EVALUATION OF NUTRIENT MANAGEMENT FOR IMPROVED NITROGEN USE AND AGRONOMIC EFFICIENCIES IN RICE (*Oryza sativa L.*) IN KISUMU, BUSIA AND KIRINYAGA COUNTIES, KENYA

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A144/32872/2015

A Thesis Submitted in Partial Fulfilment of the Requirements for Award of the Degree of Master of Science in Agronomy in the School of Agriculture and Enterprise Development, Kenyatta University

November, 2018

DECLARATION

This thesis is my original work and has not been presented for any degree or award in any University

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DEDICATION

To my lovely parents Sebastian Gitonga and Jane Inoti, my two brothers Festus Gitonga and Laban Murithi

ACKNOWLEDGEMENT

I wish to register my sincere and heartfelt gratitude to my supervisor Dr. Joseph Onyango Gweyi from the Department of Agricultural Science and Technology, Kenyatta University for his inspiring guidance, scholarly comments, positive criticism, encouragement and constructive suggestions throughout the course work and research. Dr. Cargele Masso from International Institute of Tropical Agriculture (IITA) for his encouragement, guidance and support during the fieldwork. I thank them most sincerely for dedicating their time and effort to make me complete this course within the shortest time possible.

I acknowledge International Institute of Tropical Agriculture (IITA) through the support of International Nitrogen Management System-(INMS) project for partially financing the research work.

I thank Kenyatta University, especially the Department of Agricultural Science and Technology, for the support and scientific guidance during course work and presentation of the findings. Special thanks to my family for support, prayers and patience during the study period. Above all, I thank Almighty God for giving me knowledge, patience and strength to accomplish this work.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of variance
ATP	Adenosine Triphosphate
FAO	Food and agriculture organization
H_2SO_4	Sulphuric acid
N	Nitrogen
NADPH	Nicotinamide Adenine Dinucleotide Phosphate
NaCIO	Sodium hypochlorite
NAE	Nitrogen Agronomic Efficiency
NO_3-	Nitrate
NO_2–	Nitrite
NH_4^+	Ammonium
NUE	Nitrogen Use efficiency
SPSS	Statistical Package for social Sciences
SAS	Statistical Analysis for Sciences
UNECE	United Nations Economic Commission for Europe

ABSTRACT

Nitrogen is a major mineral nutrient limiting growth, development and production of crops in Kenya. The cost of production is way beyond the purchasing power of smallholder farmers, coupled with the low availability of nitrogen in the soil has significantly contributed to the reduction in rice productivity in Kenya. In rice growing regions, including Busia, Kisumu and Kirinyaga counties, there is evidence of pollution due to high losses of N experienced from agricultural fields. Reduction of the losses through proper N management is critical to ensure increased yield and reduced pollution rates of through promotion of good agricultural practices. Therefore, the objectives of this study were to:-(1) analyze farmer's practices that contribute to nitrogen losses in rice farming fields, (2) evaluate growth and yield of irrigated rice in response to methods of N applications, forms and levels, (3) determine nitrogen partitioning and nitrogen uptake as affected by levels of nitrogen sources and methods of application and (4) determine nitrogen use efficiency (NUE), nitrogen agronomic efficiency (NAE) and nitrogen harvest index (NHI) of irrigated rice under different levels of N sources. The studies were conducted through survey and field experimentations. The surveys were conducted in Kisumu and Busia counties, where 100 farmers were interviewed. The field experiments were conducted at Ahero irrigation scheme in Kisumu county and KALRO Mwea in Kirinyaga county. Field experiments were laid out in Randomized Complete Block Design (RCBD) in factorial arrangements. The treatments included two sources of N as ammonium sulphate [$(NH_4)_2SO_4$] and urea at three levels (0, 25, and 50kgha^{-1}) applied in two methods (full dose and split). Survey data was subjected to SPSS software while the field data were subjected to ANOVA using SAS software and statistical differences were separated using Fischer's LSD at 5% level of probability. The survey revealed that $(NH_4)_2SO_4$ was most commonly used form of fertilizer in both Kisumu and Busia (61% and 48% respectively). Burning and feeding to livestock were the leading N loss pathways farmers were aware of, with 32%, 34% stating that they burned the straws in Kisumu and Busia respectively while 39% and 40% fed to livestock in Kisumu and Busia respectively. N sources and levels led to increased days to 50 % flowering that significantly varied across the treatments, with the unfertilized plot taking the shortest duration (64 and 97 days in Ahero and Mwea respectively). Ammonium sulphate (50kgha^{-1}) led to highest yields in Kisumu and kirinyaga (11.2 t ha^{-1} and 7.90 t ha^{-1} respectively) while the control had the lowest. Significant differences were observed on uptake during different growth stages ($p \leq 0.05$), with a higher N uptake being observed during reproductive and harvesting stages in both study sites. In all treatments, highest N was partitioned to the grain. The $(NH_4)_2SO_4$ (25, kg ha^{-1}) revealed balanced NUE in both study sites recording 73.15 and 90.10 in Kisumu and Kirinyaga counties. In Ahero, $(NH_4)_2SO_4$ at 50 kgha^{-1} and Urea at 50 kgha^{-1} exceeded 100% of the normal NUE, recording 120.6 and 146.5 respectively. This was an indication of excessive soil mining by the plants at this particular stage. In regard to NAE $(NH_4)_2SO_4$ at 25kgha^{-1} and urea 25kgha^{-1} at Ahero and Mwea resulted in higher value of 21.53 and 12.90 respectively. In conclusion, farmer's straw management practices was thought to contribute N losses in farming systems. $(NH_4)_2SO_4$ at 50kgha^{-1} led to highest yield in both study sites. Further studies, need be carried out on nitrogen forms on NUE and NAE on long-term conditions.

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Nitrogen (N) is a nutrient that forms an integral part of crop growth and productivity. It is also considered as the most abundant nutrient in the earth's crust, taking approximately 78% in the atmosphere (Elbert *et al.*, 2012). However, the N must be converted into forms that can be absorbed by the plants to enhance various growth processes. Main forms in which N is taken up by the plants roots include Nitrate (NO_3^-) and Ammonium (NH_4^+). Most of the nitrogen available for plant growth is from soil through the fixation and conversion, enhanced by the nitrogen cycle (Zuliang *et al.,* 2012). Some reports also show that crops uptake nitrogen from the soil by absorption through their roots as amino acids, nitrate or ammonium ions (Kielland, 1994, Gioseffi *et al.,* 2012). In addition, if nitrate is taken up, it is first reduced to nitrite ions and then ammonium ions for incorporation into amino acids, nucleic acids, and chlorophyll (Galloway *et al.*, 2008). Importantly, most nitrogen obtained by terrestrial animals can be traced back to the eating of plants at some stage of the food chain. Irrespective of N form that is naturally available in the ecosystems, most of the agricultural farming systems strive to increase use of N fertilizers to boost the rate of growth and assure increased yields (Follett, 2012). The injudicious rates of N fertilizer have the ability to cause poor N efficiency; leaching losses and ammonia volatilization (Fageria and Baligar, 2005). Over the decades, nitrogen loss to the environment has been a primary concern (OECD, 2008). This is probably due to increased fertilizer use, which has increased rapidly since the 1990s worldwide, which has led to a rise in N losses to the environment (Dinnes *et al*., 2002).

Excessive application of N fertilizers affects the growth of the plants through arresting of some major process such as photosynthesis and chlorophyll formation (Russell *et al.*, 2006). On the other, little application of N leads to retarded plants and thus leading to poor productivity. Agriculture being the cornerstone to enhancing food security, there is need to develop approaches to enhance management of N in order to improve production while reducing losses that cause pollution. Partial Nitrogen budget is another essential tool that can be used to determine the extent of losses of N applied in the cropping systems (Jin *et al.*, 2012). It gives an account of all nitrogen inputs applied and output removed in the agricultural setting (Leip *et al*., 2014).

Rice (*Oryza sativa*) is the third most important crop in the Kenya as it forms part of the diet and the economy (Seck *et al.*, 2012). Yields range from less than 1 t/ha under very poor rainfed conditions to more than 10 t/ha in intensive temperate irrigated systems globally. Both white and brown rice in the world substitutes 20% of the dietary energy supply. Besides, it is a crop with health benefits and thus becomes important in the diet. In the world, there is an increasing population, and thus rice serves as one of the sources of diets to prevent malnourishment (Ray *et al.,* 2013). It is cultivated in both upland and swamp ecosystems. Regardless of its demand, there is a limitation to enhance full capacity of production. A major limitation of the yield increase is nutrient availability, more specifically nitrogen (Ladha *et al*., 2016). Nitrogen plays a key role in ensuring a successful vegetative growth and reproductive contribution towards the grain filling and thus assuring high yields (Awan *et al*., 2015).

Nitrogen use efficiency (NUE) is defined as a ratio of the amount of N obtained from the field by the crop to the amount of N applied during the growing period (Cassman *et al.,* 2002). The NUE provides a numerical measure of the usefulness of plants to absorb and transform available N into potential yield under different cropping systems. In Africa specifically, N removal with crop production permanently exceeds the N input with mineral fertilizer. This means that almost two decades ago 40% more nitrogen was being removed from the agricultural system in Africa than what was being replaced by mineral N fertilizer ((Fathi, 1998). Therefore, there is need to develop a model for which N will be applied to enhance nutrient balance (Fathi, 1998). Previous research on NUE in crop production systems has emphasized the need for greater synchrony between N required by the crop N supplied from various sources throughout the growing season (Hamidi, and Dabagh, 1995).

Nitrogen Agronomic Efficiency (NAE) is another important indicator in terms of nitrogen management and is described as the N accumulated in the above-ground part of the plant or the nutrients recovered within the entire soil-crop-root system (Wortmann *et al.,* 2016). To prevent N loss, there has to be a balance of the nutrient applied at different stages of plants during plant growth. Thus NAE is a good indicator of the amount of nutrient recovered in various cropping systems.

1.2 Problem Statement

Currently, effects of nitrogen losses to the ozone layer are profound as it plays a critical role in catalyzing and destroying the stratosphere. Nitrogen loss is a major threat in rice cropping systems in Sub-Saharan Africa (Kayombo and Jorgensen, 2006). This has caused a reduction in yields due to limited potential for growth in crops. Specifically, rice production has been limited in these areas due to low levels of nitrogen available during various growing stages (Özkan , 2007). This is a problem that has been attributed to various sources of N loss such as denitrification, leaching, and volatilization. Rice has the potential of higher losses to the environment due to increased rates of emissions and leaching in flooded regions (Rose *et al.,* 2018, Raun and Johnson, 1999), and this varies with different stages of development. The resultant emissions contribute to increment in environmental pollution. The pollution could result from the depositions and other sources, especially leaching into the water bodies (Schlegel *et al.,* 1996). The amount of N that is lost through leaching is not quantified and thus makes it difficult to manage pollution as well as improving crop yields.

According to FAO (2000), nutrient balance is key to enhance food security among the world’s population. Incidentally, the N lost in the farmers’ fields finds its way to the Lakes or any other neighboring water bodies, thus contributing to the massive growth of the algae and consequently algal bloom. This hinders fishing activities which is the main economic activity embraced by the population within the lake regions (Liu *et al.,* 2014). Besides, the aquatic life is also uninhabited due to limited oxygen because of nutrient (N) loading in water bodies (Bouraoui and Grizzetti, 2014). Therefore, to minimize losses, there is need to develop Nitrogen use efficiency for the region to reduce the losses and promote good practices for increased productivity. The established NUE does not apply in Kenya, for instance and other African countries in general due to the difference for nitrogen in the ecosystem (Brentrup and Pallière, 2010). Additionally, there is need to calculate the partial N budget for rice in the region to understand the pathways of nitrogen loss during production. Understanding Nitrogen agronomic efficiency is also essential for maintaining nutrient balance. In this light, there is a balance between the amount of N required by the plant for optimum growth while reducing the nitrogen that is carried to ground and surface waters. This is a major constraint for researchers attempting to understand and improve agricultural nutrient use efficiency.

1.3 General objective

To evaluate nitrogen and agronomic efficiencies of applied Nitrogen to improve rice crop productivity

1.3.1 Specific objectives

i. To analyze farmers’ practices contributing to nitrogen losses in rice farming systems
ii. To evaluate growth and yield of irrigated rice in response to different methods of N application under various levels of nitrogen forms.
iii. To determine the uptake and partitioning of nitrogen in irrigated rice in response to N application methods, sources and levels based on the local farmers’ practices

iv. To determine Agronomic Use Efficiencies, Nitrogen Use Efficiencies and Nitrogen Harvest Index (NHI) of rice cultivated with different methods of applications of N sources and levels.

1.4 Research questions

i. How do factors related to farmer practices on Nitrogen use and management contribute to increased losses and pollution?

ii. Do application methods and nitrogen forms at different levels have any effect on growth and yield development of rice?

iii. Are there differences in nitrogen uptake and partitioning in irrigated rice in response to forms, levels and methods of Nitrogen fertilizers?

iv. Do nitrogen levels and forms have effect on Agronomic Use Efficiencies, Nitrogen Use Efficiencies of irrigated rice?

1.5 Hypotheses

i. There are no significant differences in growth and yield of rice under different levels, forms and application method of N fertilization
ii. Methods and different levels of N forms have no effect on nitrogen uptake and Partitioning at different stages of rice growth
iii. There are no significant differences in nitrogen forms and levels on the effect of Agronomic Use efficiencies, Nitrogen Use efficiencies and Nitrogen Harvest Index of irrigated rice

1.6 Significance of study

This research work aimed at generating more knowledge on the management of nitrogen in irrigated rice farms. Data obtained are envisaged to provide deeper scientific understanding of the N cycle through identification of possible pathways that contribute to losses. Rice production will be increased due to a better understanding and consequent realization of higher NUE. High losses have been documented in the region, and this lead to little available N for crop production. The farmers' practices leading to poor management of nitrogen were identified, and recommendation to enhance change and improvement generated. Therefore, N cycle management in the farming fields will be improved, implying reduction in the losses through leaching or seepage into the water bodies. The quality of water in the surrounding communities will be improved and thus promote the alternate source of livelihood. Thus, the levels of poverty among the population will be reduced by a greater percentage. Besides, the establishment of NUE for the region will reduce the cost of production hence increasing levels of incomes. Importantly, findings derived from this study will be disseminated to extensions and policy makes to emphasize on the right criterion to use so as to enhance management of N. Establishment of partial N budget for different levels of nitrogen for crops applied with N will lead to improved efficiencies of nutrient management hence reduce pollution to greater levels.

