scale farmers often does not go beyond the optimal thresholds (Ogola *et al*., 2011). Soil nutrients taken up by crops can be separated into either mobile or immobile forms (Barber, 1995). Hence, N in form of nitrate is highly mobile and maize needs a big quantity of it. On the other hand, P and K are moderately mobile and also are macronutrients used by the maize (Marschner, 2012).

2.5.2. Nutrient use efficient (NUE)

The NUE can be explained as the efficiency of the crop to take up nutrients from the soil and effectively utilize it to produce grain yields (Brentrup and Palliere, 2010). It is also called “Coefficient of utilization’’. Nitrogen Use Efficiency (NUE) is expressed by " the ratio between the quantity of the nitrogen fertilizer taken up from the soil by plant and the quantity of nitrogen used as fertilizer" (Pires *et al.*, 2015).

Nutrient use efficiency by maize is affected by origin, rate and time of nutrient fertilizer application, agronomic, environmental conditions mainly rainfall pattern and water-table changes during the maize growth season (Riziki, 2014). Considering the above factors, soil test is the best option to predict precisely the dosage to supply of soil inorganic fertilizer and also to respect the appropriate rate of recommended fertilizer. According to the research done in Southern Africa, with half nitrogen, the highest level of agronomic efficiency of nitrogen (AE) was 45.3 kg grain yield increased by kg^{-1} N on Leptosols whereas the lowest was – 28.8 kg grain increased kg^{-1} N on Cambisols which had high base status and great structure (Román-Sánchez et al., 2018).

Furthermore, with the same research at full N application, the highest level of AE was 42 kg grain per kg^{-1} N with the Nitisols while the lowest AE was 2.5 kg grain per kg^{-1} N with the Cambisols. Hence, over dosage of a decline as evidenced in the low gain yield obtained (Verzeaux *et al*., 2017). However, the recommended application of N fertilizer dosages and acceptable field management systems are a true way to achieve the great high crop yields.

2.6. Effects of nitrogen application on soil properties

The nitrate N is quickly lost through leaching and denitrification in the field, but the ammonium N is lost through volatilization at high pH levels, >8 (Dinnes *et al*., 2002). Nitrogen fertilizer plays a crucial role in physical and chemical soil status, which might work out an impact on maize crop yields. According to the research conducted at Kansas State University in 2013, N fertilized plots compared with the no-nitrogen applied showed no significant difference ($p > 0.05$) in chemical properties of either soil layer or nitrogen treatments.

Thus, fertilizers in form of NH_4 contain naturally an acid-forming due to released hydrogen (H^+) ion which occurres during the nitrification process of NH_4 to NO_3 (Mompati, 2019). However, exchangeable K^+ was not significantly affected by the nitrogen application.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1. Description of the study area

This study was carried out in Rongo, Migori County, Western Kenya. Two sites were used for the experiment, namely at Kambija sub-location, East Kamagambo, and at Koderobara sub-location, central Kamagambo of Rongo division (Fig 3. 1) and both experimental sites are in the same agro-ecological zone. Migori County shares the border with Kisii and Narok counties to the East and the United Republic of Tanzania to the South, Home Bay County to the North and Lake Victoria to the West, a distant of about 30 km from Rongo Town. Rongo sub-county experiences a bimodal rainfall with long rains (LR) beginning from March to July and short rains (SR) from September to December (Midega *et al.*, 2015).

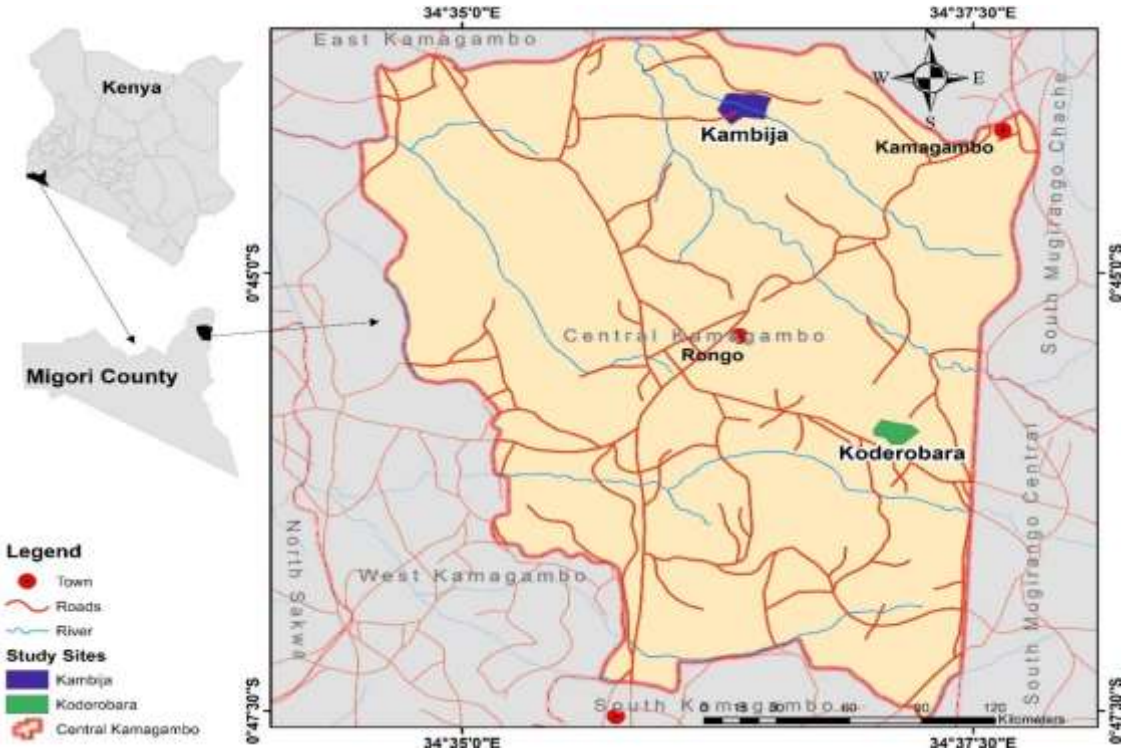

Figure 3.1 : Map of Kenya and the study areas in Rongo (Kambija and Koderobara), Migori County (Source: Internet)

Migori County is mainly an agricultural region, generating its economic incomes from tobacco, sugarcane, maize, beans, coffee, groundnuts, and vegetables farming. Livestock farming is practiced at a low level, while fishing is main source of income from L.Victoria. Rongo sub-county is located at 0^{o} 46' 00" S and 34^{O} 36' 00" E. It covers an area of 208.4 km^2 and has a population of 98,613 people with a density of 473 persons / km^2 (KNBS, 2017). The range annual precipitation is1400-1800 mm with an average temperature of 20.6^{o}C which is also the optimal threshold for maize growth (Onyango, 2016). The main soil type of Rongo is humic acrisol and well-drained with clay to clay loam. Maize needs well-drained and fertile soils and negatively tolerates waterlogging in the early growth phases (Easton *et al*., 2017). Maize is one of the crops naturally with a high requirement of N during its vegetative period (Pan *et al*., 2017).

3.2. Initial soil fertility characteristics

The initial soil fertility properties were determined in the two experimental sites. Soil sampling was done using the hand hoe and soil auger from each trial site for the analysis of physical and bio-chemical soil properties. Three soil samples from each depth were sampled and then thoroughly mixed to make a composite sample from which a portion of soil sample was taken for analysis. The depths sampled were 0-10, 10-20 and 20-30 cm. The composite soil samples from the field were properly packed in the khaki paper bags, properly labeled (date, depth, plot, and site) and then transported to the laboratory, dried and prepared for analysis. The soil properties analyzed in the laboratory included: soil pH, Nt, OC, mineral N (NH_4^+, NO_3^-), available P, exchangeable cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+) and microbial biomass (bacteria and fungi).

3.3. Experimental design and treatment layouts

Experimental trials were established at two small-scale farmers' fields at Kambija and Koderobara sites. The treatments were arranged in Randomized Complete Block Design (RCBD). CAN (26%N) fertilizer was used and applied at four levels (0, 25, 50 and 75 kg N ha^{-1}). Also, a blanket TSP (46% P_2O_5) fertilizer of 10 kg P ha^{-1} was applied to all treatments except to the control (Table 3.1). This was necessary so as to avoid P deficiency for P as a role to play in N metabolism. Maize (Duma 43) was used as the test crop as it is commonly grown in the area. Plot sizes of 6 m x 6m were used and each treatment was replicates 3 times.

Table 3.1: Nitrogen fertilizer treatments at both experiment sites

Treatment	Nitrogen (Kg ha^{-1})	Phosphorus (Kg ha^{-1})
1	N0	P0 (control)
2	N0	P10
3	N25	P10
4	N50	P10
5	N75	P10

3. 4. Crop establishment and management

Before planting, the fields were cleared of grasses and other weeds and plowed using hand tools to make seedbed clean and weeds free. Maize seeds were planted with 3 seeds per hill which were thinned to1 at 4 weeks after planting in order to maintain the recommended population of 44,444 plants ha^{-1}. The spacing was 0.75 m between rows and 0.60 m within the row.

For uniform distribution of fertilizers in the plots, small plastic spoons prepared for each treatment were used to place equally measured fertilizer to each hole in the plot. Nitrogen fertilizer was applied twice, that is at planting and at top dressing four weeks after planting while phosphate fertilizer was applied once at planting only. The crop husbandry practices such as pesticide application (for stalkborer) was done at heading stage and the fields were weeded three times during maize growth period.

3.5. Soil sampling and preparation for analysis

To determine the initial soil fertility status, the soil sampling was done at 0-10, 10-20, 20-30 cm depths at the starting and at the end of the experiment in order to assess the effect of the treatments on selected soil chemical properties. Khaki paper bags were used for storage and transporting soil samples from the field to the Lab at Kenyatta University. Soil sampling was done using a soil auger while for bulk density, core rings were used. At the laboratory, soil samples were dried in preparation for physical and chemical analyses. However for the measurements of available N (NH_4^+ and NO_3^-) and biomass microbial analyses, moist soils were used in order to avoid or to limit changes that might occur during drying. To measure the available N in soil and its effect on plant tissues, the available N (NH_4^+ and NO_3^-) was monitored in the soil depths (0-10, 10-20, 20-30 cm) during the entire crop growth period. Sampling of soil and plant tissues was done three times according to crop phenological phases or stages. That is at seedling and milking and at grain maturity stages. The soil samples were kept in cool boxes with ice cubes to preserve the initial field moisture content for available N analysis. Similarly, 3 plant stalks were sampled from each plot of the same treatments at four and eight weeks after emergence.

In addition, flag leaves, maize stalks and grains were also sampled from harvest area, to analyze for total N uptake of crop during its growth period and as affected by N input.

3.6. Laboratory Analysis

3.6.1. Soil pH analysis

For soil pH analysis, 10 g of dried soil was weighed and placed in a 50 ml beaker. To it, 25 ml of distilled water was added (pH water) using a pipette in the ratio of 1:2.5 (soil: water). Then the soil-water solution was shaken thoroughly by an electric shaker for 10 minutes and then the mixture was left to settle for 30 min. The pH value was determined by using the pH meter according to (Okalebo *et al*., 2002). Before the pH meter was used, it was calibrated by using buffers (buffer 4 and 7) after which the electrodes were rinsed with distilled water and immersed in the suspension and then the pH stabilized values were recorded. The same procedure was used for pH KCl (potential pH) where 1M KCl was used instead of distilled water. The mixture of 10g dried soil sample and 25 ml of KCl 1M were put into 50 ml beaker, shaken, left to settle after which the pH meter was read, and values recorded.