1.7 Conceptual framework

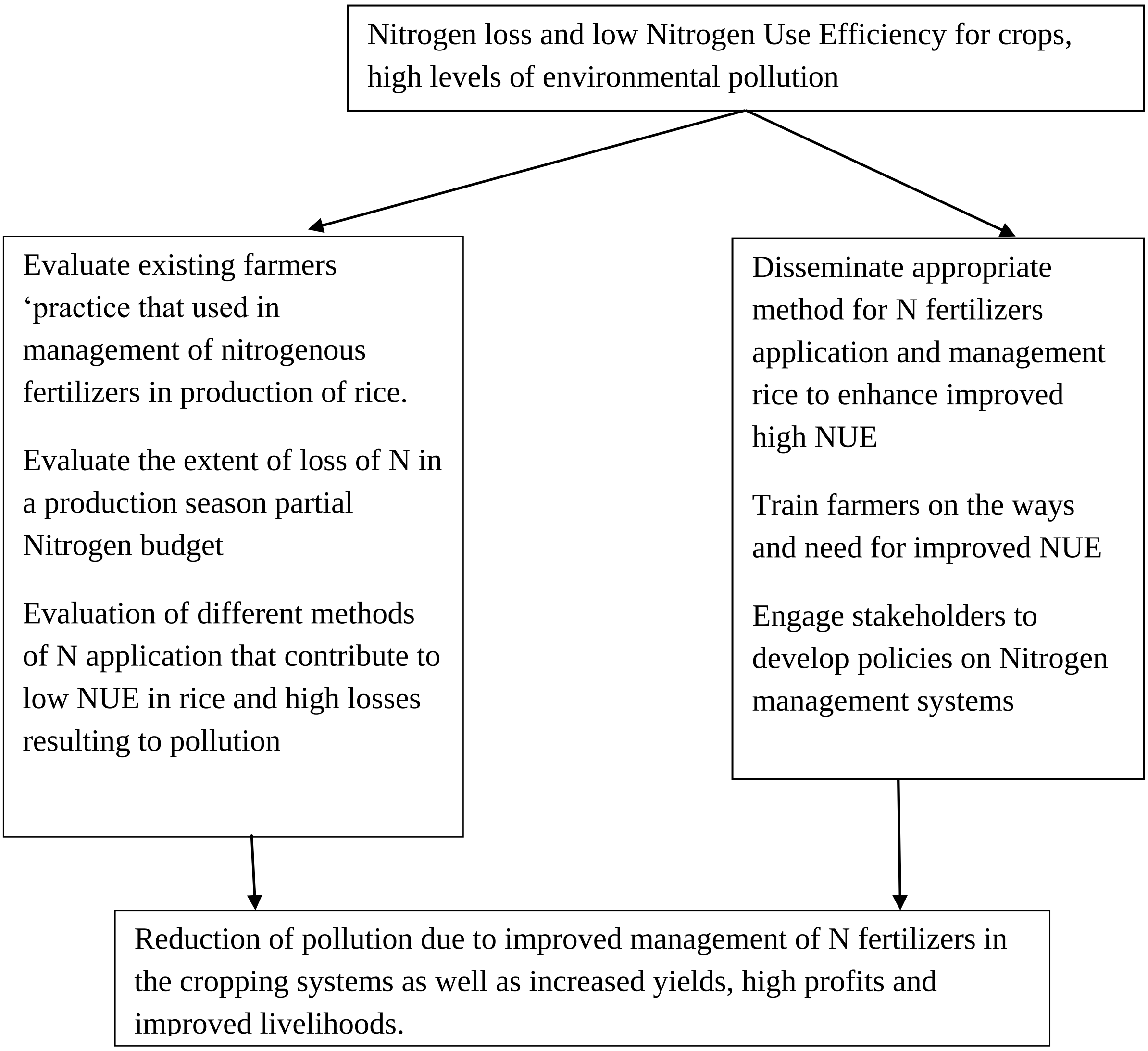

Figure 1.1 Conceptual framework

CHAPTER TWO: LITERATURE REVIEW

2.1 Nitrogen Dynamics

Nitrogen (N) makes up 78 percent of atmospheric gaseous form of nitrogen (N_2). However, this form is not available for utilization by plants. Approximately, 34,000 tons of N is available in the atmosphere but cannot be utilized by crops for growth (Tischner, 2000). It must be fixed in order to become available, which is done through the process of producing industrial fertilizers or through nitrogen-fixing bacteria associated with the roots of legumes (Yang *et al.,* 2012).

Nitrogen is a crucial but limiting element for plant growth and production. Nitrogen is important for the assimilation of carbohydrates in the plant and plays an important role in root growth for the absorption of other essential minerals including K and P. It is a key component of chlorophyll, an essential pigment needed for photosynthesis, as well as amino acids; the key building blocks of proteins (Galloway *et al.,* 2008, Foyer and Noctor, 2006). It is also found in other important biomolecules, such as Adenosine Triphosphate (ATP) and nucleic acids. The path that N follows in and out of the soil system is referred to as the "nitrogen cycle" (Warren, 2014). This cycle is usually influenced biologically through useful microorganisms (Galloway *et al,* 2004). In addition, biological processes, in turn, are influenced by prevailing climatic conditions along with the physical and chemical properties of a particular soil. Organic nitrogen is found mostly in living and previously living material in the soil (Yang *et al.,* 2012). Nitrogen is naturally available in the soil as organic matter, which is mineralized, resulting in approximately 60–80 pounds of N per acre in annual basis for plant utilization

(Mason, 2007). Two forms of inorganic nitrogen that are readily available for plants are plant available are ammonium (NH_4^+) and nitrate (NO_3^-).

2.2 Nitrogen Cycle

Nitrogen cycle describes all the processes through which N undergoes to be converted into various forms. The conversion can be done either through the physical or biological process in different ecosystems where it circulates including; terrestrial, marine and also in the atmosphere (Pelletier and Leip, 2014). Processes of importance in this include ammonification, fixation, nitrification, and denitrification (as illustrated in figure 2.1)

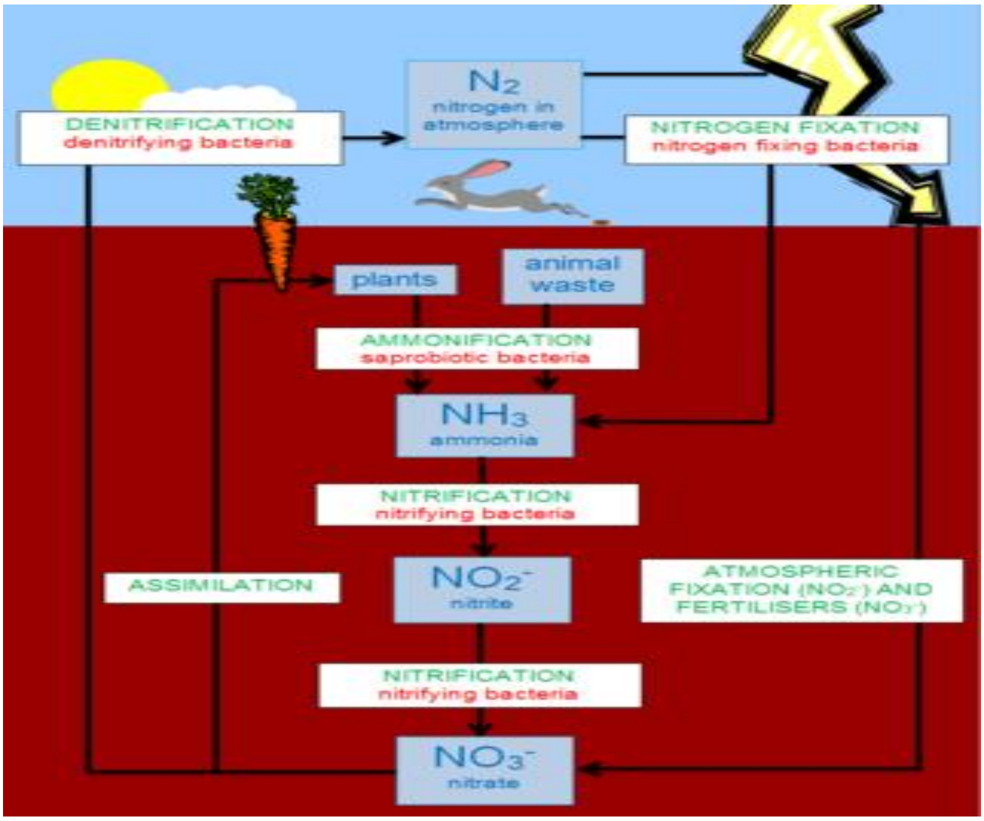

Figure 2.1: Flow chart showing the pathways of N cycle (source: Galloway *et al.*, 2008).

Chemical forms of nitrogen present in the environment include organic nitrogen, ammonium, nitrite, nitrate, nitrous oxide, nitric oxide or inorganic nitrogen gas (Galloway *et al.,* 2008, Jones, 2016). In addition, organic nitrogen may be in the form of a living organism, humus or in the intermediate products of organic matter decomposition (Farrell *et al.,* 2014). Many of the nitrogen cycle processes are performed by living organism, through their effort to acquire energy or to harvest nitrogen in a form needed for their growth (Santi *et al.,* 2013).

In biological fixation, symbiotic bacteria known as diazotrophs are major free-living organisms that carry out the process of nitrogen fixation (Geddes *et al.,* 2015). The fixation process involves conversion of free nitrogen atoms from their triple bonded atomic form, N≡N, to be used in other ways (Hoffman *et al.,* 2014). There is also presence of nitrogenase enzyme in the bacteria that catalyzes denitrification of nitrogen to ammonia (Burns and Hardy, 2012). Symbiotic nitrogen-fixing bacteria like rhizobium establish a mutualistic relationship with legumes to facilitate nitrogen fixation. The bacteria benefit with carbohydrates as they provide the plants with nutrients. In addition, little amount of nitrogen is 'fixed' through a process of high energy fixation that occurs majorly as lighting strikes, converting atmospheric nitrogen into ammonia (NH_4^+)and nitrates (NO_3-) (Fowler *et al.,*2013). Nitrogen can also be fixed through man-made processes, like the Haber- Bosch industrial processes that create ammonia and nitrogen-rich fertilizers (Nancharaiah *et al.,* 2016).

Assimilation is also another process in the nitrogen cycle of plants from the soils. During this process N is taken up as nitrates, and then to ammonium that is incorporated into amino acids, chlorophyll and other proteins (Masoni, 2007).

Ammonification is also another important component of nitrogen cycle, which is a product of decomposition of plants into wastes. For instance, when plants die, the organic N is converted by micro-organization to inorganic ammonium states. Some of the enzymes involved include; ’GlnSynthetase (Cytosolic and Plastic), GOGATGlu 2-oxoglutarate aminotransferase (Ferredoxin and NADH-dependent) and GDH: Glu Dehydrogenase. However, different plants have unique pathways through which they take up such compounds into the metabolic pathways and growth process (Hanke and Mulo, 2013).

Nitrification process also forms a major step in the nitrogen cycle. In this process ammonium is converted to nitrite and then to nitrate by soil- living organisms, collectively known as nitrifying bacteria, like the *Nitrobacter* (Schlesinger *et al.,* 2006). Possible reason for ammonium conversion into nitrates is due to the toxicity of the ammonia gas to the crops (Canfield *et al.*, 2010). However, this process contributes greatly to eutrophication in water bodies due to huge losses associated with high amounts of nitrates in the soils. Therefore, in flood zones, this proves to be real problem to both farmers and the users of these water bodies. Denitrification is yet another key process in the nitrogen cycle (Luo *et al.,* 2000). In this step, nitrate is reduced back to the nitrogen gas through use of organisms such as *Pseudomonas* and *Clostridium* species. In addition, this process only takes place in the anaerobic conditions such as water-logged conditions (Fanning, 2000).

2.3 Nitrogen uptake and assimilation in plants

Uptake of nitrogen by crops constitutes several steps, including uptake, assimilation, and translocation during growth and when a plant is aging, recycling and remobilization occurs. The preferred form in which N is taken up by the plant is dependent on its adaptations and the soil conditions (Ashton *et al.,* 2008). Crops that grow in low pH conditions tend to take up ammonium or amino acids, while on the other hand, in higher pH levels and aerobic conditions soils nitrate is commonly preferred (Masclaux-Daubresse *et al*., 2010). Uptake of nitrate takes place in the roots where two-nitrate transport systems establish a co-existence relationship to enhance uptake of nitrate from the soil solution and distribute it within the whole plant. Ammonium ions are taken up by ammonium transporters, and nitrates are taken up by various nitrate transporters that are powered by a proton gradient (Masclaux-Daubresse *et al*., 2010). Nitrogen transportation occurs from the root to the shoot via the xylem in the form of nitrate, dissolved ammonia and amino acids. Most of the nitrate reduction is carried out in the shoots while the roots reduce only a small fraction of the absorbed nitrate to ammonia (Uscola *et al*., 2014). The absorbed and synthesized ammonia is incorporated into amino acids via the glutamine synthetase-glutamate synthase pathway. Nearly all ammonia in the root is incorporated into amino acids at the root itself, significant amounts of ammonium ions are transported in the xylem and fixed in the roots (Garma and Bloom, 2014). This may help avoid the transport of organic compounds down to the roots just to carry the nitrogen back as amino acids.

Nitrate reduction in the plant takes place in two major steps. Nitrate is first reduced to nitrite (NO_2^-) in the cytosol by nitrate reductase and nitrite is then reduced to ammonia in the chloroplasts by a ferredoxin-dependent nitrite reductase (Hanke and Mulo, 2013). In photosynthesizing tissues, it uses an isoform of ferredoxin that is reduced by Photosystem 1 while in the root it uses a form of ferredoxin that has a less negative midpoint potential and can be reduced easily by Nicotinamide Adenine Dinucleotide Phosphate (NADP) (Hanke and Mulo, 2013). In non-photosynthesizing tissues, Nicotinamide adenine dinucleotide phosphate is generated by glycolysis and the pentose phosphate pathway. Glutamine synthetase incorporates ammonia as the amide group of glutamine using glutamate as a substrate in the chloroplasts (Lea, 2014). Glutamate dehydrogenase does not perform a direct role in the assimilation, instead it protects the mitochondrial functions during periods of high nitrogen metabolism and takes part in nitrogen remobilization

2.4 Nitrogen use efficiency and agronomic efficiency

Nitrogen use efficiency (NUE) is described as dry matter accumulation per unit of nitrogen applied (Fageria and Baligar, 2005). Thus, NUE idea delivers a numerical measure of the usefulness of plants to absorb and transform available N into potential yield under different cropping systems (Huggins and Pan, 2003). In addition, it provides information about the utilization of additional N applied to an agricultural production system of a country or a region (Fageria and Baligar, 2005). The two major components of NUE are the efficiency of absorption (uptake) and the efficiency with which the N is utilized to produce grain. Suitable N application rates and timing are practices for fulfilling plant requirements and enhancing NUE (Samonte *et al.*, 2006). The NUE has lately gained increasing importance in agro-environmental policies, e.g. the revised United Nations Economic Commission for Europe (UNECE) Gothenburg Protocol and thus shows the need for assessment in various cropping systems such as irrigation and crop rotation (Dalgaard *et al.*, 2017). Higher use of artificial fertilizer may result in soil and environmental pollution like eutrophication (Abril *et al.,* 2007). Crop rotation, soil edaphic features, temperature, soil water, N fertilizer rates and crop types affect NUE (Halvorson *et al.,* 2002).

According to Halitligil *et al.,* (2000) and Thomas *et al.* (2007), plant NUE is affected by nitrogen fertilizers in semi-arid and variable rain-fed situations. Globally, the NUE for cereals has been determined and has been estimated to be 33% (Brentrup and Pallière, 2010). This implies that there is 67% of nitrogen applied to the farms that goes to wastes through other sources. Therefore, NUE is an effective tool to increase nitrogen for production while reducing losses that have harm to the environment. From the N cycle, it is apparent that losses are exported from the agricultural products as well as the environmental losses, which are unavoidable. Theoretically, without any N losses to the environment, NUE of 100% would be ideal, since the inputs would exactly match the outputs (Carranca, 2012). Practically, this is not possible since agriculture takes place in an open environment with a continuous exchange of nutrients between the environmental compartments such soil, water and air (Berendse and Aerts, 1987). Therefore, losses of N are unavoidable since crops do not require all the nutrients that are cycled in the agricultural system. For instance, in cases where application rate of 96 kg N/ha and the removal in grain is almost the same 92 kg N/ha, the resulting NUE is 96% (Brentrup and Pallière, 2010). The NUE values of 90-100% show risk of soil mining, since the applied N demand for roots and straw, are not achieved by N input. Importantly, there are also unavoidable losses for example due to leaching during the off period are not compensated (Raun, and Johnson, 1999).

In Africa N removal with crop production has been reported to permanently exceed the N input with mineral fertilizer (Rahimizadeh *et al.,* 2010). The development shows that NUE even further increases over time from 120% to about 140% (Brentrup and Pallière, 2010). This implies that today 40% more nitrogen is removed from the cropping system in Africa than what is replaced by mineral N fertilizer. On the contrary to other places like China, NUE has shown decrease from about 50% in 1987 to less than 40% in 2006 ((Yuan *et al.,* 2018).This corresponds with increasing crop production but even more increasing N application rates. Moreover, in Europe NUE increased from around 40% in 1987 to more than 60% in 2006, mainly due to improved agricultural practices (Carranca, 2012). The world mean NUE remained relatively stable at 50-55% between 1987 and 2006. It is also clear that lately, NUE has already gained increasing importance as an agro-environmental indicator (Asplund *et al.,* 2014).

2.4 Rice production in Kenya

Economically, rice (*Oryza sativa* L.) is a major source of income and most popular cereal crop in Kenya as it feeds the majority of the country's population. According to reports by (FAOSTAT, 2018) it was classified as the most important food crop depended on by over 50% of the world population for food needs. It is considered the third most important staple crop in the Kenya after maize and wheat (Atera *et al.,* 2018). Most of the consumed rice in Kenya is imported from the Far East, where Pakistan accounted for 74 percent of total amount during the period 2006-2010 (FAO (2013). Rice does well various environments such as lowland, irrigated through flooding and upland rice that diversifies the region in which it can be grown Kenya. However, the highest percentage is produced under irrigation and thus can only be grown in swampy areas. The country has a potential of about 540,000 hectares of irrigable land and 1.0 million hectare rain fed for rice production (Atera *et al.,* 2018). Major growing areas of rice include Mwea, Ahero, Pekerra, Bunyala and some individual few private farms. -

2.5 Role of nitrogen in rice

Nitrogen, among other nutrients, is the most essential and the most limiting element in rice growth. It promotes carbohydrate accumulation in culm and leaf sheaths in the pre-heading stage and grain and also at the ripening stages (Sabbagh *et al,* 2015). However, the positive impacts only occur when applied at the required time or stage, especially during different intervals of irrigation so that yield can optimized. For instance, optimal use of the available nitrogen by rice increased the formation of tillers which is an indication of higher yields (Yosef, 2012). Grain filling is also another aspect that is highly influenced by the availability of nitrogen in the crop during reproductive stage (Artacho *et al.,* 2009). Limitation of nitrogen in the growth period leads to reduced accumulation and hinders grain from filling and hence increases the number of unfilled grain which leads to reduced accumulated yields (Thuy *et al.,* 2008).

Nitrogen remains the most difficult nutrient to manage, especially in irrigation for the case of rice (Samonte, 2006). This nutrient at times acts differently depending on the forms, with nitrate and ammonium being dominant, hence making its use and application more difficult (Fageria and Baligar, 2001). In some reports, it is documented that, nitrogen application efficiency is less in non-submerged irrigation compared to submergence condition. According to Fageria *et al.* (2011), NUE efficiency in flooded rice is less than 50%, implying that more than half of the N applied is prone to losses either through major pathways such as volatilization of ammonia, nitrate leaching, denitrification and soil erosion or runoff (Raun and Johnson, 1999). This shows that there is need to evaluate better means of nitrogen management to reduce losses, to increase yield and minimize environmental pollution.

2.6 Nitrogen dynamics in flooded rice

Among all mineral nutrients applied as fertilizer, nitrogen is required by rice in higher quantities and is most susceptible to losses (Tilman *et al.*, 2002). At least 90% of the rice grown across the globe is grown in fields that are flooded for most of the growing season (Carrijo *et al.*, 2017). Nitrogen is usually applied in the form of broadcast into the flood water from where it is rapidly absorbed if the application is timed carefully to match the plant's demand. However, the N that is not absorbed is lost through gaseous emission. To improve the recovery, either farmers' fertilizer management must be greatly improved, and options for these are well established, or the efficiency with which the plant captures and uses N must be improved (Rowe *et al.,* 2016). Immediately after the broadcasting of fertilizer on the rice field with flood water, the concentrations of N in the flood water and soil solution near it are initially sufficiently large that rates of uptake are not limited by root properties. However, after the N in the flooded water has been exhausted, whether by uptake or gaseous loss, the crop relies on N in the soil, and there the concentration in solution is much smaller because the (NH_4^+) cation - the main form of plant-available N is adsorbed on soil clays and organic matter (Nguyen *et al.,* 2018).

Fertilizer nitrogen is applied to rice fields in the form of ammonium ((NH_4^+). or urea which is later converted to ammonium. When a rice field is flooded, the fertilizer largely remains as ammonium (Linquist *et al.*, 2006) and is taken up as ammonium. When the field is drained and the soil becomes aerobic, ammonium is oxidized through microbial processes through the process of nitrification into nitrate (NO_3^-). Nitrate is susceptible to losses in rice systems, and it disappears from the rice rooting zone within a week or two of the flooded soil (Linquist *et al*., 2006). When the field is reflooded and the soil becomes anaerobic, microbes convert a portion of the nitrate into nitrogen gas through denitrification process and later lost to the atmosphere (Buresh and De Datta, 1991).

2.7 Timing of nitrogen fertilization at different growth stages of rice

Proper timing of the fertilizer application leads to an increase in yields, reduction of nutrient loss and also reduces the extent of environmental pollution. Due to the high cost of fertilizers, application in the cropping systems needs to be timed to reduce economic losses (Zhao *et al.,* 2015). Due to nitrogen shortage, the pricing is extremely high and requires proper management specifically for the developing countries (Shimono *et al.,* 2012). Timing of N fertilizer application is therefore imperative since it promotes proper balancing of crop demand and also enhances effective management of the nutrition aspect (Hasegawa and Horie, 1997). When N is applied in a timely manner it provides the plant with an efficient way to utilize nutrient throughout the growing period of rice plants. Timing is also effective since it provides the plants with nutrients during peak growth period such as the vegetative and flowering of rice to enhance higher yields (Fageria, 2016). According to a study carried out in Japan, it was reported that increasing the concentration of N during the spikelet formation led to higher number of spikelet’s which is a measure of high yield (Hasegawa and Horie, 1997). Liu *et al.*, (2016), reported that when rice plants are supplied with sufficient amount of nitrogen during the transplanting stage it produced significantly higher yield compared to when applied to other growing stages.

Temperature of is a key factor that affects uptake of nitrogen at different stages of rice (Shimono *et al*., 2012). Low temperature in the water supplied to the rice plants at both the vegetative and the reproductive stage results in low uptake of nitrogen. Importantly, the low uptake was more pronounced during the vegetative growth than at reproductive stage (Shimono *et al*., 2012). The panicle initiation and boot stages are also the most nitrogen-demand stages based on the increased metabolism process of the plant, which is enhanced by the water temperature (Saberioon *et al.,* 2012).

Levels of N enhance the yield and the yield attribute of rice since they determine the amount of N supplied to the plant. The main aim of supplying nitrogen in different levels is to achieve a balanced nutrition for the crop demand (Shah *et al.,* 2017). Therefore, an optimal dose is critical at different times during the planting season to ensure there is no negative effect on the production. According to Anil *et al*. (2015), yield and yield parameters increase with increased rate of nitrogen up to the recommended levels. Some of these attributes include number of spikelet per hill, number of productive tillers, grain yield and straw yield. This is influenced by the demand of crop itself to meet the reproductive organs to ensure there is a maximum realization of the potential yield (Anil *et al*., 2015).

2.8 Nitrogen management and levels of nitrogen on harvest index, NUE and ANE

Nitrogen being one of the most essential mineral nutrient in the growth, reproduction and yield it requires proper management to facilitate maximum yield. In management, there is minimization of the nitrogen losses that result to pollution of the environment as well as reducing the cost of production for the farmers (Shibata *et al*., 2017). Timing of application seems to be a challenge regarding when to apply the fertilizers to improve its utilization by the crop. Taking an example of farms that have the fertigation; small application of N together with irrigation water is a way of ensuring there is maximum supply of nitrogen to the crops at different times of growth (Quemada and Gabriel, 2016). This approach is essential as it improves the NUE of the crop and thus less is lost either through leaching, volatilization or denitrification process. By supplying balanced nitrogen, the crop is able to create a balance of its needs of the nutrients requirement and thus promoting the NAE (Quemada and Gabriel, 2016). In an attempt to achieving more yields, farmers tend to use high dosage of nitrogen that end up being degraded in the soil and thus reducing the NUE (Beegle and Lanyon, 1994).

Soil testing in the agricultural field is the most beneficial aspect towards nitrogen management. This gives a rational amount of the nitrogen that is required by the crop before it is planted (Noor, 2017). Based on the soil analysis results it becomes easier to determine the right rate of dosage and thus increasing both the NAE and the NUE of the crops and consequently lead to high yields (Noor, 2017). Basal application of the fertilizers can also ensure there is an improved means of managing losses of nitrogen. This is since uptake of nutrients occurs in the roots and thus applying the nutrients close to the roots increases the uptake surface area and thus less is lost. With proper N management the NHI is also improved which is a sign of high yield due to the high amount of N accumulated in the grain (Fageria, 2014). The NHI is thus positively correlated with the method of N management including use of the adequate dosage, timing of planting and proper crop rotation practices (Fageria, 2014).

CHAPTER THREE: MATERIALS AND METHODS

3.1 The study Area

One experiment was carried out in Kisumu County which covers a total area of 2085.9 km^2 and 567 km^2 covered by the water mass of Lake Victoria. The other experiment was undertaken at Mwea, Kirinyaga County. Kisumu receives rainfall almost throughout the year and thus does not have a true dry season. It lies between latitude of 0^0 10’ to 0^0 60”N and a longitude of 34° 54' E and 59.99" W. The average temperature is 22.9 ^{0}C and an annual rainfall of between 1200 mm and 1300 mm in various locations (Figure 3.2). Mwea, Kirinyaga County on the hand is located in central parts of country. It lies between 1158 M and 5380 M above the sea level and Latitude (05^0 and 04^0 S) and Longitude (37^0 and 38^0 E) with temperatures ranging between 12^0C and 26^0C. It has both the tropical climate and the equatorial annual rainfall patterns ranges between 800-2200 mm and this influenced by its position along the equator and on the windward side of Mt. Kenya (Figure 3.1).

The research was evaluated using two approaches. The initial data collection included field survey at Busia, and Kisumu Counties of Kenya. This was carried out in June 2017. It targeted evaluation of farmers’ practices in regard to use and management of fertilizers with a special focus on timing, and methods of N application for rice farmers.

The second approach involved field experiments where trials were established in Kisumu and Kirinyaga counties.

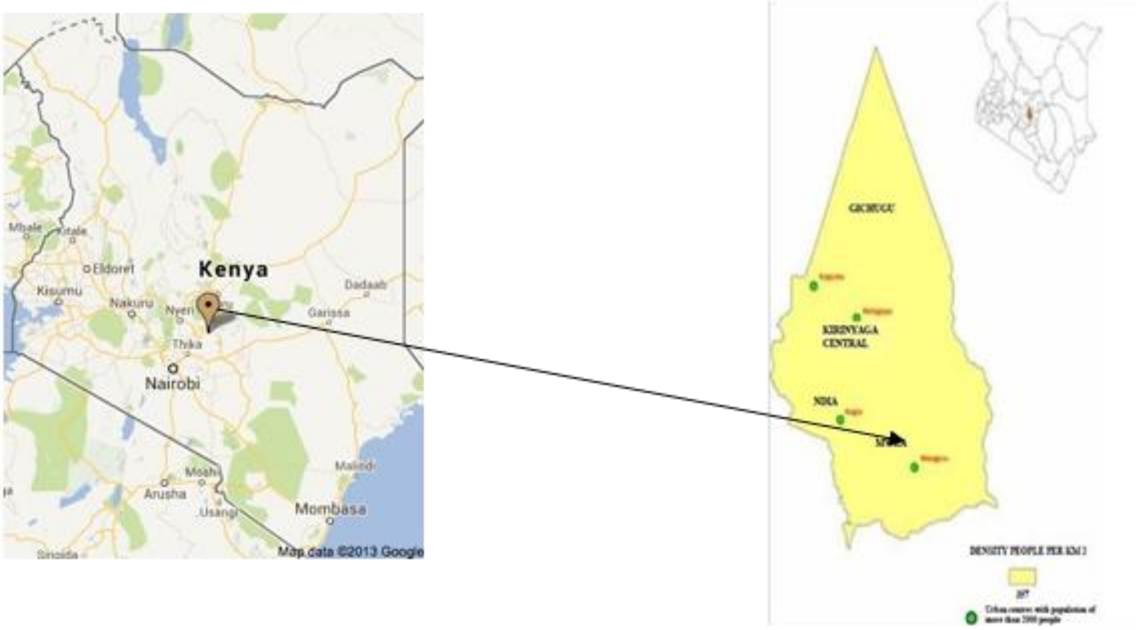

Figure 3.1: Showing Mwea experimental site in Kirinyaga County

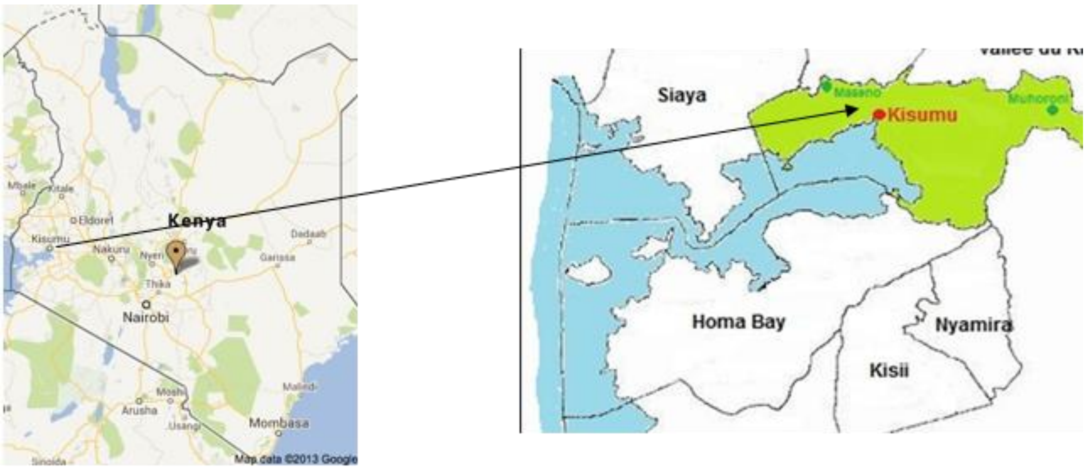

Figure 3.2: Showing Ahero study site in Kisumu County

3.2 Field Survey

Purposive sampling procedure was used to target farmers who have ventured in production of rice in Kisumu and Busia counties. The key informants for the study in the selected areas of study were agricultural officers at National Irrigation Board (NIB), farmers' group leaders and individual farmers. The questionnaire was randomly assigned to farmers growing rice. For the purpose of quantitative data, semi-structured questionnaires were administered filled through use of farmer's responses. The sample size of the farmer who were considered as the respondents was determined according to Anderson *et al*. (2007) equation:

$n= pqZ^2/ E^{2.}$ – Where n represented;- required sample size, p =estimated prevalence ,q=(1-p),.Z= level of confidence and E^2 = margin of error

From the equation a total of 100 farmers who are actively engaged in rice production were interviewed. The information collected from the farmers included; type of fertilizers used at planting, method of application, time of application, variety of rice grown, number of seasons in a year that rice cultivation took place, number of fertilizer applications in a season, watering regimes, challenges of production, and stage of crop growth during fertilization, yield, management practices of the rice straws and their perceptions on nutrient losses.

3.3 Field Experiments

This were carried out in two locations during the growing seasons between July-December 2017 in Ahero while on the other hand it was done between September 15th, 2017 and February 2018 in Mwea at NIB Kirogo research station. The experiment was laid in Randomized Complete Block Design (RCBD) in a factorial arrangement and replicated three times. The treatments included; two forms of nitrogenous fertilizers which were Sulphate of Ammonia (SA) and Urea at different levels 0, 25, and 50kgha^{-1}. There were two methods of applications; full dose and two splits. The plot sizes measured 3 m by 4 m. The IR-97 variety was used in the experiment that was sourced from National irrigation Board. Three weeks old seedlings were transplanted at a spacing (25x15) cm in the 36 plots each plot had a total of 320 plants. The fields were kept weed-free through manual weeding at different stages. Watering was done regularly and any incidences of pests and diseases were managed. Birds were managed through physical scaring while the fungal diseases were controlled using copper-based fungicides.

3.4 Data Collection

Data on growth parameters (plant height, number of tillers, and days to 50 % flowering, grain weight,) were collected for a period of 5 months in the field till harvesting. While plant samples were collected at different growth stages including vegetative, reproductive and harvesting for N analysis.

3.4.1 Growth parameters

i. Tiller Counts

The number of tillers in each experimental plot were counted at two weeks interval from 5 tagged plants and the average taken

ii. Plant Height

Plant height which was the distance from ground level to the tip of the panicle was measured using a meter rule in centimeters (cm) from 5 randomly selected plants and the average was recorded after every two weeks from 3 weeks after transplanting (WAT) till ripening stage.

iii. Dry weight

Shoots, roots, and stems of sampled plants at vegetative, reproductive and harvesting stages were dried for 48 hours at 70^0C. Weight in grams were determined using an electronic weighing balance model 6354 and recorded.

iv. Days to 50% flowering

The flowering date in each of the experimental plot was carefully observed and recorded when 50 % of the plants had flowered.