3.6.2. Determination of K^+ and Na^+ in soil

K and Na ions were analyzed at the beginning and at the end of the experiment (at harvest). Mehlich1 (M1) as an extractant was used for initial K and Na content of the soil (Harmon *et al*. 2017). Four grams (4 grams) of dried soil sample was measured and poured into 50 ml polythene bottle correctly labeled and 20 ml of the Mehlich1 extractant solution was added (0.1 N HCl and 0.025 N H_2SO_4). The suspension was mechanically shaken for 10 min and filtered by Whatman No.2 filter paper to obtain a clean filtrate.

A calibration graph was obtained from the working standard series with the elements (K and Na) with 0.4% Lanthanum chloride 0.2% ($LaCl_3$). The concentrations of the cations in the extracted soil were determined by flame photometer with a concentration in (mg kg^{-1} soil) for each cation.

3.6.3. Determination of Available phosphorus

The available P was determined before and at the end of the experiment, addition of 12 g Ammonium molybdate ($(NH_4)_2MoO4$), 0.29g Antimony potassium tartrate ($C_8H_{10}K_2O_{15}Sb_2$) and 160 ml of Sulfuric acid (H_2SO_4) and filled up to 2liters with distilled water were used to form reagent A. Also, 1.32 g of Ascorbic Acid was added to reagent A to form reagent B. Two grams 2 g of dried soil was weighed and put into 250 ml plastic bottle and 24 ml of the distilled water was added with 8 ml of reagent B that was used for extraction after swirling for 10 minutes. The extract solutions were filtered using Whatman No1 filter paper into clean 50 ml bottles. Phosphorus was determined by colorimetry method with a blank and standards made in the Bray P-1 removing solution (Miller and Arai, 2016), and analyzed by using UV/Vis spectrophotometer at 430 nm (Fornasier, 2015).

3.6.4. Determination of Mg^{2+} and Ca^{2+} in the soil

Determination of Mg and Ca ions concentration in the soil was done at the beginning and at the end of the experiment. Mg and Ca content in the soil were analyzed by Melhich 1 extraction method according to Zbíral *et al.*, (2018). Two grams 2 gr of dried soil were weighted in 50 ml polyethylene plastic and 20 ml of extracting solution of (0.1 N HCl and 0.025 N H_2SO_4) was added to it.

The mixture solution was then shaken for 5 min and filtered using Whatman No.1 filter paper to get a clear filtrate. Then milliliters of the filtrate solution were pipetted into each test tubes of the standard. Five milliliters of distilled water was added, also with 4 ml of Lanthanum Chloride ($LaCl_{3,}$ 0.2%) solution for each tube. The content of Mg and Ca was read by 660 nm AAS spectrophotometer.

3.6.5. Soil organic carbon

Soil organic carbon was determined at the beginning and at the end of the experiment using digestion method (Kraas, 2017). Two grams of a dried soil sample, ground to pass through 0.2 mm sieve was weighted and put in 250 ml Erlenmeyer flask and added 2 ml of deionized water using a pipette. Addition of 10 ml of Potassium dichromate (K_2 Cr_2 O_7 5%) solution was added into both standard, blank and sample tubes. Then, slowly 5 ml of 99% concentration of sulphuric acid (H_2SO_4) was added and mixed thoroughly with a vortex mixer. Digestion of the mixture was heated at 150^{o}C for 30 minutes and allowed to cool. After cooling, 50 ml of 0.4% barium chloride (BaCl) was added, also shaken and stood overnight. Then, the soil organic carbon content (SOC) was determined by using UV spectrophotometer at 600 nm according to Heinz and Zak (2018).

3.6.6. Total soil nitrogen

Kjeldahl digestion method as described by Tahir and Marschner (2017) was used to determine the soil total N at beginning and at the end of the experiment. One gram of dried soil, ground to pass through a 0.2 mm sieve was weighed and put into Kjeldahl digestion tubes.

About 3 g of catalyst (Mixture of 250 g of K_2SO_4, 6.25 g of $CuSO_4$ and 2.5 g of Se) and 10 ml of concentrated H_2SO_4 were added into the tube samples and shaken thoroughly with vortex electric mixer. The tubes were then put on the digestion block and heated gently. When the frothing calmed, the heat was raised up to 150^o C for 1hour, then to 250^0C for another one hour and lastly to 350^0C for the 3rd hour. When the solution became greyish-white, the tubes were allowed to cool for one hour and added 10ml of distilled water to avoid hardening. During distillation, 50 ml of 4% boric acid (H_3BO_3) were placed in a beaker to capture the released NH_3 gas. To the distillation bottle, 10 ml of sample solution plus 30 ml of concentrated Sodium hydroxide (NaOH) were mixed and distillation started. At the end of distillation, the color changed from pink to green, after which the content of the flask was titrated with 0.01N HCl. Then, the solution changed the color from weak green to pink as end point.

The volume of 0.01N HCl used was recorded and the percentage N was calculated as follows:

$$\% \textbf{ Total N } = \frac{(\textbf{mL HCl sample} - \textbf{mL blank})\textbf{x N of HClx } \textbf{0.014g/meq}}{\textbf{soil sample size } (\textbf{g})} \textbf{x 100 } (\textbf{4})$$

3.6.7. Determination of soil available nitrogen (NO_3^- and NH_4^+)

Kjeldahl digestion method (Wang et al., 2019) was used to determine the available N (NO_3 and NH_4). The moist soil samples were placed in a cool box from the field and kept in the fridge (roughly 4^oC) before extraction. Twenty grams of moist soil sample were weighted and mixed with 150 ml of 2N KCl. The mixture was shaken for an hour then filtered through No 42 Whatman filter paper. The quantity of 50 ml of the filtrate

solution was used in the conical flask, mixed with 30 ml of Sodium hydroxide (4% NaOH) and added with a scoop of 0.8 grams of MgO and distillation was started.

After collecting about 150ml of the distillate in a beaker with 50 ml of boric acid, the distillate was removed but distillation continued with a fresh boric acid in a new beaker. To the distillation flask, devarda's alloy (roughly 0.8 g) was added into the conical flask to reduce nitrates (NO_3) and nitrites (NO_2) in the sample into ammonia (NH_3) gas which was distilled and captured in the new 50 ml boric acid. After collection of about 150 ml of the distillate, the distillation was stopped. At the end of the process, the colour of the distillate changed from colorless to a green colour. This meant that all the quantity of NH_3 present in the sample was collected in the conical flasks. The captured NH_3 content in the boric acid was titrated with 0.01N HCl using a burette. The color in the beaker with boric acid changed from green to light pink. Consequently, equation 5 was used to calculate the captured NH_3 in ppm

$N{-}NH_4$ and $N{-}NO_3$ in the soil sample:

$$\text{PPm NH4 or NO3} =$$

$$\frac{(\text{mLHCl sample} - \text{mL blank}) \text{x N of HCl x} \frac{0.014\text{gN}}{\text{meq}} \text{sample size (g)}}{1} \text{ x } \left(\frac{\text{mL of aligot}}{\text{mL of extract}}\right) \quad (5)$$

3.6.8 Soil texture analysis

Soil particle size analysis was determined by the hydrometer method (Okalebo *et al.*, 2002). Weighing of 50 g dried soil sample was done and put into a 400 ml beaker and thoroughly mixed with 300 ml of distilled water prior to adjustment with 50 ml of Calgon solution.

The samples were shaken overnight until the suspension was thoroughly mixed after which it was transferred to a beaker and adjusted to 1 liter with distilled water. The solution was stirred 60 times, after which it was allowed to settle for 40 seconds before the first reading was done using hydrometer.

After first reading was done, the temperature of the suspension was noted, and the suspension was allowed to settle for 3 hours before second reading was done. This first reading considered the percentages of silt and clay contents while the percentage of sand was obtained by deduction of clay and silt percentages from 100%. The second hygrometer reading indicated the density of clay particles content.

3.7. Plant tissues sampling preparation and analysis

3.7.1. Plant tissues sampling prepation

The samples (leaf, stalk, and grain) were collected in the beginning and at the end of the experiment from each treatment and were placed in small manila bags sealed and correctly labeled (date, plot, treatment, and site). The samples were transported to the laboratory where they were oven dried at 60^{o} C for 48 hours to a constant weight. The dried plant samples (leaves or stalks, and maize grains) were then crushed and analyzed for the total N content by Kjeldahl method as described for soils in section 3.6.6.

3.7.2. Determination of total nitrogen in the plant tissues

Determination of total N in the plant tissues was done by the Kjeldahl method using a mixture of Hydrogen peroxide, Lithium sulfate and Selenium (catalyst) and Sulphuric acid (H_2SO_4). The plant tissues were crushed thoroughly with mill machine. 0.2 grams of each sub-sample (leaf or stalk) from the respective plots was mixed with 4.4 ml of the above catalyst, digested and allowed to settle overnight (Okalebo *et al*., 2002). The

procedure for total N analysis (section 3.6.6) was also used for grain samples from different treatments after harvest period.

Before digestion, all plant samples were oven dried to a moisture range between 1-2% to limit the loss of nitrates due to the reaction with a sulphuric acid (H_2SO_4). The solution was digested by increasing temperature from 200ºC to 250ºC, and 350ºC in the interval of 30 minutes. After 3 hours, the digested solution was allowed to cool in the digestion block by adding 75 ml distilled water in each sample tube. Regarding distillation, 10ml of the sample solution and that from the blank were pipetted and mixed with 10 ml of NaOH and 20 ml of distilled water into the distillation tubes. 20 ml of Boric acid with mixed indicator was placed in a conical flask. The released NH_3 gas during distillation was captured by boric acid in the conical flask. Titration was done using 0.01N HCl where colour changed from green to pink as end point. The amount of 0.01N HCl used in titration was recorded and used for calculation as section 3.6.6.

3.8. Determination of bacteria and fungi population in soil

Determination of bacteria and fungi population was done from the soil samples taken at the beginning and end of the experiment. The dilution and spread plate technique was used to compute the bacteria and fungi populations (Dutta et al., 2018). The colonies of bacteria and fungi were demarcated by using the dilution plate counting method. Soil microbial growth medium was prepared using Nutrient Agar (NA) for bacteria and Potato Dextrose Agar (PDA) for fungi (Miura *et al*., 2016). One gram of soil sample from each treatment and depth was put into a beaker of 50 ml and mixed thororughly with 9 ml of sterilized and distilled water and allowed to stand.

One mL of the mixed soil solution was then taken by using a calibrated micropipette and a serial dilution of up to 10^5 either for bacteria or fungi in water using universal bottles which were already prepared. Fourty two gram (42 g) of Nutrient Agar (NA) was weighted and dissolved into 1.5 L of distilled water to make a bacteria growth medium while 58.5 g of Potato Dextrose Agar (PDA) was weighed and put into 1.5 l of distilled water for fungi growth media. The mixture was put into conical flask, then covered by cotton and Aluminium foil to protect the medium against the eventual contaminations. The medium was then autoclaved until the autoclave sounded the alarm for completing the sterilization (± 1hour). The media were allowed to cool around 37^0C and then PDA medium was mixed with an antibiotic to inhibit the bacteria growth. The medium of a range between 10-15 ml were put into each sterilized Petri dish and allowed to solidify overnight. 0.1 mL aliquots of the diluent was aspirated by using micropipette and put into tri-replicated sterile medium plates of each treatment.