3.4.2 Yield and yield components

i. Straw weight

Soon after harvesting, the above ground biomass was cut at an area of 1m x 1m for each plot and weighed using an electronic weighing scale. This was dried for 48 hours at 70^0C. Weight in grams were determined using an electronic weighing balance model 6354 and recorded.

ii. Grain yield

Grain yield was determined after harvesting of the net plot and transformed to Kg/ha for every experimental unit. This was dried for 48 hours at 70^0C. Weight in grams were determined using an electronic weighing balance model 6354 and recorded. The moisture content was brought to 13%.

iii. Harvest Index

Harvest index for the net plot was determined by dividing grain weight by the total of the above ground biomass multiplied by 100.

3.4.3 Physiological growth stages for N analysis

(a)Vegetative Stage

Plant samples of rice were uprooted at vegetative stage, taken to the laboratory, dried, and kept for N tissue analyses. This was the period between transplanting date and panicle initiation approximately 60 days after transplanting (DAT)

(b)Reproductive Stage

The N tissue analysis was done from the time of flowering to physiological maturity of the rice this was 90 DAT

(c) Ripening Stage

This was done just before harvesting of the crops and was period from the time of planting to the time the plant leaves start turning yellow. Sample crops were uprooted and grains dried for N analysis 120 DAT.

3.4.4 Soil samples collection

Before commencement of the experiment, soil samples were collected to analyze the concentration of mineral N in soil from the experimental fields. Sub-samples of soil were collected using a soil auger in a zigzag pattern from the demarcated spots at a depth of 0-30 cm. The sub-samples were mixed thoroughly to obtain a composite sample that was air dried in ventilated room for 3 days, grounded and taken to the laboratory for analysis of initial mineral N in the soil.

3.5 Analysis of Soil Total Nitrogen

Reagents used in the analysis included; Selenium powder, concentrated sulphuric acid (H_2SO_4), Sodium citrate, sodium hypochlorite (NaOCl), sodium nitroprusside, Sodium Salicylate, sodium tartate, Potassium Permanganate and copper sulphate.

The process involved digestion and distillation according to Kjeldahl AOAC (1883). Nitrate in the soil was reduced and distilled; subsequently the samples were ground, mixed and spread through a thin layer of paper. The digestion process was carried out in batches. An amount of 0.200 grams of ground soil samples were weighed and put in the digestion tubes. One of Kjeldahl tablets was developed in each of the test-tube. Digestion tubes were placed in a block digester and temperature regulated slowly to about 330^0C$^{\cdot}$ A typical heat sequence of 200^0C for 30 minutes and a 330^0C for the remainder of the digestion time was regulated. The digestion time varied from 4 -6 hours during which stoppers were removed and allowed to cool. A blank digestion was prepared with 0.1 g Ethylene –Diamine –Tetraacetic standard Acid.

Ten (10) ml of Potassium permanganate was added, shaken well and left to stand for 30 seconds while the digestion tubes were held at an angel of 45^0, sulphuric acid at 50% concentration was added and in the tube to facilitate cleaning up of the tube neck. A little of boiling pumice granules were added into the blanks and the sample digest tubes. Fifty (50) ml of deionised water was added into the mixture until all the sediments in the test-tube dissolved. Excessive frothing at this stage was altered by 5ml distilled water that was poured through the glass funnel. During the process of analysis after each samples, the preceding was re-analysed to ensure determination of stability of the standards. The standards were prepared using the following procedure; drying 7 grams of anhydrous ammonium sulphate at 105^0C for 60 minutes. This was allowed to cool and later dissolved in the deionised water to form 100ml of the volumetric flask which was stored in refrigeration. The 0.1 ml of the standard was transferred into the samples in the labelled test tubes and was allowed to react for one hour. Standard and sample absorbance was done at 655 nm.

The calculations were done by the use formula:

$$\% \text{ N in soil} = \frac{\text{(sample N conc.mg/l-N blank conc.mg/ L X 0.0001X 50ml}}{\text{0.2g}}$$

3.6 Analysis of Plant Tissue Nitrogen and Partitioning

Five plant samples from the experimental plots were collected at vegetative, reproductive and harvesting stages. Plants were thoroughly washed in running water free from soil. The samples were separated into leaves, stems, roots and grain at harvesting and taken to the laboratory for drying at temperature of 70^0 C for 48 hours. The N content in the plant tissue was determined by Kjeldahl digestion procedure since it converts N compounds into ammonium that can be analysed titrimetrically. The machine was rinsed six times before the start of the analysis procedure. Four (4) % of boric acid solution was pipetted into 20 ml test-tube containing bromocresol green and methyl red indicator. Ten (10) ml of the plant sample was pipetted into Gerhardt tubes, blanks being the first to start followed by quality control samples. The digestion tubes were injected with 10ml of 40% NAOH and 20 ml of water. Forty (40%) of aliquot was distilled against the boric acid and later boric was titrated against 0.05 of $H_2SO_{4.}$ The residue was dissolved in 25ml pf of 1.00 M hydrochloric acid. A sample of 0.25g of the tissue was mixed with 2 g of Na_2SO_4 and 7ml of digestion mixture was concentrated into Sulphuric acid, selenium and salicylic acid. Drops of Sodium Thiosulfate was added after 2 and 3-4 hours. The mixture was then allowed to cool for 45 minutes and 4 ml of hydrogen peroxide at 30 % was added. Mixture digestion was done at 410^0 C till a clear liquid was obtained and cooled with water. The % of nitrogen was determined calorimetrically by an auto-analyzer. To determine nitrogen partitioned to roots, stem, leaves and grain the N content obtained was divided by the total amount of N in the whole plant and later converted to a percentage through multiplying by 100.

3.7 Computation formulas for Nitrogen Use Efficiency

The NUE in rice was determined as per the Wang and Zhou (2014) method. Which was computed as follows: N use efficiency=N uptake from fertilized plants- Uptake in un fertilized crops / rate of application

3.8 Computation of N-agronomic efficiency and Nitrogen Harvest Index

Agronomic use efficiency was determined through use of the following equation; Difference method by (Varvel and Peterson, 1990).

NAE = (GY_1)-(GY_0) / R

GY_1 = Grain yield from fertilized plots

= GY_0 = Grain yield from unfertilized plots

R = rate of fertilizer N applied

NAE- Nitrogen Agronomic efficiency

NHI was computed according to Muchow, (1988), ass the ratio between N uptake in the grain and N uptake in the straw.

3.9 Data Analysis

Data collected in the field was arranged and compiled for statistical analysis. Analysis of variance (ANOVA) was performed using SAS statistical computer package version 9.00 TS Level 00M0 XP-PRO platform to test for levels of significance due to treatments and interactions Means were separated using least significance difference (LSD) test at a significance level of 5%. Associations between variables were determined by regression analyses, while SPSS software version 21 was be applied for the analyses of data gathered from survey.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Survey Findings

4.1.1 Demographic factors and rice production challenges

Results showed variability between the two counties surveyed in terms of age. In Kisumu, the majority of farmers were within 50-60 years old, representing 29% of the respondents while in Busia it was between 40-50, which represented 31% of the respondents. The second most dominant age group in Kisumu was between 30-40 years that had 24% whereas in Busia farmers above 60 years were the second most dominant; representing 25% of the farmers as illustrated in Table 4.1. At 60 years (case of Busia county), this age group is assumed to have less knowledge in regard to management of rice nitrogen applications but more experience in the production practices (Amudavi *et al.,* 2009).

These findings from Busia are in disagreement with the findings of Ibitoye *et al.* (2012), who found that the mean age of rice farmers in their study area was 45years, which was an indication that rice farmers belonging to the middle age classes, are physically fit to withstand the stress and risks involved in rice production, and are more mentally alert to embrace new techniques of rice production. This could be due to low economic status among the respondent at 60 years hence forced to still to do farming. According to Guo *et al.* (2015), at elderly age, have less potential in farming, however when levels of poverty are high most of the aged individuals will be forced to rely on farming for livelihood.

Table 4.1 Age, education levels and challenges experienced by rice farmers in Kisumu and Busia Counties

Age of the respondents	**Kisumu (%)**	**Busia (%)**
20-30	7	2
30-40	24	29
40-50	20	31
50-60	29	14
Above 60	20	25
Education levels		
Primary	48	50
Secondary	26	20
College	12	16
None	14	14
Challenges		
Accessibility of seeds and fertilizers	17	18
Shortage of irrigation water	42	48
Marketing	41	34

Report also revealed that among interviewed farmers, 48% in Kisumu County and 50% in Busia County had basic primary education. Twenty-six percent (26%) and 12% of the interviewee had secondary and tertiary education respectively in Kisumu county. On the other hand, 20% and 16% of the interviewed farmers had secondary and college education respectively in Busia County. However, 14 % in Kisumu County and 14 % Busia County did not have any formal education (Table4.1). This implied that a large population of the interviewed farmers from the two survey sites had minimal educational understanding. According to Ojiewo *et al*. (2010), farmers with higher level of education (above secondary education) stand a better chance of improving and managing their nutrient application in their agricultural fields. Furthermore, according to Schippers, (2002), the low acquisition of tertiary education among the farmers does not always make them competitive enough to take into consideration some of the improved methods. This can be of importance in adoption and improvement of nutrient management that consequently results to better yields.

Seventeen percent (17%) in Kisumu County and 18% in Busia County had challenges in accessing seeds and fertilizers challenges. Forty one (41%) percent of interviewed farmers in Kisumu and 34 % in Busia reported to have experienced challenges in marketing of the produce. The critical challenges that recorded a higher frequency was shortage of irrigation water; where 42% of the farmers in Kisumu and 48% in Busia counties revealed having challenges in accessing irrigation water. In paddy rice, shortage of irrigation water is one of the leading factors to losses in nitrogen applied. There is the creation of aerobic environment in the soil when the field gets drained by water. The ammonium form of N that was applied gets oxidized immediately though nitrification by the microbial present in the soil into nitrate which has higher risks of losses due to its negative charge that repels with the soil colloids (Linquist *et al*., 2006). These findings are in agreement with those of Facon, (2000) who reported that in Asia rice farmers have a higher challenge of accessing adequate water throughout the growing season. In another report by International Fund for Agricultural Development, (2018), it was reported in Columbia that domestic rice farmers experience constraints in fertilizers and seeds.

4.1.2 Gender and rice production system in Kisumu and Busia counties

The report revealed that both men and women were involved in the production of rice although the population of men was substantially higher in Kisumu County. In Kisumu county 80% and 20% male and female were respectively involved in rice production In Busia County on the other hand had 68% males and 32% females involved in the farming of rice (Table 4.2).

Table 4.2 Role of gender and farm size on production of preferred rice varieties in Kisumu and Busia Counties

Gender	**Kisumu (%)**	**Busia (%)**
Male	80	68
Female	20	38
Size of land (acres)		
0.1-5.0	93	91
6-10	7	7
Above 10	0	2
Preferred variety		
Basmati	10	21
IR	90	79

These findings disagree with the report given by FAO (2017) which reported that more women were involved in rice farming in major regions of the world. Women are considered to be more careful in their farming activists as they focus on their priorities and other needs in life. Therefore, where more women are involved in farming systems there are less wastage and reckless farming hence leading to improved yield that curb the issue of food insecurity (Magdoff and Tokar, 2010). Further, regarding nutrient management, women tend to be cautious during application and conservation of the resources compared to men. Therefore, it implies that losses of nitrogen in the lake region could be attributed to by the dominance of male gender in the production systems (Nilssen, 1984). In the two counties, the scale of production by farmers in terms of acreage ranged between 0.1-5.0 with 93% and 91% in Kisumu and Busia counties respectively. This aspect can greatly lead to poor management of nitrogen due to absence of intensive farming that is commonly adopted by most of the largescale farmers. According to Giller *et al.* (2009), the size of farm plays a significant role in management of nutrients, where large scale holders have the capability of maintaining good agricultural practices as compared to small scale farmers. In addition, the large holders can set aside a large portion of their holdings for non-food uses such as pasture or woodlot and other land-use practices that help control soil loss and fertility depletion (Jew, 2016). Moreover, these farmers are also comparatively wealthy, they can invest more in inputs and improvements that raise their long-term productivity as well as enduring in anti-erosion and anti-leaching technologies (Grabowski 1990). In terms of the most dominant varieties, IR was the most dominant variety at 90% in Kisumu while in Busia it was 79%. This was preferred due to apparently less management practices required in the field. The report also revealed that Basmati was also grown by a small percentage of the population at 10% and 21% in Kisumu and Busia counties respectively.

4.1.3 Types of nitrogenous fertilizers used in production of rice in Busia and Kisumu counties

In the two counties, respondents reported to have used fertilizers in the production of rice. The main forms of fertilizers used include Urea, Ammonium sulphate and Calcium Ammonium Nitrate (CAN). The most dominant form they reported to have used was Ammonium sulphate (AS) at 61% and 48% in Kisumu and Busia counties respectively. Urea was the second most dominant in the two counties at 31% and 41% in Kisumu and Busia counties respectively (Figure 4.1).

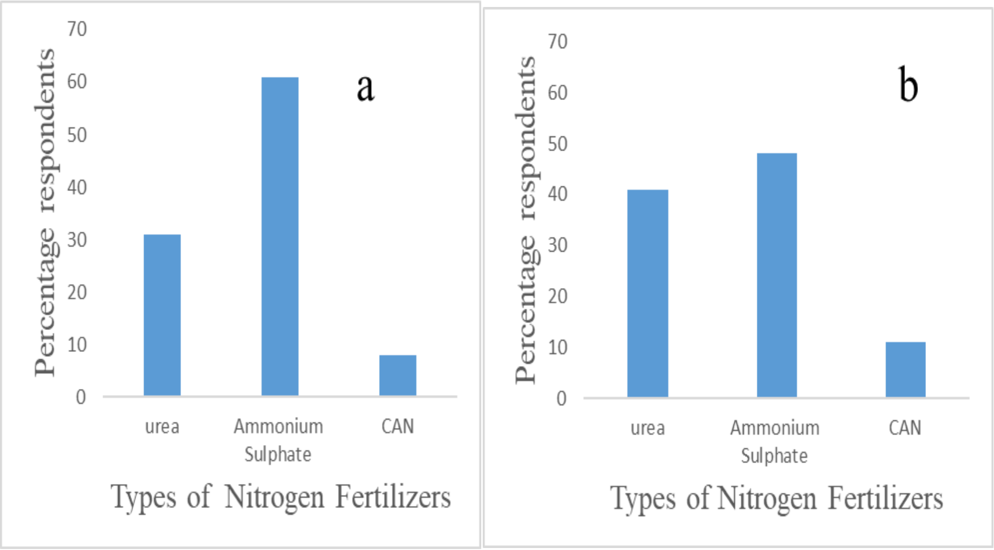

Figure 4.1 Farmers' responses to types of nitrogenous fertilizers used in production of rice in Kisumu (a) and Busia (b) counties respectively.

These findings disagreed with those of Setyanto *et al.* (2016) who reported that most of the farmers used urea in production of paddy rice in Indonesia. Importantly, across the world, urea is the most commonly used form of N fertilizer by many farmers (Azeem, *et al.*, 2014). In terms of losses, urea has lower loss risks as compared to other sources of N through leaching and nitrification. However, in terms of emissions, Ammonium sulphate is less prone to volatilization as compared to urea since urea hydrolyzes easily leading to high losses of nutrients in the compound and this could be partial reason as to why most farmers preferred to use it over urea. The choice of the N form to use in production system is considered as key component in management of nutrient. Calcium Ammonium Nitrate although not common as revealed by the survey findings (8% and 11% in Kisumu and Busia counties respectively.

4.1.4 Methods of nitrogen application, farmers Awareness on nitrogen losses and nutrient pollution

There was a slight variability in responses from farmers in terms of methods of nitrogen application, and farmer's awareness to nitrogen losses and nutrient pollution as shown in Table 4.3 among interviewed farmers, 54 % in Kisumu County and 52% in Busia County reported to apply full dose of nitrogen as indicated in Table 4.3. This method of application is done during transplanting of the seedling to the paddy fields.

Table 4.3: Respondents' perception on Methods of nitrogen application, farmers Awareness on nitrogen losses and nutrient pollution

Method of nitrogen application	**Kisumu (%)**	**Busia (%)**
Full dose	54	52
Split	46	48
Awareness on nitrogen losses		
Yes	49	50
No	51	50
Awareness on nutrient pollution		
Yes	20	23
No	80	77

The findings of the survey were consistent with those of Osman *et al.* (2006) who reported that many farmers applied full doses of urea in the second day after transplanting. The reasoning is that the fertilizer is less likely to drift to one side of the flat bed with the incoming water if applied before irrigation, hence leading to reduction of N losses. Forty six (54) percent and 52% in Kisumu and Busia respectively used full dose method of application. Split applications are preferred to reduce the extent of losses of applied nitrogen depending on the crop demand at particular growth stages. This disagrees with Kamanga *et al.* (2001) who reported that most farmers used split application of fertilizer in maize crops to improve nutrient balance as well as meeting the need of the plants in critical growth stages. From the interviewed farmers almost half of them were aware of nitrogen losses, with 49% and 50% in Kisumu and Busia counties respectively indicating their awareness of nitrogen losses. The farmers also concurred that nitrogen losses were the greatest challenge facing rice production due to high cost of fertilizers they experience. Fifty one percent (51) and 50% of the respondents in Kisumu and Busia counties respectively were not aware of consequences of losses of nitrogen in ice farming (Table 4.3). These findings were in consistence with those of Wu *et al.* (2015) who reported that absence of farmers' general knowledge on mechanism through which nitrogen is lost is key to poor agronomic balances hence resulting to low yields. Absence of extension services in teaching farmers about the potential impacts of nutrient budgets was considered as one of the socio-economic factor leading to increased losses. A study carried out in Thailand illustrated that awareness and understanding of nutrient balance approach is an imperative component in ensuring there is site specific tool for improved management of applied nutrients (Wijnhoud *et al*., 2003).

4.1.5 Farmer’s straw management practices

From the surveyed area, the respondents reported a number of straw management practices that they embraced after harvesting the rice grains. In Busia County, 40% of the farmers reported to burn their straws after harvest, 39% revealed to feed to their livestock, 10 % indicated to sold the straw and 11 % reported to leave in the field. In Kisumu, 34% of the respondents burnt, 32% fed to the livestock, 15% sold out to others and 19% left in the land as indicated in figure 4.2.

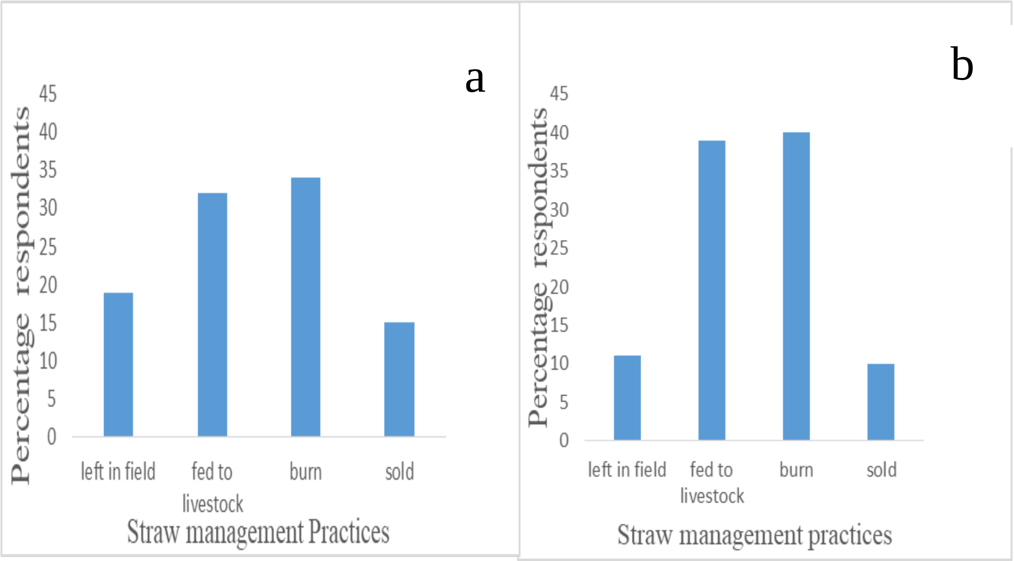

Figure 4.2: Farmers straw management practices in Kisumu (a) Busia (a) counties

These findings are in agreement with the findings of Quayle (2016) who reported burning to be the most dominant practice of straw management. Post-harvest management of straws is key since straw is estimated to contain about 40 percent of the applied N (Dobermann and Fairhurst, 2002). When straws are burnt, there is a complete N loss from the soil, which is one of the pathways through which nutrients are lost. This practice also leads to transfer of nutrients to a common area since most farmer’s burn the straw in a central location. Thus, this also contributes to nutrient imbalances in the growing field. According to Yin *et al.* (2017), burning causes atmospheric pollution since burning of straw composing nitrogen leads to production of methane and nitrous oxide, which are hazardous to the environment. Burning results to considerable long-term effects in the soil, contributing to environmental pollution due to emissions of greenhouse gases. Furthermore, smoke from the straws get trapped in inversion layers in typical autumn weather conditions and are not considered aesthetically pleasing from a community perspective (Quayle, 2016). Therefore, there is a significant indication that a gap in agronomic and soil science research about the loss of nutrients due to straw burning in the farm is existing based on the poor management practices by the farmers. These findings are in agreements with a report written by NARC newsletter (2004) that farmers offer rice straws to livestock, based on the case studies of countries such as Thailand, Vietnam, and Indonesia. Feeding the straws to livestock and selling out significantly lead to exportation of nitrogen that would have been retained in the field (Ahmed *et al.,* 2010). Ruminant animals have low efficiency of utilizing nitrogen contained in the rice stover hence it gets excreted as faeces and urine therefore making the extent of losses to be extremely high (Smith *et al.,* 2008). Composting and vermicomposting of the straws which are considered as effective tools for preparing manure are also associated with detrimental effects of causing environmental pollution since during the process production of gases such as ammonia, methane and nitrous acid. According to O’mara, (2011) animal agriculture contributes 8–10 % of global greenhouse, which is hazardous to the environment. Furthermore, the production of such gases is of no value to agronomic balance since it reduces the availability of nitrogen in the compost manure.

Therefore, farmers using this form of manure supply unbalanced amounts of nitrogen that leads to poor yield.

Retaining and incorporating straws in the field is probably the most beneficial practice in management of nutrients. Incorporation of the remaining stubble and straw into the soil returns most of the nutrients and helps to conserve soil nutrient reserves in the long-term. Although the left straws have short term effects on grain yield, in the long run, farmers who use this practice experience significant benefits. Where mineral fertilizers are used and straw incorporated, reserves of soil N, P, K, and Si are maintained and may even be increased. Incorporation of straw and stubble into wet soil (during plowing) results in temporary immobilization of N and a significant increase in methane (CH_4) emission from rice paddy, a practice that contributes to greenhouse gases. Incorporation of large amounts of fresh straw is either labor-intensive or requires suitable machinery for land preparation and may result in the build-up of disease problems. Transplanting should be carried out two to three weeks after straw incorporation.

According to Lal (2005), soil quality will improve by returning crop residue into soil through its potential influence on reducing risks of soil erosion, stabilizing soil structure and improving tilth, reducing soil bulk density, storing or recycling nutrients, improving water retention and transmission properties, providing energy for microbial processes, increasing cation exchange capacity and enhancing agronomic productivity. Composting is also very suitable for growing fruit plants, vegetables, and general horticulture-use (Rosmiza *et al.,* 2017). Around 61.5% of rice straw in Japan is ploughed into the field for general organic compounds to also encourage the activity of microorganisms (Matsumura *et al.,* 2005). Several countries such as Taiwan South Korea (46.0%) have previously successfully developed and utilised rice straw as a compost (Supaporn *et al.,* 2013).

4.2 Effect of nitrogen forms, levels and methods of application on growth of rice

4.2.1 Plant Height

Application of different nitrogen forms had a significant ($P \leq 0.05$) effect on plant height in both Ahero and Mwea sites. At vegetative stage, ammonium-N at 25 kgha^{-1} resulted in highest plant height in the two sites. In Ahero, ammonium-N at 50 kgha^{-1} recorded the highest plant height at both reproductive and harvesting stages; with reproductive stage being 56 cm and 72.6 cm at harvest stage compared to control of 41.9 cm during reproductive and 51.2 cm at harvest stage (Table 4.4).

In Mwea, the trend was different since Ammonium sulphate (AS) at 25 kgha^{-1} recorded the highest plant height at vegetative, reproductive while at harvesting Urea 25 kgha^{-1} had the highest plant height. Height is a measure of growth that shows the progress of the plant in response to the nutrition supplied to it. However, the differences were not statistically different from, urea at 50 kgha^{-1}. Urea applications at rate 50 kgha^{-1} recorded highest plant height followed by 25 kgha^{-1} while the control had the lowest in all major of growth stages. In Ahero, full dose method was statistically significant ($P \leq 0.05$) at vegetative and reproductive stages recording 53.3 cm 66.3 cm respectively. In Mwea, no statistical differences were observed across all stages (Table 4.4).

Table 4.4: Plant height as affected by N sources and levels at vegetative, reproductive and harvesting stages

			Plant Height (cm)			
Method		**Ahero**			**Mwea**	
	VS	**RS**	**HS**	**VS**	**RS**	**HS**
Full dose	53.3^{a}	66.3^{a}	75.9^{a}	31.4^{a}	49.9^{a}	82.7^{a}
Split	49.3^{b}	62.1^{b}	77.5^{a}	31.4^{a}	49.8^{a}	82.8^{a}
LSD	1.8	3.1	3.2	1.2	1.7	2.1
N rates kg/ha						
Control	41.9^{c}	51.2^{c}	59.5^{c}	24.9^{c}	32.6^{b}	51.0^{b}
As25	57.6^{a}	71.1^{ab}	83.7^{ab}	38.7^{a}	57.6^{a}	83.5^{a}
As50	56.0^{ab}	72.6^{a}	90.4^{a}	31.0^{b}	48.7^{a}	82.0^{a}
Ur25	49.3^{b}	64.4^{b}	78.5^{b}	31.4^{b}	51.7^{a}	83.7^{a}
Ur50	56.3^{a}	79.2^{ab}	85.9^{ab}	29.9^{bc}	50.4^{a}	82.2^{a}
LSD	1.7	3.0	3.6	4.8	12.5	19.7
NR*M	*	*	*	NS	NS	*

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$). VS- Vegetative stage (60 DAT), RS- Reproductive stage (90 DAT), HS- Harvesting stage (120DAT) M- method of application, NR-Nitrogen rates As25-Ammonium sulphate 25 kgha^{-1} AS50-Ammonium sulphate 50 kgha^{-1}, Ur25-Urea 25 kgha^{-1}, Ur50- Urea 50 kgha^{-1}

Ammonium sulphate applied at 50 kgha^{-1} in full dose method showed the highest height at the end of the cropping system and urea at 50 kgha^{-1} when applied in split exhibited high interaction on plant height in Ahero. Similar trend was observed in Mwea with urea at 50 kgha^{-1} recording a higher plant height compared to full dose at harvesting stage (Figure 4.3).

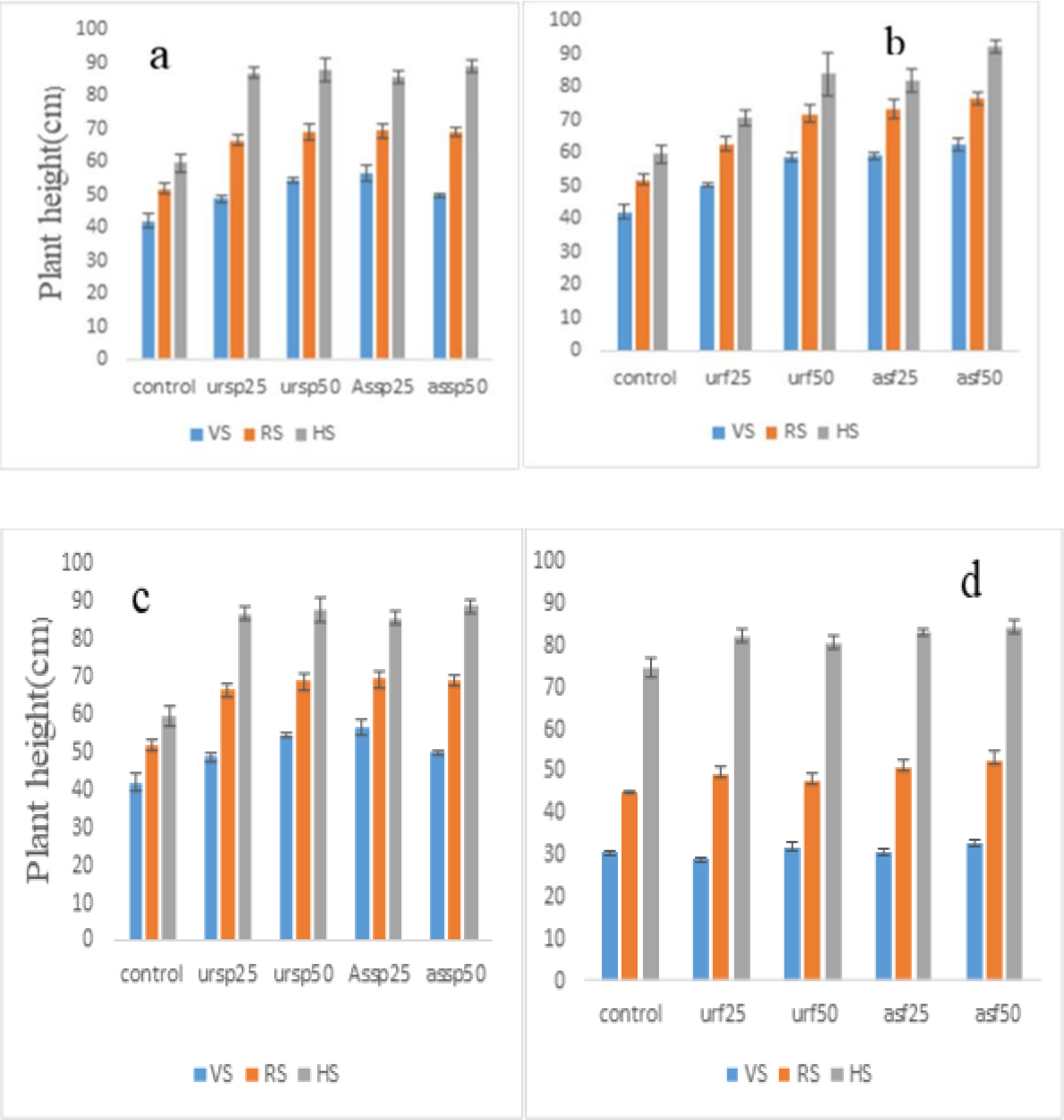

Figure 4.3 Effects of interactions on nitrogen sources, rates and methods of application on plant height at vegetative (VS-60DAT), reproductive (RS-90DAT) and ripening stages (HS-3 120DAT) A and B in Ahero and C and D in Mwea study sites. Ursp25-Urea split 25kgha^{-1}, Ursp50-urea split 50kgha^{-1}, Assp25-Ammonium sulphate split 25kgha^{-1}, Assp50- Ammonium sulphate fulldose 50kgha^{-1} Urf25-Urea fulldose 25kgha$^{-1,}$ Urf50-urea fulldose 50kgha^{-1}, Asf25-Ammonium sulphate fulldose 25kgha^{-1}, Asf50- Ammonium sulphate fulldose 50kgha^{-1}

There was no difference in the trend in plant heights when supplied with ammonium Sulphate either as split or full dose in Mwea since both methods showed the same trend in their influence of plant height as illustrated in figure 4.3. The difference in the trend of urea could be due to higher efficiency use to reduce losses when it is applied in split hence minimal are included. For ammonium sulphate, the losses in terms leaching are not as high as for urea since it can be held by the negative soil colloids and thus no loss is incurred in either the methods of application used.