The aliquots were spread with a sterile glass rod. After one week, the mature colonies in dishes were counted using a colony counter and the average was used to determine the colonies of each sample. Fungi population was also determined from the soil samples using the same method as bacteria colonies determination but using the medium potato dextrose agar (PDA) instead of nutrient agar (NA) as in the case of bacteria. 58.5 g of PDA were weighted and dissolved into 1.5mL of sterilized distilled water in the conical flask. After spreading 0.1mL of an aliquot from a sample solution, the colonies were developed and counted after 4 days at a temperature of 25^{o}C. After that period, the forming of colonies in soil solution were individually counted and converted to the number of colonies per gram of soil.

3.9. Maize yield quantification and Total Nitrogen determination

Maize grain yields were harvested in the first week of August 2018 at physiological maturity. The samples were taken from the harvest area (HA) of 4.8 m x 4.5 m. The two outside rows of the experiment were not considered. Mixed grain yields (1kg) from each treatment were taken and dried in an oven at 105^{o}C for 48 h until a constant weight at moisture contents of 12.5% was attained. The total N content was determined using the Kjeldahl digestion method according to Thind *et al*., (2018)

3.10. Determination of fertilizer use efficiency

Agronomic use efficiency or Fertilizer use efficiency (FUE) is the quantity of harvestable yield (i.e. Maize grain) per kg of applied nutrient. FUE was calculated to determine the efficiency of maize in utilizing nitrogen fertilizer from soil in relation to maize grain yield.

The method by Nyamasoka *et al*. (2017) for determining fertilizer use efficiency was used:

$$\textbf{FUE (kg grain/kg N)} = \textbf{(YN-Y0)/FN} \quad (6)$$

Where:

YN = yields in fertilized plots (kg ha^{-1}),

Y0 = yields in control plots (kg ha^{-1})

FN = amount of nutrient applied (kg ha^{-1})

3.11. Data management and Statistical analysis

The data were subjected to analysis of variance (ANOVA) and t - test using GenStat software (15^{th} edition) to determine if significance exists, also means' separation was performed using LSD test. Data arrangement was done using Microsoft Excel. Regression analysis was performed to assess the relationship among the variables. All data analyzed were carried out at 5% confidence interval ($p<0.05$).

CHAPTER FOUR

4.0. RESULTS AND DISCUSSIONS

4.1. Introduction

The results of this study are presented as follows: section 4.1 Introduction, 4.2 Initial soil fertility properties and rainfall patterns, 4.3 Effect of N fertilizer on maize grain yields, 4.4 Effect of N fertilizer on N content in the maize plant tissues, 4.5 Nitrogen fertilizer use efficiency by maize grain yield production. 4.6 Effect of applied N fertilizer on available N concentration in soil during maize crop growth period. 4.7 Effect of applied N fertilizer on bio-chemical soil properties at the end of experiment.

4.2. Initial soil fertility status and rainfall distribution in Rongo

4.2.1. Soil physical and biochemical properties

The initial soil fertility data from Kambija and Koderobara sites are shown in Table 4.1. The soil pH at Kambija site ranged between 6.6 and 5.9 for pH water (active pH) while the pH KCl (potential pH) between 4.7 at top soil layer and 4.1 at sub-surface soil layer. Both the pH water and KCl, decreased with soil depth. This means that soil acidity at Kambija site decreased with depth. In the case of Koderobara site, the pH water ranged between 5.4 and 5.8 while that of KCl (potential pH) was around 4.0 both at surface and sub-surface soil layers. According to pH classification, the soils at Kambija could be classified as slightly too strongly acidic while those soils at Koderobara as strong to very strongly acidic.

The total N content in soils of both sites were practically very low ranging from 0.08 - 0.06% and 0.08 - 0.07%, respectively for Kambija and Koderobara. The soil organic carbon, values varied between 1.7-1.4 % at Kambija and between 1.1-1.0 % at Koderobara, a value which is also said to be low (Mtambanengwe and Mapfuno, 2006). The resultant C/N ratios in the soils of both sites ranged between 11 and 23, values favoring net mineralization of N (Mahbul and Mohsen, 2012). Except for NH_4^+, N contents which were low in soils of both sites, the other cations/nutrients such Mg, Ca, K, Na, P and available N were fairly adequate in soils for plant use. The soil types of the area were sandy clay loam at Kambija and sandy clay at Koderobara.

Table 4.1: Initial soil fertility status at Kambija and Koderobara sites

Parameter	**Kambija**			**Koderobara**		
	Depth (cm)					
	0-10	**10-20**	**20-30**	**0-10**	**10-20**	**20-30**
pH water	6.6	6.24	5.92	5.44	5.15	5.83
pH KCl	4.74	4.26	4.08	3.99	4.0	4.0
Total N (%)	0.08	0.13	0.06	0.08	0.06	0.07
Organic C (%)	1.70	1.40	1.40	1.10	1.20	1.00
C/N	21.0	11.0	23.0	14.0	20.0	14.0
P (mg kg^{-1})	14.03	14.77	14.77	18.92	16.72	14.03
Mg (meq$100g^{-1}$)	12.31	11.22	10.76	5.28	5.54	5.22
Ca (meq $100g^{-1}$)	7.41	4.81	4.78	2.04	2.39	2.38
K (meq $100g^{-1}$)	3.96	2.79	1.93	1.61	1.50	1.32
Na (meq $100g^{-1}$)	0.74	0.79	0.60	1.94	0.55	0.56
NO_3 (mg kg^{-1})	8.31	7.27	7.93	7.93	7.72	8.97
NH_4 (mg kg^{-1})	1.89	0.63	1.02	1.18	0.86	1.02
B D (g cm^3)	1.22	1.22	1.36	1.23	1.20	1.34
Sandy %	40	36	32	48	48	46
Silt %	18	12	20	6	8	4
Clay %	42	52	48	46	44	50
Texture grade	SCL	SC	SCL	SC	SC	SC

B D: Bulk Density**, CL:** Clay; **SC:** Sandy Clay**; SCL:** Sandy Clay Loam

4.2.2. Rainfall pattern during 2018 long rains at Rongo sub-County

Figure 4.1 shows the amounts and distribution of rainfall as recorded during the growing season of 2018 at Rongo Sub-County, Migori County. High rainfall was received from the beginning of the experiment (March up to May) with the peak in April (240 mm). The total amount of rainfall in the long rain season (March to July) was around 791mm which caused some slight floods especially at Koderobara site. The average temperature in the season in Rongo was estimated at 21^{o}C.

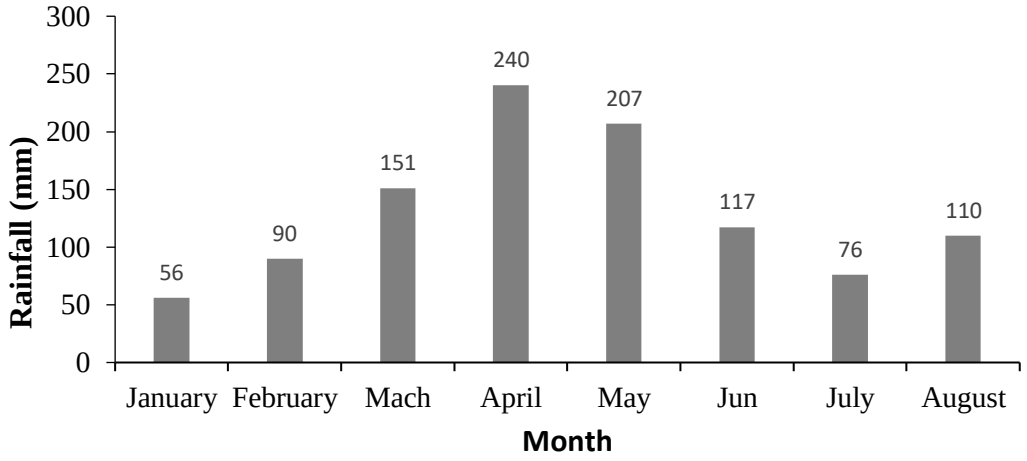

Figure 4.1: Monthly rainfall amounts (mm) at Kambija and Koderobara in 2018, long rain Season.

Source: Miyare Agricultural Training Centre (ATC), Weather station

4.3. Effect of nitrogen fertilizer on maize yields

4.3.1. Kambija

Maize grain yields responded significantly (p=0.001) to nitrogen nutrient with the highest yields of 3.41 t ha^{-1} obtained by 50 Kg N ha^{-1} (Table 4.2). This yield increase was 62% above the control (1.3 t ha^{-1}). Generally, maize grain yields increased with increasing nitrogen fertilizer rates at Kambija.

4.3.2. Koderobara

At Koderobara, the maximum maize grain yield was 4.34 t ha^{-1} which was obtained with 50 Kg N ha^{-1}, a case similar to that at Kambija (Table 4.2). This yield increase was highly significant with a yield increase of 73.9 % above the control (1.13t ha^{-1}). Yields obtained at Koderobara with the control treatment were 1.13 t ha^{-1} while at Kambija it was 1.3 t ha^{-1} a difference of 13% from the yields obtained at Kambija. In comparison however, mean yields of the two sites were more or less the same, that is 2.5 t ha^{-1} at kambija and 2.2 t ha^{-1} at Koderobara (Table 4.2) and that the trends within treatments of the two sites in terms of yield performances were also not significantly different from each other (Fig.4.2). Worth noting is that some plots at Koderobara were at one moment flooded due to heavy rains in two months after planting and this could have affected maize yields at that site.

Table 4.2**:** Effect of N fertilizer on maize grain yield (t ha^{1}) at Kambija and Koderobara

Attribute	**Maize grain yield**	
Treatment/Rate (kgha^{-1})	**Kambija**	**Koderobara**
N0	1.29^{c}	1.13^{b}
N0P10	1.27^{cd}	1.96^{b}
N25P10	2.29^{b}	1.74^{bc}
N50P10	3.41^{a}	4.34^{a}
N75P10	3.03^{a}	1.75^{b}
P (0.05)	0.001	0.01
$LSD_{0.05}$	707.4	1646.2
MEAN	2263	2189.8

Means followed by the same superscript letter within a column are not significantly different ($P \leq 0.05$) by F- protected LSD test.

Generally, maize grain yields responded positively to nitrogen fertilizer application and tended to increase with application rates. Application rate of 50 kg of nitrogen fertilizer per hectare in both sites had the highest maize grain yields. These findings indicate that nitrogen is an indispensable nutrient in crop productivity in the area. Similar findings had been reported by various researchers (Cambouris *et al*., 2016, Peng *et al*., 2017 and Riziki, 2014). For instance, Cambouris *et al*. (2016) reported that applied N at different rates increased crop production significantly in the study done in Quebec. In her study, Riziki (2014) at Kambi ya Mawe, Eastern Kenya, reported that nitrogen application increased significantly sorghum yields by between 100 kg and 700 kg ha^{-1} compared to P application. Shahid *et al.* (2017) also reported the importance of nitrogen in maize performance, both in grain yields and other crop components. Other researchers (Kaizzi *et al*. 2012 and Ngome *et al*. 2013) have reported similar effects of nitrogen on crop production and went further to report that an extra N use may not always produce an extra maize grain yield, but could increase plant biomass or lost from the soil ecosystem, a case also that was observed in this study especially on plant biomass increase.

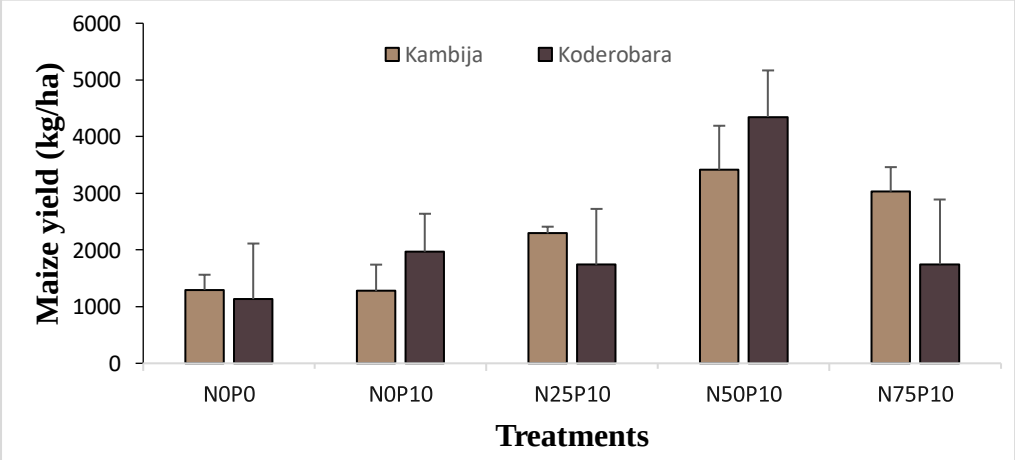

Figure 4.2: Maize grain yields at Kambija and Koderobara in relation to N fertilizer

4.3.3 The relationships of available N concetrations in soil and maize grain yields

The figures 4.3 (a, b, c) and 4.4 (a, b, c) show the regression analyses between available soil nitrogen concentrations (NH_4, NO_3 and NH_4+NO_3) and maize grain yields at Kambija and Koderobara experimental sites, respectively. At both sites, the regressions were linear and positive, but with strong relationship between maize yields and available N at Kambija than at Koderobara. At Kambija site, the regressions (R^2) were 0.81, 0.71 and 0.83 whereas at Koderobara (R^2) were 0.51, 0.53 and 0.51 with respect to NH_4, NO_3 and NH_4 + NO_3 nitrogen concentrations in soil.

Interestingly, the strong relationship effect between the variables at Kambija than Koderobara did not translate to higher maize grain yields (Table 4.2) but indicated the strength of the fit to the linear regression lines where data at Kambija had a better fit than at Koderobara. Similar findings had been reported by Olufemi and Solomon (2008).

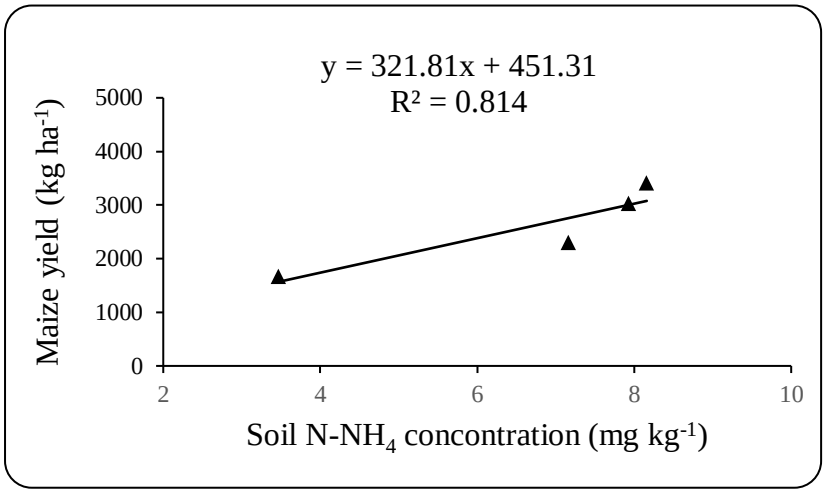

Figure 4.3a: Relationships between mean maize yield and Soil N-NH_4 concentration (mg kg^{-1}) at Kambija

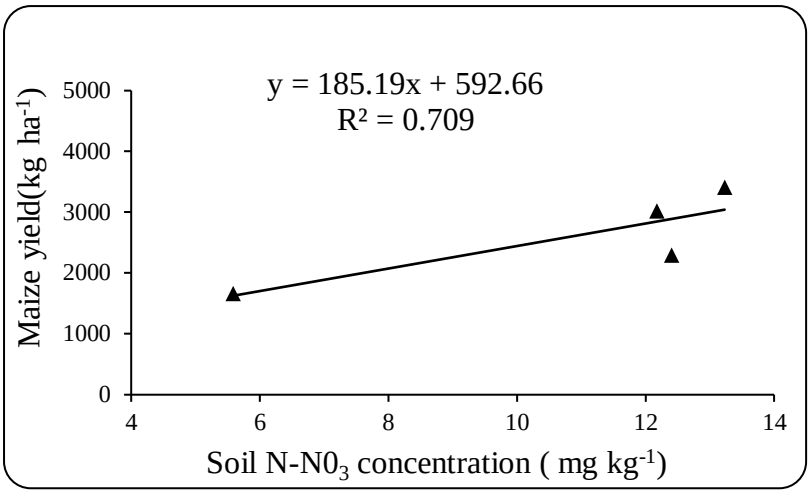

Figure 4.3b: Relationships between mean maize yield and Soil N-$N0_3$ concentration (mg kg^{-1}) at Kambija

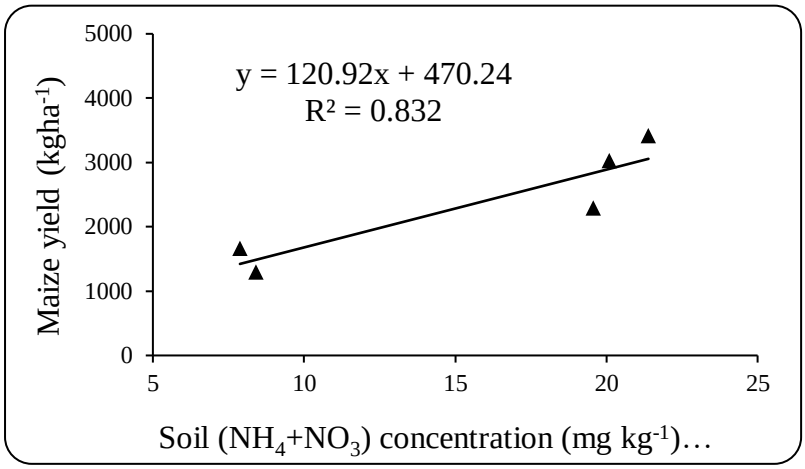

Figure 4.3c: Relationships between mean maize yield and soil available N concentration (mg kg^{1}) at Kambija

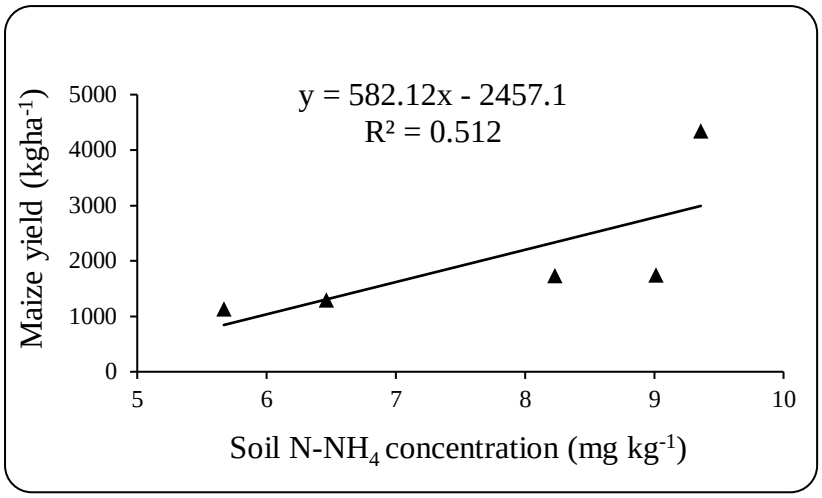

Figure 4.4a: Relationships between mean maize yield and Soil N-NH_4 concentration (mg kg^{1}) at Koderobara

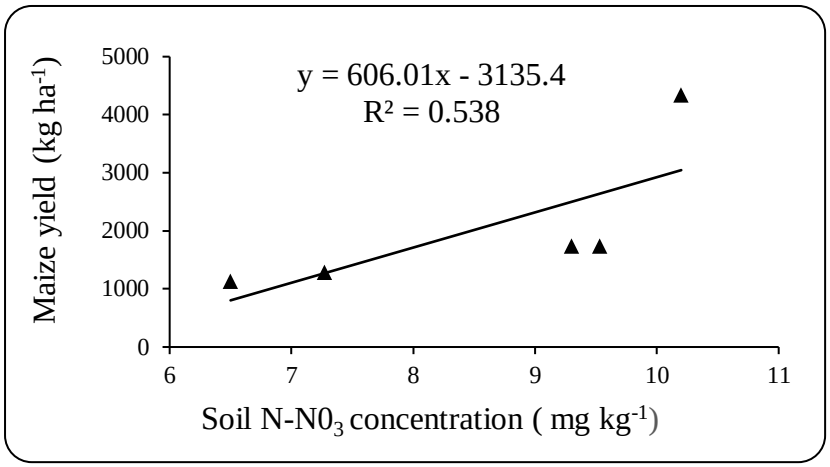

Figure 4.4b: Relationships between mean maize yield and Soil N-$N0_3$ concentration (mg kg^{-1}) at Koderobara

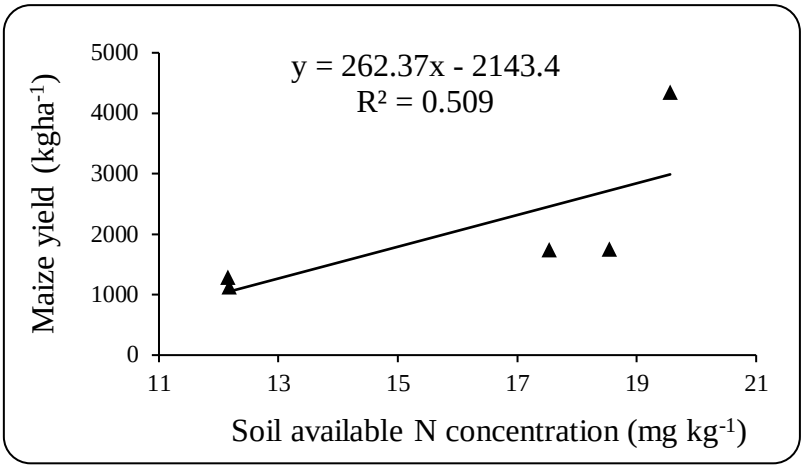

Figure. 4.4c: Relationships between mean maize yield and available N concentration in soil (mg kg^{-1}) at Koderobara

4.4. Effect of Nitrogn fertilizer on N content in the maize plant tissues

Nitrogen fertilization contributed to the increased N content observed in maize tissues compared to the control (Tables 4.3 and 4.4). Significant differences of N content were recorded in maize leaves, stalks and grains (at various maize growth phases) except at seedling stage at both sites. At heading stage, the amount of N in the leaves was comparatively higher than in the other stages both at Kambija ($p=0.003$) and Koderobara ($p= 0.001$) as shown in (Tables 4.3 and 4.4). At seedling stage, the amount of total nitrogen was low at both sites probably due to low root biomass which are responsible in nutrient uptake by plants. At heading stage, there was a slight elevation of N content in the leaves (flag leaves).This is the period when the cobs are at milking formation and therefore could need more nutrients. At maturity stage, the maize stalks (at harvest) had low N content compared to that in the maize grains.