The current results on plant height are in agreement with those of Kirna and Patra, (2002) who reported that ammonium nutrition result into higher plant height than Urea. This could be attributed to slow releases of nitrogen that is exhibited in this form of fertilizer hence supplying nitrogen requirements during various critical growth stages. In addition, increase in plant height at various stages of growth implied crop responses in times of nutrient demand. According to Marschner, (1995) urea has extensively higher losses that lead to less supply of nitrogen to the plant during the stages of high nutrient demand, which agrees with the findings of this study. The results also conforms with those of Assefa *et al.* (2009) who found significant effect on rice plant height using urea, a source of N and applied in split in the hot-humid North-western part of Ethiopia compared to ammonium sulphate. This corresponds to the results reported by Russo *et al*. (1991) that nitrogen applications two or three times in growing seasons led to increased plant height in rice. This is attributed to improved use of nitrogen applied, hence reducing the extent of losses in the rice farming systems. Shaiful *et al.* (2009) also reported that when rice genotype was supplied with nitrogen in splits methods resulted in higher height during the late stages which was evident in this study.

4.2.2 Effects of Nitrogen Forms and Rates on Number of tillers at different stages of rice growth

Number of tillers per plant were significantly influenced ($P \leq 0.05$) by sources and rates of nitrogen compared with the control in both Ahero and Mwea. Ammonium at 50 kgha^{-1} recorded highest number of tillers at vegetative, reproductive and harvesting stages. At ripening, the maximum number of tillers at 50 kg ha^{-1} of ammonium was 44.5. While at 25 kgha$^{-1,}$ the number of tillers recorded were 35.2 per plant. On the other hand, urea at 50 kgha^{-1} and 25 kgha^{-1} of N exhibited significance difference ($P \leq 0.05$) at the final stage, with 50 kgha^{-1} and 25 kgha^{-1} recording 42.8 and 34.3 tillers respectively. The control (no N supply) had the lowest number of tillers at vegetative, reproductive and harvesting stages with 17.5, 20.4 and 22.5 tiller counts in the Ahero sites, respectively as shown in table 4.5. Methods of application showed significant difference at vegetative stage in Ahero site with full dose recording highest 28.3 tillers while in in Mwea there were no significant difference observed (Table 4.5) Split applications of urea rates resulted to more number of tillers when compared to when applied in full dose in vegetative, reproductive and harvesting stages in the two sites. On the other hand, when ammonium sulphate was applied in full does all the growth stages resulted in higher number of tillers compared to split applications in the two sites as illustrated in figure 4.4.

At Ahero site, the results revealed superior tiller numbers under full dose when the N application was at lower rate (full dose of ammonium sulphate at 25 kgha^{-1}, Fig. 4.4 A) compared to split application (Fig. 4.4 B for ammonium sulphate). However, when N rates were doubled to 50 kgha^{-1} as ammonium sulphate, the full dose was only superior during the vegetative and reproductive stage but this advantage vanished at harvest stage such that the split and full dose method of application led to same results. Similar trends were observed with ammonium sulphate at 25 kgha^{-1} at the same site, though the differences were less conspicuous at lower N rates. Moreover, similar tends were observed with urea at both levels and methods at Ahero.

Table 4.5: Mean number of tillers as affected by N sources and levels at vegetative, reproductive and harvesting stages of rice growth

			Number of tillers			
Method		**Ahero**			**Mwea**	
	VS	**RS**	**HS**	**VS**	**RS**	**HS**
Fulldose	28.3^{a}	32.3^{a}	33.4^{a}	5.0^{a}	16.6^{a}	22.3^{a}
Split	24.5^{b}	29.6^{a}	34.5^{a}	5.2^{a}	16.2^{a}	23.7^{a}
LSD	1.8	3.0	3.3	1.0	2.3	1.8
N rates kgha^{-1}						
Control	17.5^{c}	20.4^{c}	22.5^{d}	4.30^{c}	13.1^{b}	15.3^{c}
As25	28.3^{b}	33.6^{ab}	35.2^{bc}	7.3^{c}	17.0^{ab}	24.6^{ab}
As50	34.4^{a}	38.9^{a}	44.5a	13.3^{a}	22.2^{a}	29.9^{a}
Ur25	27.9^{b}	31.3^{b}	34.3^{c}	7.2^{bc}	15.1^{b}	22.0^{bc}
Ur50	29.4^{a}	38.5^{ab}	42.8^{ab}	10.2^{ab}	18.0^{ab}	24.3^{ab}
LSD	1.7	2.8	3.1	5.8	6.5	6.6
M*NR	*	*	*	NS	NS	*

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$). VS- Vegetative stage (60 DAT), RS- Reproductive stage (90 DAT), HS- Harvesting stage (120DAT). M-Method of application, NR-Nitrogen rates As25-Ammonium sulphate 25 kgha^{-1} AS50-Ammonium sulphate 50 kgha^{-1}, Ur25-Urea 25 kgha^{-1}, Ur50- Urea 50 kgha^{-1}

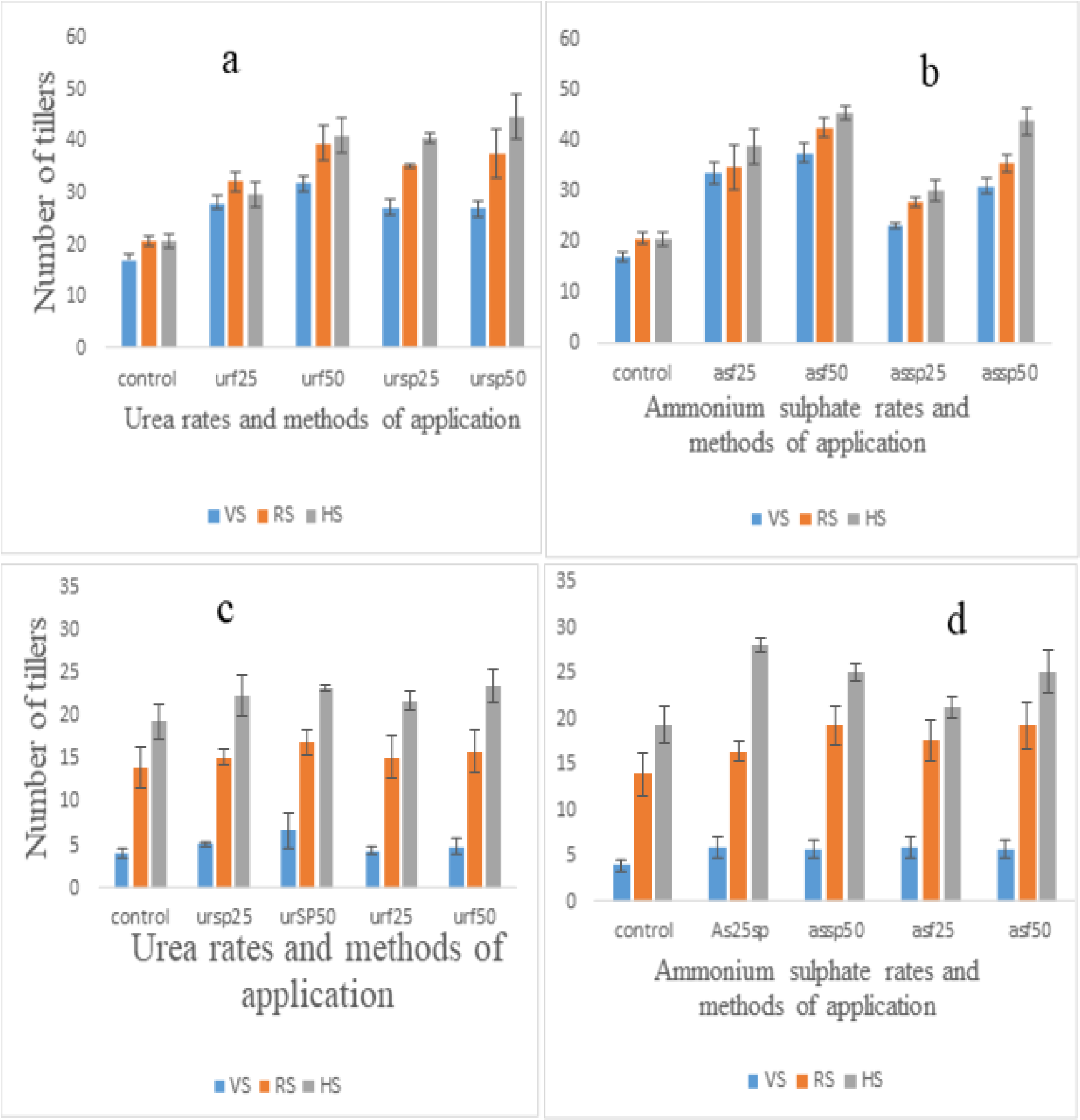

Figure 4.4 Effects of interactions on nitrogen rates and methods of application on number of tiller at vegetative (VS-60 DAT), reproductive (RS-90 DAT) and ripening stages (HS -120DAT) in Ahero a, b and Mwea c, d. Ursp25-Urea split 25kgha^{-1}, Ursp50-urea split 50kgha^{-1}, Assp25-Ammonium sulphate split 25kgha^{-1}, Assp50- Ammonium sulphate fulldose 50kgha^{-1} Urf25-Urea fulldose 25kgha$^{-1,}$ Urf50-urea fulldose 50kgha^{-1}, Asf25-Ammonium sulphate fulldose 25kgha^{-1}, Asf50- Ammonium sulphate fulldose 50kgha^{-1}

These findings on number of tillers are in disagreements with those of Babowicz *et al.* (1985), who reported urea to be more effective in producing higher number of tillers in wheat compared to ammonium sulphate. This difference could be due to high volatilization of urea in flooded rice hence increasing losses of nitrogen that consequently lead to less productivity of new tillers. However, the current findings are in conformity with those of Mohamed *et al.* (2012) who reported increase in number of spikelet tillers of wheat cultivars in ammonium sulphate compared with that of urea. This was attributed to the efficiencies of N during plant growth. Also, when nitrogen is supplied to plants in form of ammonium sulphate, it is shown to be five times less volatile compared to urea (Pan *et al*., 2016). This therefore, provides evidence of more number of tillers when ammonium sulphate was used in rice fields. Consequently, high assimilation of nitrogen is envisaged to proceed to anthesis, leading to increased amount of biomass, since higher number of tillers is a yield component indicator (Chang and Zhu, 2018). The lower absorption of nitrogen from urea leads to a greater leakage of nitrogen bound in urea, hence lowering the efficiencies of urea as source of N (Barrows and Kilmer, 1963). According to Chaturvedi (2005), number of tillers in a particular plant is an imperative component since it plays a role in enhancing yield and therefore influenced by the nitrogen levels and sources.

. The superiority of ammonium sulphate applied in full dose at vegetative stages of growth was due sufficient supply of nitrogen nutrition to the crops at early stage. These findings agrees with those of Krishnakumar *et al*. (2005) who reported full dose of nitrogen to be more effective in development of early stages when supplied in form of Urea and ammonium sulphate.

These findings were in agreement with those of Ellen and Spiertz, (1980) who reported that when urea was applied as a source of nitrogen at different stages resulted to greater number of tillers, which are indicators of yield components. Split applications are associated with improved utilization of applied nutrient during critical growth stages hence resulting to better development and growth. In another study, ammonium sulphate produced considerable number of tillers when applied in full dose than when on split dosage (Jan and Khan, 2000). The findings are in agreement with the current experiment in Ahero site with ammonium at 25 kgha^{-1} (Asf25) (Fig.4.4 a). Another reports indicate that presence of Sulphur element in ammonium sulphate may partially provide an explanation as to why nitrogen is released slowly to the rice crops hence performing well when applied in full doses at the beginning of the cropping system than when it is splits in three phase although this depends on other factors such as soil chemical properties, including the acidity and oxidation status (Ladha *et al.,* 2005).

4.2.3 Days to 50% flowering

There were no significant differences ($P \leq 0.05$) in terms of days to 50% flowering among the various sources and rates of fertilizers applied and the control (no N applied). Ammonium sulphate at 50 kgha^{-1} took the longest time to flower with a mean of 76.7 days followed by urea at 25 kgha-1, urea 50 kgha^{-1} and ammonium sulphate at 25 kgha^{-1} with 75.7, 75.5 and 74 days receptively (Fig 4.5).

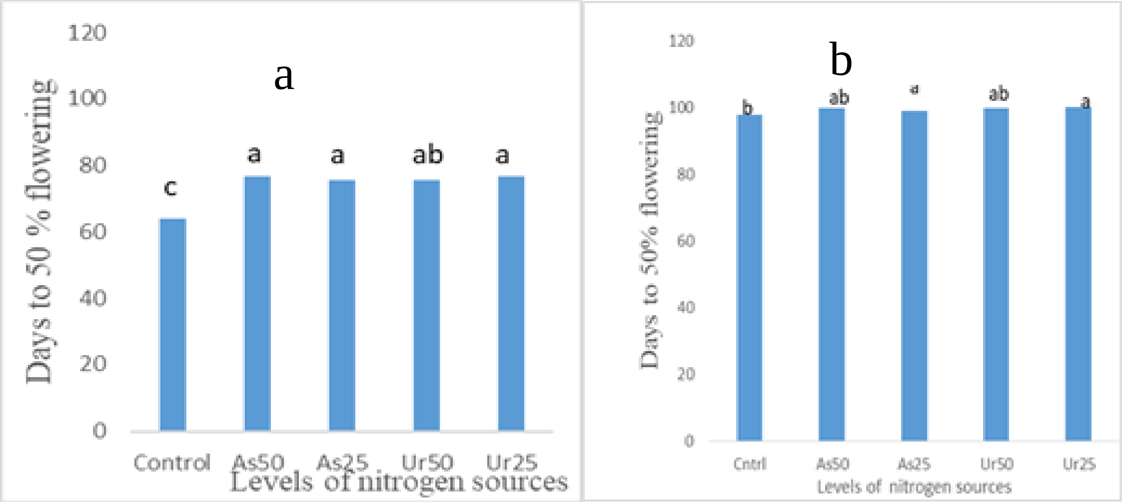

Figure 4.5: Influence of Nitrogen forms and levels on days to 50% flowering in Ahero (a) and mwea (b) As25-Ammonium sulphate 25 kgha^{-1} AS50-Ammonium sulphate 50 kgha^{-1}, Ur25-Urea 25 kgha^{-1}, Ur50- Urea 50 kgha^{-1}

The control took the shortest period to flower with a mean of 64 days, which was significantly different from the rest of the treatments. In Mwea the trend was the same; with ammonium sulphate 50 kgha^{-1} and urea 25 kgha^{-1} taking longer to flower (100 days). Urea at 50 kgha^{-1}and ammonium sulphate 25 kgha^{-1} followed in flowering with 99.8 and 99 days respectively while the control took shorter days with 97.7 days. The differences were however not statistically significant (figure 4.5).

Similar results were obtained by Wani *et al.* (2016) who showed that absence of nitrogen accelerated phenological stage of flowering in rice plants. These results were however not in agreement with those of Richard *et al.* (1983) who revealed that nitrogen decreased the interval of flowering of maize plant. When rice plants experience deficiency in nitrogen, they use their roots to mine more of the available nitrogen in the deeper layers of soil. Therefore, due to this form of stress, they tend to produce flowers earlier to complete their life cycle before depleting the available nitrogen (Day and Ludeke, 2012). When rice plants are subjected to low-N conditions, they acquire N by increasing the root surface area, which increases their ability to complete the life cycle early hence the early flowering (Marschner *et al.* 2011). According to Lian *et al.* (2006), nitrogen stresses trigger molecular responses in rice resulting to rapid repression of genes related to photosynthesis and metabolism energy production that fasten the life cycle of a plant.