Kambija site indicated higher N content in both maize growth phases than with Koderobara site due to its history land management and the effect of flooded plots due to heavy rains at the early stage of maize growing period. The current findings are contrary to the findings of other researchers who reported high elevation of N in the seedling stage as compared to the heading stage (Riziki, 2014). Riziki (2014) reported a continuous decline of N content in plant tissues from seedling stage to heading stage but with a slight increase in the grains in relation to the stalks. Similarly, Garcia *et al*.(2018) reported gradual decrease of N concentrations in different plant tissues until 75 days after planting after which it increased up to the physiological maturity (grains). This could be due to storage of nutrients in grains while stalks acted as transient of nutrients to the grains.

Table 4.3: Effect of N fertilizer on total N (%) in maize plant tissues at Kambija, 2018 long spots of rain season.

N Fertilizer rates	Heading stage		Maturity stage	
(kg/ha)	Seedling stage [x]	(Flag leaf)	Stalk	Grain
N0	1.32^{a}	1.39^{b}	0.03^{bc}	0.55^{c}
N0P10	1.41^{a}	1.31^{bc}	0.04^{c}	0.71^{bc}
N25P10	1.44^{a}	1.48^{b}	0.06^{c}	0.72^{b}
N50P10	1.42^{a}	1.95^{a}	0.21^{a}	1.09^{a}
N75P10	1.34^{a}	2.07^{a}	0.18^{b}	0.84^{b}
P=0.05	0.05	0.003	0.001	0.001
$LSD_{(0.05)}$	0.46	0.06	0.01	0.05
CV%	4.10	4.90	3.10	8.10

Means followed by the same superscript letter within a column are not significantly different ($P \leq 0.05$) by F- protected LSD test. [X] whole plat tissues were used at seedling stage

Table 4.4: Effect of N treatments on total N (%) in maize plant tissues at Koderobara during 2018 long spots of rain season.

Fertilizer rates	Heading stage		Maturity stage	
(kg/ha)	Seedling stage [x]	(Flag leaf)	Stalk	Grain
N0	1.08[a]	1.28[cd]	0.01[d]	0.10[e]
N0P10	0.67[a]	1.29[c]	0.05[c]	0.82[b]
N25P10	1.39[a]	1.42[c]	0.02[d]	0.35[d]
N50P10	1.58[a]	1.90[a]	0.36[a]	1.81[a]
N75P10	1.42[a]	1.63[b]	0.17[b]	0.41[c]
P=0.05	0.18	0.001	0.01	0.001
$LSD_{(0.05)}$	0.97	0.13	0.02	0.04
CV%	3.4	5.8	7.2	2.4

Means followed by the same superscript letter within a column are not significantly different ($P \leq 0.05$) by F- protected LSD test. [X] whole plant tissues were used at seedling stage.

Brevik *et al.* (2015) pointed out that the crop uptake is often influenced by climate conditions and soil characteristics. Lack of soil aeration (Anaerobic condition) and deficient of nutrients among others may limit the access to nutrients plant roots uptake. Chomba *et al*. (2013) argued that the rates of nutrient uptake relate to the type of crop especially during the maximum crop growth and varied with crop growth phases.

4.5 Nitrogen fertilizer use efficiency by maize grain production

At Kambija, NUE was 23.84, 17.76 and 10.50 kg of maize yields per kg of N while at Koderobara, the NUE was 18.08, 22.61 and 6.09 kg of maize yields per kg of N with respect to N fertilizer applied at 25, 50 and 75 kg N ha^{-1} at both sites (Table 4.5).

The findings of this study show that N fertilizer rate at 50 kg ha^{-1} had the highest NUE 22.61 kg yields per kg N applied at Koderobara while at Kambija, the highest NUE was 23.84 kg yields per kg N applied at treatment 25 kg N ha^{-1} of the fertilizer. The lowest NUEs were recorded at treatment 75 kg N ha^{-1} for Kambija (10.50) and 6.09 kg maize yields per kg N applied for Koderobara.

At Kambija, applied N at 25 kg N ha^{-1} had been fully used by maize to produce grain yields, while at 50 and 75 kg N ha^{-1}, applied N mighty have been leached or accumulated in the vegetative biomass. At Koderobara, N fertilized at 50 kg N ha^{-1} had been efficiently used by maize to produce grain yields, while the rest (> 50 kg N ha^{-1} of N fertilizer) might have been leached or participated in the vegetative development.

Table 4.5: Nitrogen Use Efficiency of maize at Kambija and Koderobara, 2018, during the long rainy season.

Fertilizer rates (kg ha^{-1})	NUE (kg grain yields kg^{-1} applied N fertilizer)	
	Kambija	Koderobara
25	23.84	18.08
50	17.76	22.61
75	10.50	6.09

These results concur with the findings by other researchers (Thind *et al*., 2018). In their findings, Thind *et al*. (2018) concluded that the NUEs decrease significantly with increase of N rates.

4.6. Effect of N fertilizer on available N concentrations in soil during maize crop growth period

Tables 4.6 and 4.7 show the distribution of available N fractions ($N\text{-}NO_3$ and $N\text{-}NH_4$) in soil profile at four weeks (FWAP) and at eight weeks after planting (EWAP) at the two sites with respect to different N treatments. The concentration of $N{-}NH_4$ was not significantly different ($p=0.53$) at seedling stage but $N{-}N0_3$ was significantly different ($p=0.02$) at the same growth stage (FWAP) at Kambija. However, both $N{-}N0_3$ and $N{-}NH_4$ fractions at heading stage (EWAP) were significantly different at Kambija ($p<0.05$). Similarly, the concentrations of $N{-}NH_4$ and $N{-}NO_3$ at Koderobara were also significantly different ($p<0.05$) at seedling and at heading stage ($p<0.05$).

The results in Tables 4.6 and 4.7, indicate high concentrations of available N in subsoil layer (20-30 cm) at seedling stage while at heading stage, the concentrations increased in top soil layer (0-10cm) and this happened at both sites. This could mean that available N concentrations at seedling stage in subsoil layer were low but increase at the heading stage probably due to accumulation of leached $N{-}NO_3$ from the above soil layers originating from applied N fertilizer.

Table 4.6: Effect of N treatments on available N concentrations in soil depth (cm) at Kambija four and eight weeks after planting.

Available N	Four weeks after planting					Eight weeks after planting			
	Depth (cm)	**N0**	**N25**	**N50**	**N75**	**N0**	**N25**	**N50**	**N75**
N-HN_4^+ (mg kg^{-1})	**0 -10**	1.16^a	1.36^a	2.43^a	3.25^a	2.43^a	2.77^a	9.40^a	7.80
	10-20	1.36^a	2.40^a	3.26^a	3.40^a	2.17^b	2.20^c	9.13^b	7.63^b
	20-30	2.50^a	2.51^a	3.33^a	3.36^a	2.04^c	2.04^b	8.17^c	6.70^c
	p(0.05)	0.53				0.01			
	LSD	0.83				0.12			
N-NO_3^- (mg kg^{-1})	**0 -10**	2.24^b	2.40^b	4.40^b	4.97^b	2.93^a	3.10^a	13.07^a	9.47^a
	10-20	2.53^a	2.70^a	4.03^c	4.40^a	2.37^b	2.40^b	12.67^b	8.90^b
	20-30	2.67^a	2.77^a	5.57^a	5.27^a	2.73^a	2.60^b	12.33^c	7.27^c
	p(0.05)	0.02				0.001			
	LSD	0.23				0.31			

Means followed by the same superscript letter within a column are not significantly different ($P \leq 0.05$) by F- protected LSD test.

Table. 4. 7: Effect of N treatments on available N concentrations in soil depth (cm) at Koderobara four and eight weeks after planting

Available N		Four weeks after planting				Eight weeks after planting			
	Depth (cm)	**N0**	**N25**	**N50**	**N75**	**N0**	**N25**	**N50**	**N75**
N-HN4^{+} (mg kg^{-1})	**0 -10**	1.37^{b}	1.43^{b}	3.83^{b}	2.47^{b}	4.90^{a}	5.60^{a}	8.77^{a}	6.66^{a}
	10-20	1.40^{b}	2.13^{a}	4.50^{a}	2.43^{b}	3.63^{c}	4.10^{b}	5.28^{b}	6.60^{a}
	20-30	2.07^{a}	2.14^{a}	4.57^{a}	3.44^{a}	4.23^{b}	4.13^{b}	5.17^{c}	6.17^{b}
	p(0.05)	0.001				0.001			
	LSD	0.23				0.32			
N-NO$_3^{-}$ (mg kg^{-1})	**0 -10**	2.27^{b}	3.23^{a}	6.13^{c}	4.53^{b}	4.77^{a}	5.23^{a}	10.27^{a}	10.90^{a}
	10-20	2.58^{a}	2.87^{b}	6.57^{b}	4.80^{a}	4. 60^{b}	4.17^{b}	9.03^{a}	8.30^{c}
	20-30	2.63^{a}	3.24^{a}	6.93^{a}	4.93^{a}	4.27^{c}	4.14^{b}	8.27^{b}	10.11^{b}
	p(0.05)	0.002				0.04			
	LSD	0.24				0.25			

Means followed by the same superscript letter within a column are not significantly different ($P \leq 0.05$) by F- protected LSD test.

Table 4.8: Effect of some selected N treatments on available N fractions in soil profile after the experiment.

Available N		Kambija				Koderobara			
	Depth (cm)	**N0**	**N25**	**N50**	**N75**	**N0**	**N25**	**N50**	**N75**
N-HN$_4^{+}$ (mgkg^{-1})	**0-10**	3.63^{a}	7.16^{a}	8.16^{a}	7.93^{a}	5.67^{a}	8.23^{a}	9.36^{a}	9.01a
	10-20	3.23^{b}	6.93^{b}	7.17^{b}	5.23^{b}	5.00^{b}	7.13^{b}	7.40^{b}	6.53^{b}
	P(0.05)	0.001				0.001			
	LSD	0.59				0.70			
N-N0$_3^{-}$ (mgkg^{-1})	**0-10**	4.77^{a}	12.40^{a}	13.23^{a}	12.17^{a}	6.50^{a}	9.30^{a}	10.20^{a}	9.53^{a}
	10-20	3.90^{b}	3.37^{b}	3.43^{b}	3.23^{b}	4.78^{b}	5.53^{b}	8.30^{b}	9.07^{b}
	P(0.05)	0.001				0.001			
	LSD	1.07				0.99			

Means followed by the same superscript letter within a column are not significantly different ($P \leq 0.05$) by F- protected LSD test.

According to Jurisic *et al.* (2013), the soil available N concentrations especially $N{-}NO_3^-$ often decrease with the soil depth. Nevertheless, in this study, $N\text{-}NO_3^-$ and $N{-}NH_4^+$ ions concentrations appeared to increase with soil depth at both sites, particularly at the seedling stage. This high concentration of available N in subsoil layers (10-20 and 20-30 cm) could be due to the leaching of the nitrate ions as a result of heavy rainfall experienced during that period (Gingras-Hill, 2017). Squires *et al*. (2013) shared the same idea arguing that a lot of rainfall registered in crop growing season led to an increasing of soil nitrate concentrations with depth. According to Zhao *et al.*, (2018), the movement of $N{-}NO_3^-$ is principally governed by the amount of applied fertilizer and the concentrations available in the sub-soil depths (20-80 cm), while Iqbal (2011) reported that $N{-}NO_3^-$ is more soluble and mobile with soil solution which exacerbates the source of groundwater pollution and other environmental hazards such as enrichment of local waters with nutrient ions. Huang *et al.* (2018) also argued that more variability of precipitation mostly leads to the high amount of nitrate losses (up to 12-folds) through leaching.

Ammonium N is less dynamic but readily taken up by soil colloids which results to less concentrations in soil water. However, in the soil profile, nitrate leachates have been estimated to be six times greater than NH_4 (Zhong *et al*., 2014). Therefore, the decrease of available N concentrations with the soil depth after experiments (Table 4.8) could be due to reduced amount of rainfall towards the last two months of the experiment. However, the slight increase of available N concentration in top soil layer (0-10 cm) at both sites could partly be explained by organic matter mineralization and partly by accumulation of NO_3-N from lower soil layers due to droughts experienced towards the end of experiment necessitating upwards movement of NO_3-N by capillary rise (Liu et

al.,2018). In their research, Kebeney *et al*. (2015) found that, the type and rate of fertilizers used had also an impact on boosting the mean of soil N content.

4.7. Effect of applied N fertilizer on bio-chemical soil properties at the end of experiment

4.7.1 Overall observation of the changes

The effect of applied N fertilizer on soil chemical properties at the end of the experiment at Kambija and Koderobara sites is shown in Table 4.9. Comparing these data with those in the initial soil sampling (Table 4.1), significant changes were recorded with pH water, soil organic carbon, total nitrogen, available N, phosphorus and magnesium but not with calcium and potassium (Tables 4.1 and 4.9). The soil organic carbon (SOC) contents at both sites were significantly low compared to the initial contents (Table 4.9). The levels ranged between 1.70 -1.40% for Kambija and 1.10-1.00% for Koderobara. Similar trend was observed for total nitrogen (Nt) as that of SOC, with high initial values (Table 4.1) compared to those in (Table 4.9) for both Kambija and Koderobara. These differences were, however, not significant.

Table 4. 9: Soil chemical properties levels at the end of the experiment

Parameter	Kambija				Koderobara			
	Control		75kg N ha^{-1}		Control		75 kg N ha^{-1}	
	Depth (cm)							
	0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20
pH H_2O	5.39	5.42	5.48	5.40	5.34	5.04	5.57	5.3
NO_3(mg/kg)	16.78	8.50	67.53	59.07	16.77	13.90	50.17	43.23
NH_4 (mg/ha)	20.67	19.00	30.53	29.00	12.93	2.22	22.94	18.23
P (mg/kg)	26.12	22.61	28.23	20.51	23.30	21.74	25.42	3.31
Mg(meq/100g)	1.01	0.90	1.03	1.00	1.61	1.49	1.62	1.56
Ca (meq/100g)	1.31	1.72	1.15	1.13	2.47	2.00	2.27	2.24
Na(meq/100g)	2.67	1.44	1.80	1.61	0.84	0.63	0.93	0.85
K (meq/100g)	1.00	0.93	0.81	0.89	1.64	1.12	1.08	1.00
Total N (%)	0.02	0.03	0.01	0.02	0.01	0.04	0.21	0.19
Organic C (%)	0.41	0.30	0.30	0.27	0.10	0.27	0.39	0.33

4.7.2. Soil pH

Table 4.10 shows the results of soil active pH in the study areas as affected by applied N fertilizer. The results show that the soil pH level changes at Kambija site were significant as indicated by *t-test*, *p* where the drop of pH was more than a unit. At Koderobara, however, the pH changes were minimal and not significant. By the end of the experiment, the soils of both sites were moderately acidic but the means of soil pH changes were not significantly different between the N treatments.

Table 4.10: Changes of pH (0-10 cm depth) in different treatments, long rainy season 2018.

Treatment (kg/ha)	Initial	**Kambija** End of experim-	% Chang	*t*-test, *p*	Initial	**Kodero**bara End of Experim-	% Change	*t*-test, *p*
N0	6.61	5.34[a]	-19.21	0.002	5.44	5.39[a]	-0.91	0.02
N25	6.61	5.39[a]	-18.45	0.02	5.44	5.41[a]	-0.55	0.04
N50	6.61	5.40[a]	-17.10	0.0005	5.44	5.42[a]	-0.36	0.01
N75	6.61	5.57[a]	-15.73	0.01	5.44	5.40[a]	-0.73	0.006
P(Value)		0.25				0.89		
LSD		0.4				0.28		
CV%		6.6				3.4		

Means followed by the same superscript letter within a column are not significantly different ($P \leq 0.05$) by F- protected LSD test. Negative (-) values indicate % decrease while positive (+) values indicate % increase.

In terms of relationship between pH and maize grain yields, the relationship was moderate with a positive linear regression ($R^2 = 0.526$) at Kambija (Fig.4.5) while at Koderobara (Fig.4.6), the relationship between maize grain yield and soil pH was weak but positive ($R^2 = 0.148$). This could mean that pH has an influence on maize performance. According to the study conducted by Gitari *et al*. (2015) in central Kenya, maize dry matter exhibited a moderately high and positive linear regression ($R^2 = 0.622$) with soil pH changes whereas plant height and soil pH showed a strong, positive linear regression ($R^2 = 0.72$).

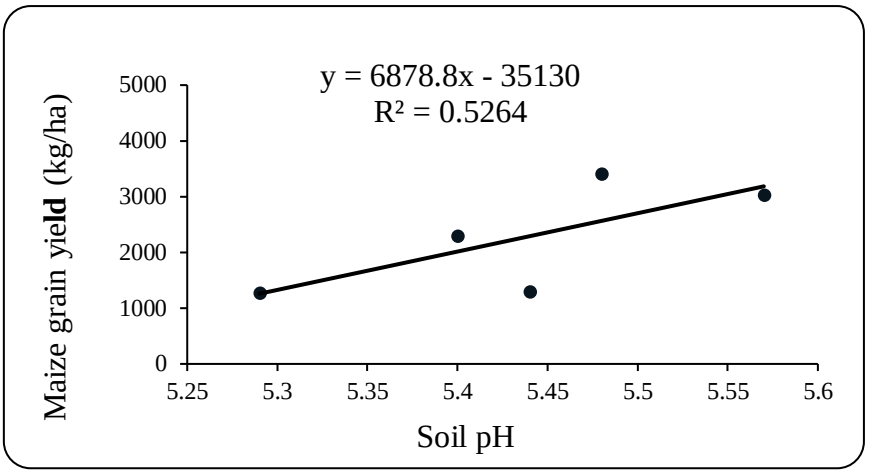

Figure 4.5: Relationship between mean maize grain yield and soil pH at Kambija site.

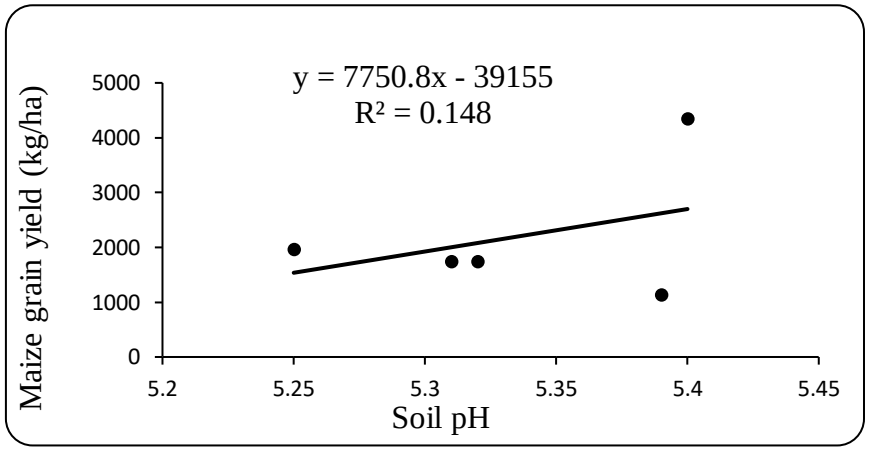

Figure 4.6: Relationship between mean maize grain yield and soil pH at the end of the experiment at Koderobara site.

4.7.3. Effect of treatments on available P in soils

At Kambija, the highest P content was recorded in the plots fertilized with 25 kg N ha^{-1} and 10 kg P ha^{-1} (26.10 mg kg^{-1}) while the lowest was recorded in the control (21.74 mg kg^{-1}) where blanket P was not applied. At Koderobara, the highest P content was recorded in the plots treated with 75 kg N ha^{-1} and 10 kg P ha^{-1} (28.26 mg kg^{-1}) and the lowest in the control (26.12 mg kg^{-1}).

Table 4.11: Changes in P (mg kg^{-1}) (0-10 cm depth) during the experiment

	Kambija				Koderobara			
Treat	Initial	End of experiment	% Change	*t*-test, *p*	Initial	End of experiment	% Change	*t*-test, *p*
N0	14.03	21.7[a]	54.9	0.02	18.2	26.12[a]	38.05	0.0002
N25	14.03	26.1[a]	86.02	0.01	18.2	28.23[a]	49.20	0.01
N50	14.03	26.0[a]	85.95	0.001	18.2	27.30[a]	44.29	0.01
N75	14.03	25.4[a]	81.18	0.03	18.2	28.26[a]	49.36	0.005
P(Value)		0.61				0.52		
LSD		4.70				2.85		
CV%		10.4				5.4		

Means followed by the same superscript letter within a column are not significantly different ($P \leq 0.05$) by F- protected LSD test.

The apparent increase in P at the end of the experiment in both sites is due to the stability of P ions in soil exchangeable complex. Three molecules of P^{3+} ions held by soil negative charge and hence less leached. In terms of relationships between soil available P levels and maize grain yields in (Figure 4.7 and 4.8) for Kambija and Koderobara sites, respectively, at Kambija, there was a strong positive linear regression (R^2=0.745) between maize grain yield and soil available P while at Koderobara the relationship between maize yield and soil available P was, though positive, had a very weak linear regression (R^2=0.088) (Figures 4.7 & 4.8).