4.2.4 Shoot dry weight at vegetative, reproductive and harvesting stages

Shoot dry weight was significantly affected ($P \leq 0.05$) by different levels and sources of N across all growth stages of rice in Ahero. The highest mean shoot dry weight was observed with the ammonium sulphate at 50 $kgha^{-1}$ which led to 6.04 g, 21.20 g and 58.08 g at vegetative, reproductive and harvesting stages respectively; followed by urea supplied at 50 $kgha^{-1}$ which recorded 4.77 g, 22.71 g and 46.817 g at vegetative, reproductive and Harvest (maturity) stage. The ammonium sulphate at 25 $kgha^{-1}$ ranked third, with 4.63 g, 19.23 g and 40.0 g at vegetative, reproductive and harvesting/maturity stages respectively (Table 4.6). The last N treatment was urea at 25 $kgha^{-1}$ with 5.67 g, 14.07 g and 39.91 g at vegetative, reproductive and harvesting stages respectively. Irrespective of the stages, ammonium resulted to higher shoot biomass than urea at similar rates. The same trends were also observed in Mwea site. However, the shoot dry weights were generally higher for each treatment when compared ammonium N. Even the control shoot biomass was much higher in Mwea than Ahero (47.3 and 27.1 g respectively at harvest/maturity stages. Irrespective of the source, N increased the shoot biomass by 39% when supplied with 25 $kgha^{-1}$ at Ahero but when the N was increased from 25 to 50 $kgha^{-1}$, shoot dry weight at harvest stage increased by 37.8% if supplied as Ammonium sulphate as compared to urea when it was a partly 17.3%.

Table 4.6: Mean shoot dry weight as affected by N sources and levels at vegetative, reproductive and harvesting stages

			Shoot dryweight(g)			
Method		**Ahero**			**Mwea**	
	VS	RS	HS	**VS**	**RS**	**HS**
Fulldose	9.3^{a}	20.0^{a}	39.6^{a}	21.1^{a}	69.5^{a}	63.2^{a}
Split	7.1^{a}	19.9^{a}	41.3^{a}	23.6^{a}	70.5^{a}	64.9^{a}
LSD	1.7	3.8	7.0	4.4	8.5	11.2
N rates kgha^{-1}						
Control	3.5^{b}	12.0^{c}	27.1^{c}	17.5^{a}	52.6^{c}	47.3^{c}
As25	4.6^{ab}	19.2^{ab}	40^{abc}	21.0^{a}	88.3^{ab}	61.1^{abc}
AS50	6.0^{a}	21.2^{a}	55.1^{a}	29.1^{a}	91.0^{a}	84.8^{a}
Ur25	5.8^{ab}	14.1^{bc}	39.9^{abc}	24.3^{a}	68.3^{abc}	58.8^{abc}
Ur50	4.8^{ab}	22.7^{a}	46.8^{ab}	22.7^{a}	66.1^{bc}	80.3^{ab}
LSD	2.4	6.6	4.2	12.7	23.0	28.5
M*NR	NS	NS	NS	NS	NS	NS

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$). VS- Vegetative stage (60 DAT), RS- Reproductive stage (90 DAT), HS- Harvesting stage (120DAT) M-Method of application, NR-Nitrogen Rates As25-Ammonium sulphate 25 kgha^{-1} AS50-Ammonium sulphate 50 kgha^{-1}, Ur25-Urea 25 kgha^{-1}, Ur50- Urea 50 kgha^{-1}

Methods of application were not significant ($P \leq 0.05$) in Ahero and Mwea study sites (Table 4.6). There was similar trend in Mwea, though there were no statistical significant differences amongst treatments. The only difference was the control, which was significantly lower than the rest. Addition of N led to 29.2 and 24.2% increase in shoot dry with 25 kgha^{-1} for ammonium and urea respectively Methods of N application did not show significant differences (P≤0.05) as illustrated in Table 4.6, which implied either split or full dose method, had no effect on biomass accumulation in paddy rice**.**

The superiority of ammonium nitrogen in enhancing rice biomass is not surprising. Indeed the current findings are in agreement with those of Heeb *et al.* (2005) who reported increased shoot dry weight when tomato seedlings were fertilized with ammonium sulphate as compared to urea. In another study by Ruan *et al.* (2007); supplying tea with ammonium fertilizers increased the dry matter accumulation of leaves, which is of economic significance. Ammonium sulphate application, especially during vegetative stages led to higher photosynthetic activity, which was influenced by nitrogen uptake and consequently higher tissue contents. The higher shoot dry weight can be connected with positive effects of nitrogen of promoting some of the essential physiological processes in plants (Tchiaze *et al.,* 2016). From the study by Eriksen *et al.* (1985) total dry matter production increased when urea was applied in flooded rice. Although more losses are incurred through volatilization during initial stages the plant is able take up some amount of nitrogen before it is subjected to losses that sustains it growth in the entire growing seasons hence increasing the productivity

4.2.5 Root dry weight at vegetative, reproductive and harvesting stages

The results did not reveal any significant differences (p≤0.05) in the mean root dry matter accumulation at vegetative stage in Ahero. This implied that the growth was uniform at this stage and did not have any effect from the fertilizers applied. Results on root dry weight indicated that different rates and sources of Nitrogen had significant difference at ($p \leq 0.05$) during the harvesting stage in Ahero and Mwea. During this stage, Urea at 50 kgha^{-1} recorded highest root dry weight of 16.97 g in Ahero while in Mwea it recorded a mean of 29.30 g. At this stage, the control treatment recorded the lowest root dry weight of 8.01 g and 16.80 g in Ahero and Mwea respectively as illustrated in table 4.7. At reproductive stage, root dry weight did not have shown any significant differences ($p \leq 0.05$) in the two sites (Table 4.7).

Table 4.7 Mean root dry weight as affected by N sources at vegetative, reproductive and harvesting stages

			Root dryweight(g)			
Method	**Ahero**				**Mwea**	
	VS	**RS**	**HS**	**VS**	**RS**	**HS**
Fulldose	1.7^{a}	4.4^{a}	13.2^{a}	2.6^{a}	23.0^{a}	20.6^{a}
Split	1.4^{a}	4.2^{a}	13.1^{a}	2.2^{a}	19.5^{a}	17.5^{a}
LSD	0.2	0.9	0.9	0.5	4.3	5.3
N rates kg ha^{-1}						
Control	1.22^{a}	3.97^{a}	8.01^{c}	0.98^{c}	19.44^{a}	16.80^{b}
As25	1.23^{a}	4.26^{a}	10.33^{b}	2.13^{bc}	28.25^{a}	24.21^{ab}
As50	1.23^{a}	4.80^{a}	15.95^{a}	3.16^{ab}	21.252^{a}	29.18^{a}
Ur25	1.85^{a}	3.73^{a}	12.35^{ab}	2.76^{ab}	19.32^{a}	17.90^{b}
Ur50	2.03^{a}	4.85a	16.97^{a}	3.89^{a}	19.31^{a}	29.30^{a}
LSD	0.96		4.23	1.27	10.68	10.80
M*NR	NS	NS	*	NS	NS	NS

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$). VS- Vegetative stage (60 DAT), RS- Reproductive stage (90 DAT), HS- Harvesting stage (120DAT) M-Methods of application, NR-nitrogen rates As25-Ammonium sulphate 25 kgha^{-1} AS50-Ammonium sulphate 50 kgha^{-1}, Ur25-Urea 25 kgha^{-1}, Ur50- Urea 50 kgha^{-1}

This could be attributed to the high demand of nitrogen nutrition by the plants to enhance flower initiation and the grain forming process hence more of the nitrogen absorbed by the roots is translocated to the reproductive organs hence massive growth of roots is limited. Interactions between nitrogen rates and methods of application were observed at harvesting stage of rice crops in Ahero while in other stages including vegetative, reproductive there were no statistical difference at $P \leq 0.05$ as illustrated in appendix 2. In Mwea, there were no significant differences in the root dry weight for all the stages. Where urea was applied at 50 $kgha^{-1}$ with spilt application, it resulted into higher root dry weight of 17.86 g. Ammonium sulphate at 50 $kgha^{-1}$ applied as full dose resulted to higher root dry matter content compared to when applied to split application recording 17.60 g and14.26 g respectively (figure 4.6).

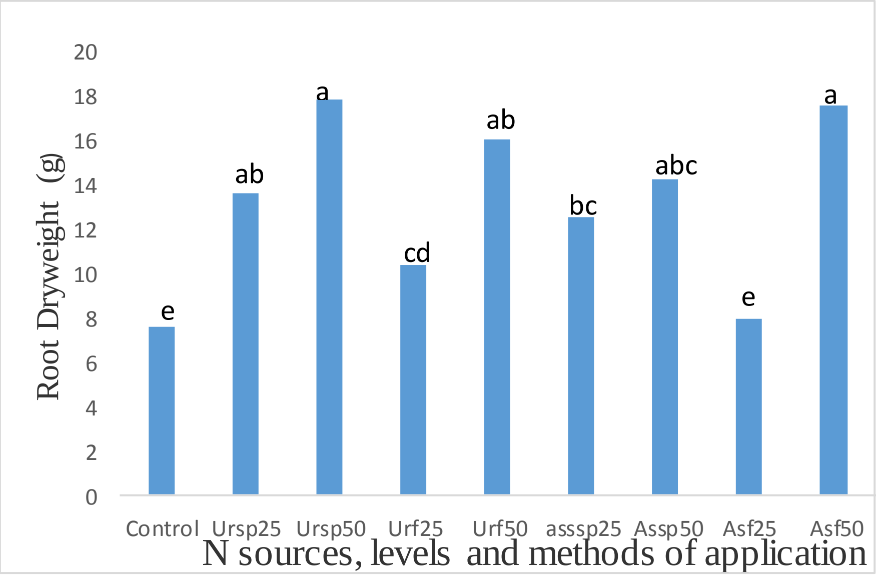

Figure 4.6: Interactions effects on nitrogen rates and methods of application on mean root dry weight at harvesting stage in Ahero study site. Ursp25-Urea split 25kgha^{-1}, Ursp50-urea split 50kgha^{-1}, Assp25-Ammonium sulphate split 25kgha^{-1}, Assp50- Ammonium sulphate fulldose 50kgha^{-1} Urf25-Urea fulldose 25kgha$^{-1,}$ Urf50-urea fulldose 50kgha^{-1}, Asf25-Ammonium sulphate fulldose 25kgha^{-1}, Asf50- Ammonium sulphate fulldose 50kgha^{-1}

The results indicated that Urea promoted vibrant growth of roots when compared to urea since it showed higher dry matter accumulation compared to others. These findings are in agreement with those of Nahar and Pan, (2015), who reported that root dry weight of castor plant increased with increase in urea fertilization across growth stages with the highest dry weight being recorded during the final level. The increased growth of castor plant underground parts was an indication that urea application had the best effects in promoting growth and development. The high dry weight of roots at the harvesting stage could be possibly due to the growth stimulation due to source of nitrogen from urea that is usually experienced at later growth stages (Sarker *et al.*, 2017). Furthermore, rice roots perform well in later stages and this give them of advantages of scavenging for the leached nitrogen in the lower layers of soil (Mackie-Dawson *et al.*, 1995).

According to Bedell *et al.* (1999) ammonium had the ability of promoting morphological characteristics of roots growth when supplied in various growth stages of maize plants. Therefore, agrees with the findings of this study that ammonium sulphate showed increased root dry weight content in vegetative, reproductive and harvesting stages. However, the results of ammonium sulphate having higher root dry weigh at high dose were inconsistent with the report given by Fageria *et al.* (2011) that root dry weight of rice was higher in the lower application of nitrogen. The interaction in the root dry weight at harvesting stage could be attributed to increased utilization of nitrogen released from urea due to multiple application. Urea has highest volatilization losses compared to other forms of nitrogen fertilizers, therefore, when applied in split doses N loses are minimized and hence the nitrogen applied is used to promote morphological growth of roots (Aulakh and Malhi, 2005). The higher root dry weight for ammonium sulphate when applied in full dose could be due to its slow release property that makes it perform better when applied as single dose during the early growth stages.

According to Vos (1999), split application of urea in potatoes resulted to significant yield of the root dry matter contents which was also reflected during growth and development stages of the plant. The study by Cheema and Ahmad, (2000) showed similar results with current study, where urea led to increased dry matter content of roots in legumes when supplied in two or three split within the crop growth period. Hozhbryan, (2013) also reported similar results in tomatoes when urea at 150 kgha^{-1} was applied both at planting and topdressing stages resulted to high root dry matter content. Ammonium fertilization at transplanting plays a significant role promoting overall growth of plant till to the final stages. Also, the extent of losses experienced in this form of fertilizer in either through volatilization or leaching are quite minimal hence higher efficiency in the plant during the vegetative stages. These finding are in agreement with those of Phongpan *et al.,* (1988) who reported that ammonium sulphate when applied in full doses results to higher roots growth in rice and consequently high dry matter.

4.2.6 Root to Shoot ratios

Root: Shoot ratio revealed significant differences at ($p \leq 0.05$) at the vegetative stage in both study sites. In ahero unfertilized plot had the highest mean if root: shoot ration recording 0.25 while in Mwea urea at 50 kgha^{-1} reported a highest mean with 0.18 (Table 4.8)**.**

The high root: shoot ratio for the control plot was due to vibrant growth of roots as they scavenge for more nutrition in the deeper layers of soil. Thus, enhancing increased growth in the lower tissues than the above ground biomass. In case of urea having a higher root: shoot ratio in Mwea it could be due to enhanced growth of both the canopy and the rooting system due to high assimilation of urea into the growth organs.

Table 4.8 Mean root to shoot ratio as affected by N sources and levels at vegetative, reproductive and harvesting stages

		Root: Shoot				
Method		**Ahero**			**Mwea**	
	VS	**RS**	**HS**	**VS**	**RS**	**HS**
Fulldose	0.19^{a}	0.22^{a}	0.36^{a}	0.13^{a}	0.35^{a}	0.33^{a}
Split	0.19^{a}	0.22^{a}	0.33^{a}	0.10^{a}	0.28^{a}	0.28^{a}
LSD	0.03	0.04	0.07	0.04	0.08	0.08
N rates kg ha^{-1}						
Control	0.25^{a}	0.28^{a}	0.41^{a}	0.05^{b}	0.36^{a}	0.23^{a}
As25	0.17^{ab}	0.19^{a}	0.37^{a}	0.11^{ab}	0.33^{a}	0.39^{a}
As50	0.15^{b}	0.19^{a}	0.40^{a}	0.13^{ab}	0.24^{a}	0.31^{a}
Ur25	0.19^{ab}	0.24^{a}	0.32^{a}	0.12^{ab}	0.28^{a}	0.31^{a}
Ur50	0.19^{ab}	0.20^{a}	0.31^{a}	0.18^{a}	0.31^{a}	0.33^{a}
LSD	0.09	0.10	0.18	0.10	0.20	0.22
M*NR	NS	NS	NS	NS	NS	NS

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$). VS- Vegetative stage (60 DAT), RS- Reproductive stage (90 DAT), HS- Harvesting stage (120DAT), M-methods of N application, NR-Nitrogen rates As25-Ammonium sulphate 25 kgha^{-1} AS50-Ammonium sulphate 50 kgha^{-1}, Ur25-Urea 25 kgha^{-1}, Ur50- Urea 50 kgha^{-1}

These findings are consistent with those of Nahar and Pan, (2015) who reported that there was higher root: shoot ratio with a higher urea application in castor bean. At reproductive and harvesting stages there were no significant differences ($p \leq 0.05$) as illustrated in table 4.8. This could be probably due to maximization of root and shoot growth as the plants reaches reproductive and ripening phases of their life cycle.

Thus, the nitrogen uptake during these stages is used for flower initiation and grain filling. These findings agree with those of Bonifas *et al*. (2005) who reported that nutrient stress influences increased roots at the early stages of growth in maize.

4.2.7 Yield and Yield components as affected by nitrogen source, rate and methods of application

Nitrogen sources and rates led to significant differences ($P \leq 0.05$) in rice grain yield in both study sites. The lowest yields were observed in the control treatments (6,900 $kgha^{-1}$ and 4,300 $kgha^{-1}$) in Ahero and Mwea respectively. Ammonium sulphate at 50 $kgha^{-1}$ recorded the highest yield with 11,200 $kgha^{-1}$, 7,900 $kgha^{-1}$ in Ahero and Mwea respectively (Table 4.8). The results showed that ammonium sulphate at 50 $kgha^{-1}$ had the higher yields, which could be probably due to the higher nitrogen efficiency exhibited by these fertilizers. The fact that they have less chances of being lost through volatilization than in the case of urea, and this may partially explain why the ammonium treated plants were superior. Methods of application were not statistically significant ($P \leq 0.05$) in the two sites for grain yield. In Mwea methods showed significant difference on straw yield and harvest index (Table 4.9).