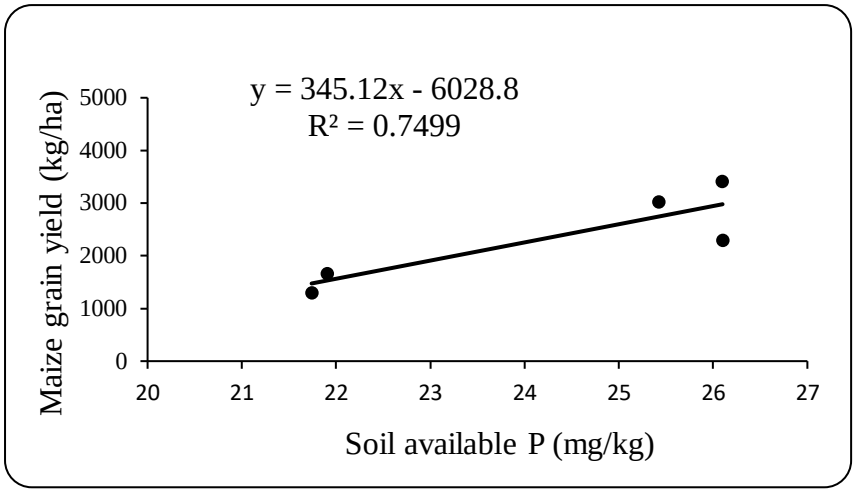

Figure 4.7: Correlation between mean maize yield and soil available P content at the end of the experiment at Kambija site.

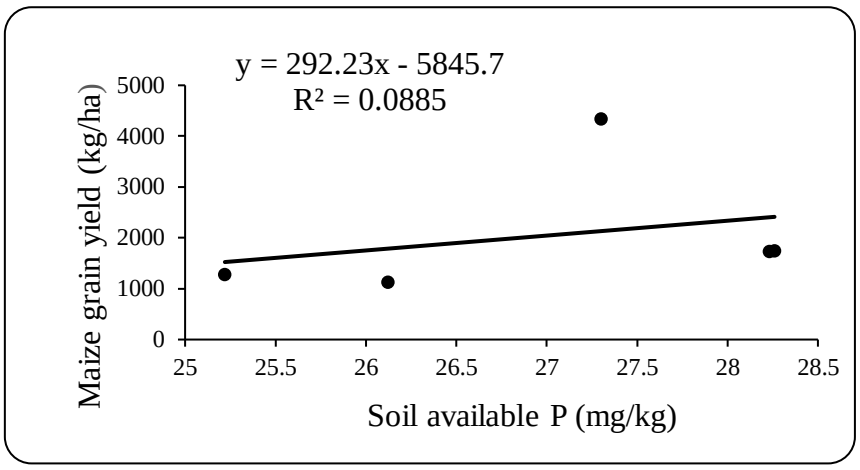

Figure 4.8: Correlation between mean maize yield and soil available P content at the end of the experiment at Koderobara site.

Nevertheless, a study by Kifuko *et al.* (2007) had reported a significant positive linear correlation between mean maize yield and soil available P concentration ($R^2 = 0.89$) at the end of the experiment.

4.7.4. Effect of treatments on exchangeable cations

Tables 4.12 and 4.13 show the soil exchangeable cations levels at the end of the experiment. Applied N treatments had significant change ($p=0.05$) effects in the decrease of exchangeable bases at Kambija and Koderobara except for sodium (Na) which had no significant differences ($p=0.23$) at Koderobara. Generally, there was reduction in all the cations except for potassium (K^+) and slightly for Ca^{2+} at Koderobara. This reduction of soil exchangeable cations could be explained by the fact that low soil pH values affect the accessibility of exchangeable cations in the root feeding zone (Mompati, 2019 and Mochoge, 1989). However, only Potassium (K^+) at Koderobara improved from initial soil K concentration as seen on Table 4.13.

Table 4.12: Changes of exchangeable base cations (Cmol $_{(+)}$ kg^{-1} soil) (0-10cm depth) end experiment at Kambija

Treatment	Ca^{2+}			Mg^{2+}			K^{+}			Na^{+}		
	Initial	End Exp.	% Change	Initial	End Exp.	% Change	Initial	End Exp.	% Change	Initial	End Exp.	% Change
N0	7.41	2.47^{b}	-66.7	12.31	1.61^{a}	-86.9	3.96	1.64^{b}	-58.5	0.74	0.63^{d}	-14.8
N25	7.41	2.53^{a}	-65.8	12.31	0.93^{b}	-92.4	3.96	1.72^{b}	-56.5	0.74	0.71^{c}	-4.05
N50	7.41	2.51^{ab}	-66.1	12.31	1.56^{a}	-87.3	3.96	1.88^{a}	-52.5	0.74	1.02^{a}	37.8
N75	7.41	2.24^{b}	-66.1	12.31	1.62^{a}	-86.8	3.96	1.08^{c}	-72.7	0.74	0.85^{b}	14.9
P(Value)		0.004			0.001			0.02			0.001	
LSD		0.03			0.07			0.08			0.01	
MEAN		2.43			1.43			1.56			0.83	

Means followed by the same superscript letter within a column are not significantly different ($P \leq 0.05$) by F- protected LSD test.

Negative (-) values indicate % decrease while positive (+) values indicate % increase.

Table 4.13: Changes of exchangeable base cations (Cmol $_{(+)}$ kg^{-1} soil) (0-10 cm depth) end experiment at Koderobara

Treatment	Ca^{2+}			Mg^{2+}			K^{+}			Na^{+}		
	Initial	**End Exp.**	**% Change**	**Initial**	**End Exp.**	**% Change**	**Initial**	**End Exp.**	**% Change**	**Initial**	**End Exp.**	**% Change**
N0	2.04	1.31^{c}	-35.7	5.28	0.90^{b}	-82.9	1.61	2.67^{a}	65.8	1.94	1.0^{a}	-48.5
N25	2.04	1.40^{b}	-31.3	5.28	0.92^{b}	-82.5	1.61	1.83^{cd}	13.6	1.94	0.89^{a}	-54.1
N50	2.04	1.62^{ab}	-20.5	5.28	1.06^{a}	-79.9	1.61	2.54^{bc}	57.7	1.94	1.05^{a}	-45.8
N75	2.04	1.15^{d}	-43.6	5.28	1.03^{ab}	-80.4	1.61	1.80^{c}	11.8	1.94	0.81^{a}	-58.2
P(value)		0.002			0.001			0.01			0.23	
LSD		0.05			0.03			0.06			0.31	
MEAN		1.41			0.97			2.21			0.93	

Means followed by the same superscript letter within a column are not significantly different ($P \leq 0.05$) by F- protected LSD test. Negative (-) values indicate % decrease while positive (+) values indicate % increase.

In terms of relationships of the soil exchangeable bases and maize grain yields in (Table 4.9 and 4.10) with respect to Kambija and Koderobara sites, the correlations were positive and linear. However, the correlation at Kambija site was stronger ($R^2 = 0.67$) than that at Koderobara site ($R^2 = 0.39$). Similar findings had been reported by Onyango, (2013) who in her study found a positive linear correlation between maize yield and exchangeable bases (Ca, Mg and K) of $R^2 = 0.82$.

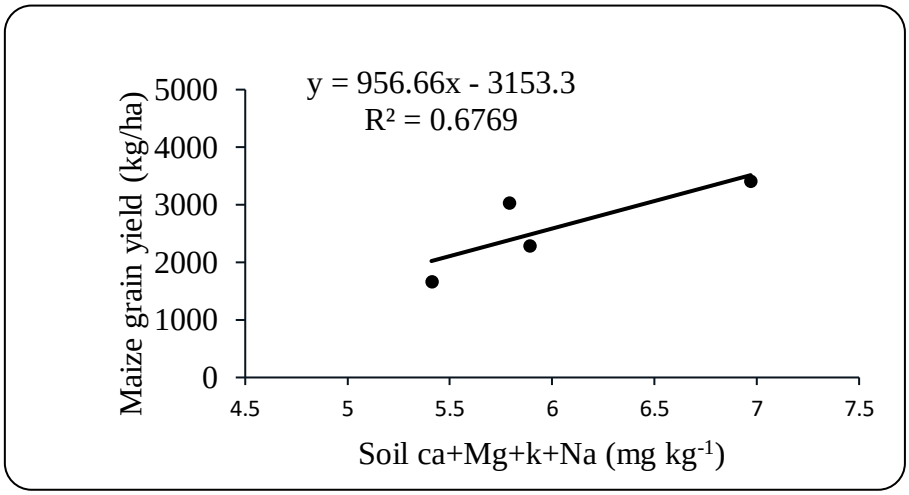

Figure 4.9: Relationship between mean maize yield and exchangeable base cations at the end of the experiment at Kambija site.

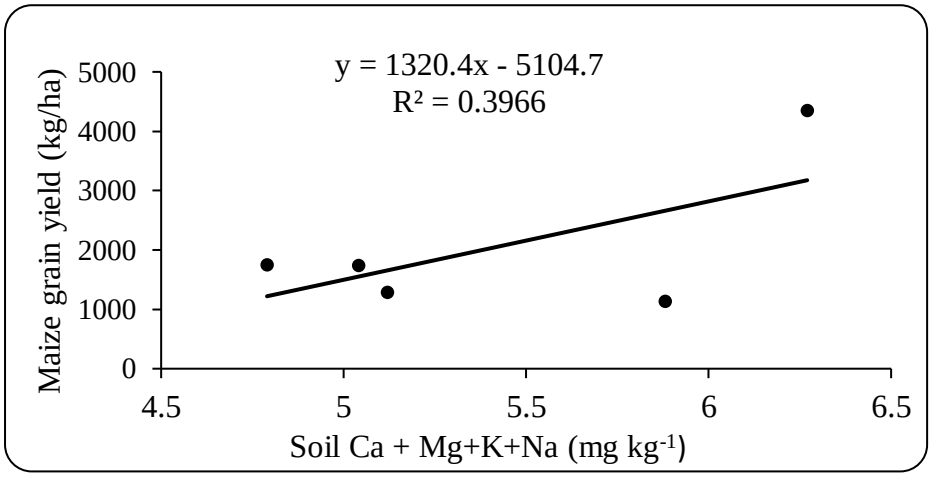

Figure 4.10: Relationship between mean maize yield and exchangeable base cations at the end of the experiment at Koderobara site.

4.7.5. Effect of treatments on microbial biomass

Table 4.14 shows the soil microbial biomass of bacteria and fungi at the beginning and end of the experiment at Kambija site in the soil depths 0-10 cm and 10-20 cm. Generally, bacteria colonies were higher than those of fungi in both soil layers and decreased with soil depth. Initial bacteria and fungi colonies counted at the start of the experiment ranged between 22.05 x 10^5 to 27.9 x 10^5 for bacteria and 10.3 x 10^4 to 13.7 x 10^4 for fungi both at 0 -10 cm depth. Whereas, at the end of the experiment for topsoil layer (0-10 cm), bacteria colonies ranged from 15.09 x 10^5 to 27.9 x 10^5 and for fungi colonies from 9.5 x 10^4 to 13.9 x 10^4. However, at the end of the experiment, bacteria and fungi colonies, increased by 1.02% and 4.10%, respectively, from the initial colonies at 75 kg N ha^{-1} both in topsoil layer (0-10 cm depth). In relation to the control, bacteria and fungi, respectively, decreased by -31.7% and -25.5% from the initial counted colonies in the 0-10 cm soil depth. Furthermore, at Kambija site at the beginning of the experiment, bacteria and fungi were not significantly different ($p \geq 0.05$) while at the end of the experiment, soil microbial biomass was significantly different ($p=0.041$) and (0.013) for bacteria and fungi respectively (Table 4.14).

Table 4.14: Microbial population as influenced by N fertilizer in soil depths (cm) before and after the experiment at Kambija

Kambija									
Depth (cm)	Treatment (kg ha^{-1})	Bacteria CFU (10^5)/g soil				Fungi CFU (10^5)/g soil			
		Before Exp.	After Exp.	% change	*t*-test, *p*	Before Exp.	After Exp.	% change	*t*- test, *p*
0-10	N0	22.05^{a}	15.06^{c}	-31.7	0.047	12.75^{a}	9.50^{ab}	-25.49	0.012
	N25	27.01^{a}	27.90^{a}	3.29	0.010	13.70^{a}	11.00^{ab}	-19.70	0.039
	N50	27.90^{a}	24.71^{b}	-11.4	0.027	10.30^{a}	12.55^{ab}	21.84	0.015
	N75	22.37^{a}	22.60^{b}	1.02	0.051	13.33^{a}	13.90^{a}	4.27	0.09
10-20	N0	5.80^{a}	6.40^{d}	10.34	0.001	6.00^{a}	6.27^{abc}	4.5	0.056
	N25	14.50^{a}	16.30^{c}	12.41	0.002	3.08^{a}	5.70^{bc}	85.06	0.008
	N50	17.62^{a}	18.80^{b}	6.69	0.003	7.22^{a}	8.67^{bc}	20.08	0.005
	N75	9.50^{a}	16.40^{bc}	72.63	0.0007	2.34^{a}	4.66^{c}	99.14	0.040
	P(value)	0.989	0.041			0.562	0.013		
	LSD	0.344	0.622			1.852	1.064		

Table 4.15 shows the soil population of bacteria and fungi at Koderobara at the start and at the end of the experiment. Like at Kambija, the soil microbial biomass (Bacteria and Fungi) at Koderobara also decreased with depth and bacteria colonies were significantly higher than those of fungi (Table 4.15) due to the fact that fungi are more sensitive and do not develop under soil acidic (Barreiro et al., 2016). The increases at treatment 75 kg N ha^{-1} were 17.6% and 11.8% for bacteria and fungi, respectively while the control made an increase of 0.54% and 40.7%, respectively for bacteria and fungi in the top soil surface layer (0-10 cm).

Table 4.15: Microbial biomass as influenced by N fertilizer rates at Koderobara before and after experiment

Koderobara									
Depth (cm)	Treatment ($kgha^{-1}$)	Bacteria CFU (10^5)/g soil				Fungi CFU (10^5)/g soil			
		Before Exp.	After Exp.	% change	*t*-test, *p*	Before Exp.	After Exp.	% change	*t*-test, *p*
0-10	N0	18.50a	18.60^{ab}	0.54	0.024	4.03a	5.67a	40.69	0.0028
	N25	24.23a	24.43^{b}	0.82	0.001	5.75a	5.86a	1.91	0.032
	N50	25.67a	24.50^{b}	-4.55	0.042	6.00a	6.39a	6.5	0.001
	N75	21.50a	25.30^{a}	17.67	0.005	5.66a	6.33a	11.83	0.018
10-20	N0	13.30a	13.39^{ab}	0.67	0.008	2.37a	2.17^{c}	-8.43	0.0090
	N25	11.40a	12.53^{ab}	9.91	0.036	4.64a	4.68^{b}	0.86	0.0025
	N50	12.67a	13.40^{ab}	5.76	0.0044	4.67a	5.60^{a}	19.91	0.0091
	N75	13.60a	10.27^{c}	-24.48	0.025	2.42a	4.33^{b}	78.92	0.022
	P(value)	0.273	0.001			0.198	0.035		
	LSD	0.166	0.301			0.112	0.512		

Based on the soil microbial colonies formed in relations with N fertilizer applied at both study sites, N fertilizer slightly increased the soil microbial populations (bacteria and fungi) at Kambija. The highest increase was observed in treatment 50 kg N ha^{-1} for both bacteria and fungi (Tables 4.14 and Table 4.15).

Similar findings had been reported by other researchers (Geisseler *et al*., 2016) who reported that applied N fertilizer increased the relative quantity of fungi in two European soils but decreased in a Swedish soil.

However, most literature indicate that there is reduction of microbial biomass when N fertilizers are applied especially urea (Roberts *et al*., 2011, Lupwayi *et al*., 2012, Cao *et al*., 2016). Cao *et al.* (2016) which has been reported to be causing significant reduction of microbial population due to high N treatment (200 kg N ha^{-1} y^{-1}) compared to unfertilized plots (0 kg N ha^{-1} y^{-1}) in China.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

From the results of this research, the major conclusions included the following:

1. Maize yields responded differently to the various N treatments. The highest maize grain yields were obtained by treatment 50 kg N ha^{-1} at both sites with fairly higher yields at Koderobara site (4.34 t ha^{-1}) than at Kambija site (3.41 t ha^{-1}). There was a positive linear correlation between mean maize grain yield and mineral N at both experimental sites

2. Regarding N concentration in plant tissues, N content at both experimental sites was not significantly different at seedling stage whereas at heading and maturity stages, N content was significantly different between the treatments also at both sites.

3. N treatment at 50 kg N ha^{-1} had the highest N use efficiency of maize grain yields (22.61) at Koderobara while at Kambija, treatment 25Kg N ha^{-1} had the highest N use efficiency (23.84). In addition, it was noted generally that NUE decreased with increased N application rates.

4. At initial stages of maize growth, available N concentrations were higher in subsoil layers (10-20 cm and 20-30 cm depth) than top surface soil layer (0-10 cm) but at heading stage, mineral N ($N{-}NO_3$ & $N{-}NH_4$) concentration appeared to accumulate in the top soil layer (0-10 cm depth) at both research sites. Furthermore, applied N treatment at 50 kg N ha^{-1} recorded higher N concentrations in the soil profile than the other N treatments at both study sites.

5. At the end of the experiment, NH_4^+, NO_3^-, P and microbial population (bacteria and fungi) significantly improved due to N fertilizer application while soil pH, NT, Mg, and SOC declined at both sites.

5.2. Recommendations

Referring to the results of this study, the following recommendations were proposed:

i. It was recommended that the farmers growing maize in Rongo sub-county to be encouraged to apply N fertilizer at the level of 50 kg N ha^{-1} which gave the best yields in the area.
ii. Proper N management practices especially with split N fertilizer application (At planting and at heading stage) is more advisable to the farmers in order to increasing plant N uptake, its use efficiency, reduce N loss and hence improve maize yields
iii. Further research should be conducted to include other macronutrients and crops in the area.

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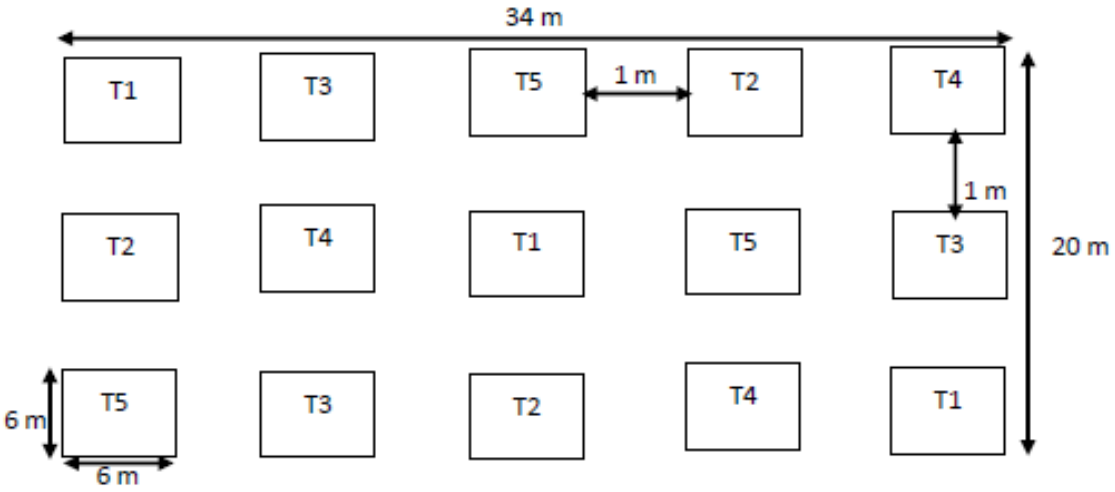
APPENDICES

Appendix I: Nitrogen treatments and its randomization

Plots size: 6m x 6m

Table 5. 1: Experiment design and treatment layout



Treatment structure	
T1	N0P0
T2	N0P10
T3	N25P10
T4	N50P10
T5	N75P10

N.B: CAN (O, 25, 50 and 75 kg ha^{-1})

TSP (0,10 kg ha^{-1})

Appendix II: Formulas

1. Available nitrogen (N)

1. Nitrate nitrogen (N-$N0_3$) and Ammonium nitrogen (N-NH_4)

$$\frac{(\text{mL HCl sample} - \text{mL blank}) \text{ x N of HCl x } \frac{0.014\text{g N}}{\text{meq}} \text{ soil sample size (g)}}{1} \text{X} \left(\frac{\text{mL of aligot}}{\text{mL of extract}}\right)$$

2. Soil total Nitrogen

$$\% \text{ Total N in soil} = \frac{(\text{mL HCl sample} - \text{mL blank}) \text{xN of HCl x } 0.014\text{g N/meq}}{\text{soil sample size (g)}}$$

3. Calculation of the microbial population (bacteria and fungi) in the soil

$$\text{CFU/g of soil} = \frac{(\text{Number of colonies}) \text{ x (Dilution factor)}}{\text{Volume of culture plated}}$$

4. **Determination Agronomic fertilizer use efficiency (AE)**

AE_N = kg grain yield increase per kg of N applied

AE= (yf – yc)/Na

Where:

Yf = yields from fertilized plots (kg/ha)

Yc = yields from unfertilized plots

Na = quantity of nutrients applied (kg/ha)

Appendix III: Maize grain yields laboratory methods used

The method utilized to determine maize grain yields was:

a. Method 1

- During harvesting, maize grain was harvested from each harvest area of each treatment and shelled and packed 1kg in labeled bags
- Sample maize grains were dried in an oven at 105ºC for 48hours until a constant weight at a moisture content of 12.5%. Then, the dry weight of maize grains was weighted using an electronic balance
- Maize yields were then calculated based on dry weight obtained

b. Maize grain yields and dry maize weight ($kgha^{-1}$)

$$\text{Maize yields } (kgha^{-1}) = \frac{(\text{Maize fresh weight} - \text{Subsample dry weight}) \text{x } 10000}{\text{Subsample fresh weight x area harvested}}$$

Appendix IV: Laboratory methods used for soil and plant tissues analysis

Table 5. 1: Laboratory methods used for soil and plant tissues

SOIL PROPERTIES	METHOD USED	EQUIPMENT USED
pH water	1:2.5 (soil: water)	pH meter
pH KCl	1:.25 (soil: KCl)	pH meter
Soil total N	Kjeldahl digestion method	Digester & Distiller
Plant total N	Kjeldahl digestion method	Digester & distiller
Available N	Kjeldahl digestion method	Digester & distiller
Soil organic carbon	Colorimetry method	UV/Vis spectrophotometer
Available P	Colorimetry method	UV/Vis spectrophotometer
Cations (Mg & Ca)	Mehlich 1 method	AAS spectrophotometer
Cations (K & Na)	Mehlich 1 method	Flame spectrometer
Soil texture	Hygrometry method	Hygrometer
Soil microbial colonies (bacteria &fungi)	Dilution plate counting method	Colony counter

Appendix V: Soil textural triangle

Figure 5.1 1: Pyramid diagram showing soil types