Table 4.9 Yield and Yield components as affected by rates of N sources at vegetative, reproductive and harvesting stages

		Yield and yield components				
Method		**Ahero**			**Mwea**	
	Yield Kg/ha^{-1}	**Straw Yield Kg/$^{ha-1}$**	**HI**	**Yield Kgha^{-1}**	**Straw Kgha^{-1}**	**HI**
Full dose	8200^{a}	20800^{a}	0.26^{a}	6200^{a}	6700^{a}	0.48^{a}
Split	9000^{a}	20500^{a}	0.24^{a}	6900^{a}	6200^{b}	0.53^{b}
LSD	1100	300	0.02	80	300	0.04
N rates kg/ha^{-1}						
Control	6900^{c}	14400^{c}	0.17^{b}	4300^{b}	4300^{b}	0.47^{a}
As25	9600^{ab}	22500^{ab}	0.26^{a}	7300^{a}	7600^{a}	0.48^{a}
As50	11200^{a}	24700^{ab}	0.31^{a}	7900^{a}	7500^{a}	0.51^{a}
Ur25	7800^{b}	19200^{abc}	0.27^{a}	7800^{a}	7500^{a}	0.51^{a}
Ur50	8300^{ab}	25800^{a}	0.30^{a}	7900^{a}	7500^{a}	0.51^{a}
LSD	3300	6800	0.08	2100	9400	0.09
M*NR	*	NS	NS	NS	NS	NS

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$). M- Methods of application, NR-Nitrogen rates As25-Ammonium sulphate 25 kgha^{-1} AS50-Ammonium sulphate 50 kgha^{-1}, Ur25-Urea 25 kgha^{-1}, Ur50- Urea 50 kgha^{-1}

Nitrogen sources and rates exhibited significant differences ($P \leq 0.05$) in the two study sites where the control had the lowest straw yield recording 11,400 kgha^{-1} in ahero and Mwea with 430 kgha^{-1} the highest was obtained in Urea at 50 kgha^{-1} recorded 25,800 kgha^{-1} ahero while in Mwea ammonium sulphate 25 kgha^{-1} was highest with 7,600 kgha^{-1} (Table 4.9). The straw yield could have been influenced by high vegetative growth that was influenced by the better growth through utilization of applied N that resulted to high biomass. In harvest index (HI), there were significant differences ($P \leq 0.05$) due to nitrogen sources compared with the control in Ahero study site, while in Mwea there were no significant differences observed. The highest HI was observed where ammonium was supplied at 50 kgha^{-1} with 0.31 while the unfertilized plot had the lowest recording 0.17 as illustrated in Table 4.9. Interactions between nitrogen rates, and methods of application were revealed in grain yield where ammonium sulphate at 50 kgha^{-1} and 25 kgha^{-1} applied in full dose resulted to highest grain weight as shown in Figure 4.7 in Ahero while in Mwea there were no significant differences.

Interactions between nitrogen rates, and methods of application were revealed in grain yield where ammonium sulphate at 50 kgha^{-1} and 25 kgha^{-1} applied in full dose resulted to highest grain weight as shown in Figure 4.7 in Ahero while in Mwea there were no significant differences.

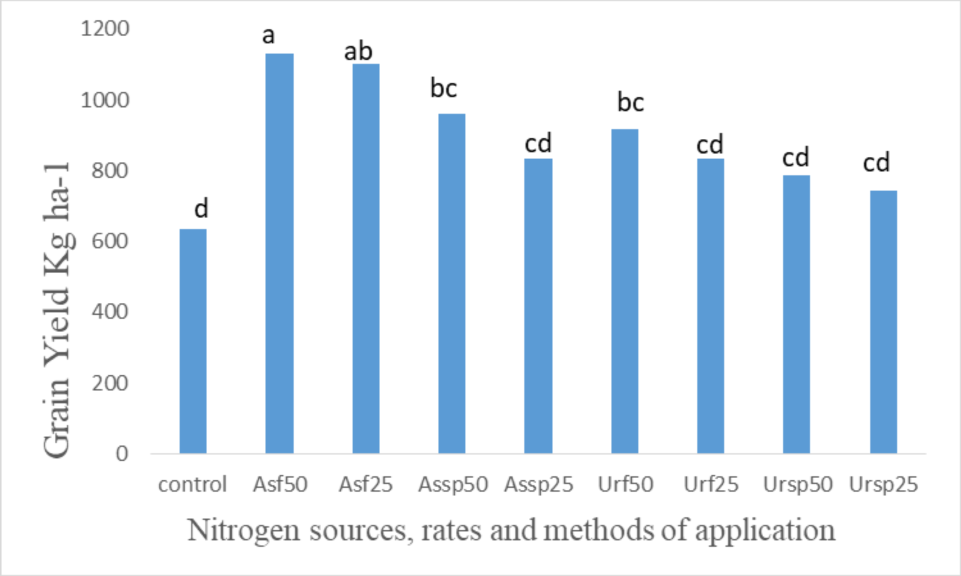

Figure 4.7 Interactions effects on nitrogen sources, rates and methods of application on grain yield in Ahero study site. Ursp25-Urea split 25kgha^{-1}, Ursp50-urea split 50kgha^{-1}, Assp25-Ammonium sulphate split 25kgha^{-1}, Assp50- Ammonium sulphate fulldose 50kgha^{-1} Urf25-Urea fulldose 25kgha$^{-1,}$ Urf50-urea fulldose 50kgha^{-1}, Asf25-Ammonium sulphate fulldose 25kgha^{-1}, Asf50- Ammonium sulphate fulldose 50kgha^{-1}

In addition, this was evident when either urea and ammonium forms were applied in either full dose or split forms. The control had the lowest level of yield while the highest was observed in both the Urea and ammonium sulphate 50 kgha^{-1} when applied in either full dose or split method. This study agrees with the results of Balasubramanian *et al.* (2007) who reported a relative increase in yield of upland rice when supplied with ammonium sulphate. However, another experiment by Fageria *et al.* (2010) working with ammonium sulphate did not result to higher yield when compared to urea in rice. There are other factors that may lead to such differences, among them being the variety used, soil structure, oxidation status and pH of the soil.

The data on straw yield was consistent with the report given by Islam *et al.* (2012) who found out that when rice plants treated with Urea resulted to highest weight of straw yield followed by ammonium sulphate in Sri Lanka. When plants have higher number of effective tillers there is a likelihood of having increased straw yield. Another study by Shubhashree *et al*. (2017) also confirmed that application of urea briquette significantly ($p \leq 0.05$) increased the yield attributes and components; including straws. A study done by Chen *et al.* (2016) demonstrated increase in straws yield when treated with different levels of urea. When urea is supplied in sufficient amounts during the early stages of growth it accelerates the aboveground biomass. The higher straw yield can be a good source of feed to livestock, especially where the farmers use them as animal feeds.

The increased harvest index in Ahero from the N fertilize plants could be due to efficient partitioning of assimilates towards the economic portion. Additionally, this could be as a result of sufficient uptake of nitrogen hence contributing to relatively increased accumulation of biomass and grain formation. These findings are in agreement with those of Hokmalipour and Darb, (2011) who reported that nitrogen levels resulted into a higher harvest index in maize resulting from optimum growth facilitated by nitrogen. In another study by *et* Kim *et al.* (2001), it was reported that application of urea at different levels led to increase in harvest index due to high simulative growth and biomass accumulation during growth stages of rice. A higher harvest index in rice crop is considered to be as result of grain population and consequent increase in grain weight, which is a factor influenced by nitrogen nutrition (Nakandalage *et al.*, 2016). This was mainly due to higher efficiency and less losses of nitrogenous fertilizers during the initial stages that promoted vigorous vegetative growth and hence was reflected in the yield. Thus, there is possibility that plants have higher chances of converting applied nitrogen into potential yield when applied just after transplanting. These findings are in disagreement with those of Fu, (2001) who reported that split application of ammonium sulphate had better yield than when applied in single doses. Another study done by Graham and Varco, (2017) on sunflower indicated that when nitrogen was supplied inform of ammonium sulphate in single dose it performed better than when split.

From the regression analyses (Fig. 4.8 and 4.9), yield increased with N rates and the response assumed polynomial function, particularly at Mwea site where the R2 values were 0.64 and 0.86 for urea full dose and slit applications respectively. The same trend was observed with ammonium (R_2= 0.64 and 0.80 for full dose and split applications respectively. The trend in Ahero was however very different with R2 values being quite low and hence unable to explain grain yield in terms of fertilizer. In the two sites, there was a corresponding increase in the grain yield with increase in nitrogen rates irrespective of the source (urea or ammonium) in the two sites (Figures 4.8 and 4.9). These may imply that the plants were responding to the increase of the nitrogen nutrition and an increment in the addition would probably lead to more yield. This may be a pointer that the doses used by the farmers are well below the plant’s needs, which partially agree with the high NUE in these sites.

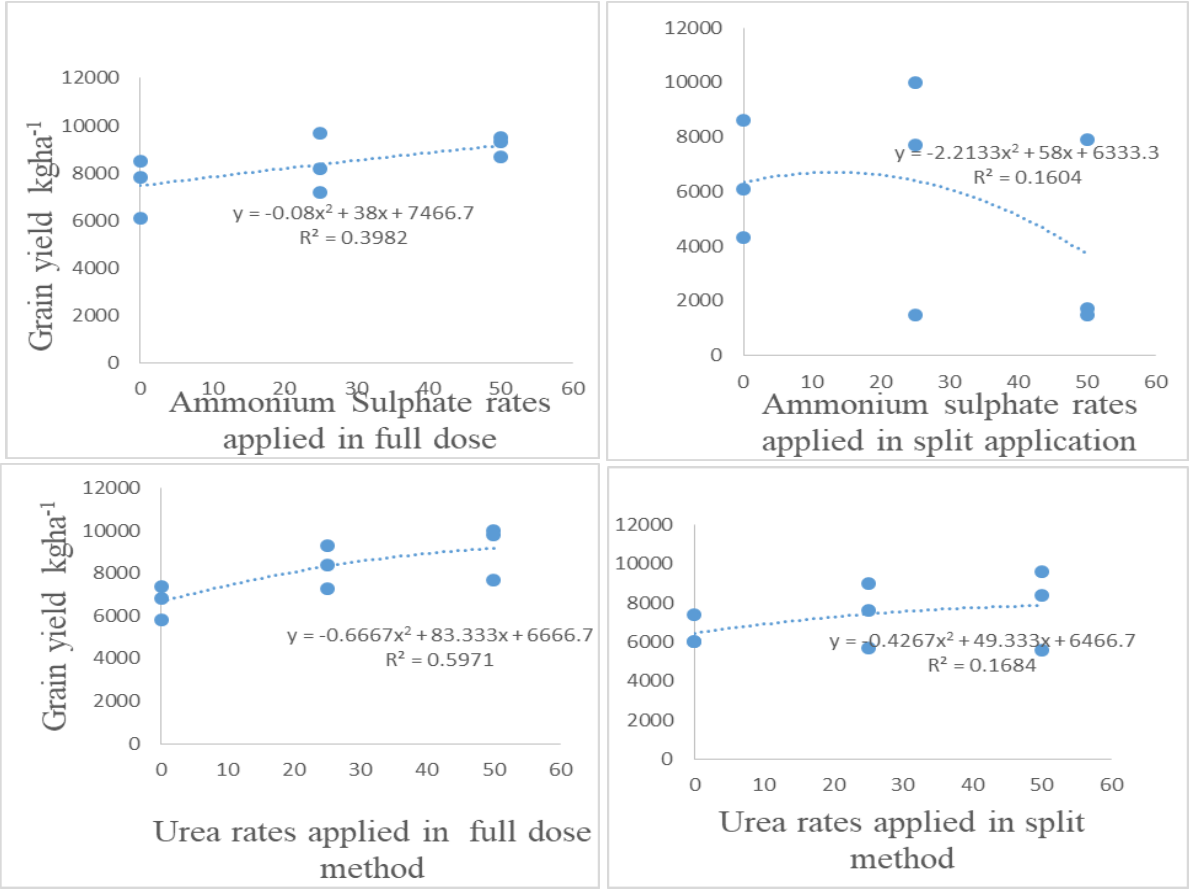

Figure 4.8: Regression analysis on grain yield and nitrogen sources, rates and methods for rice in Ahero study site

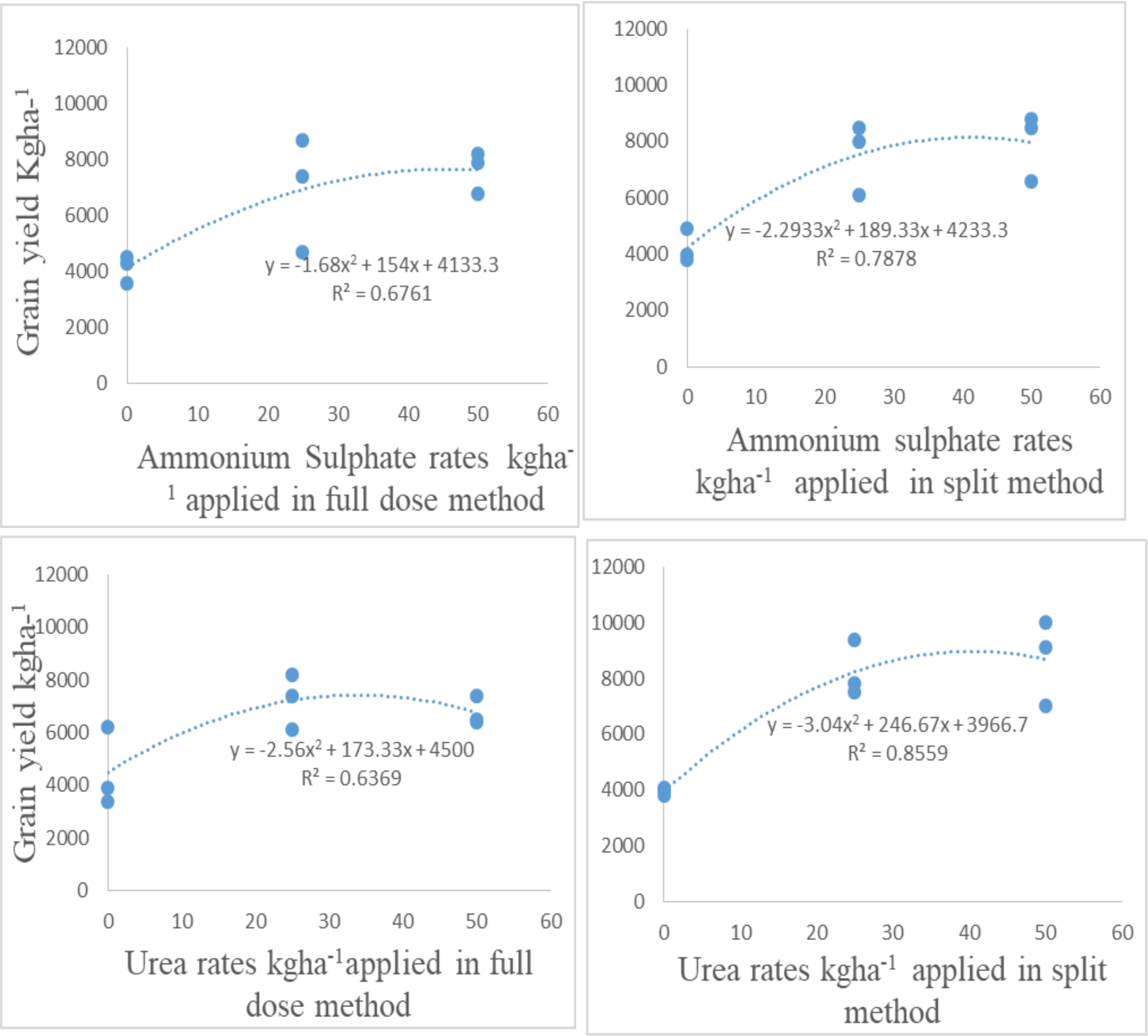

Figure 4.9: Grain yield as a polynomial function of nitrogen sources, rates and methods for rice in Mwea study site

The results of this study are in disagreement with those of Moro *et al.* (2015) who reported an increment in grain yield in rainfed rice up to a certain level of 90 kgha^{-1} and declining beyond this level in Ghana. The disagreement could be probably due to the different environment since in rain fed the arte of emission and leaching are minimal compared to low land rice hence leading to high efficiency that maximize yield. The findings of this study are in agreement with those of Ahmed *et al*. (1993)

who reported an increase in the yield of barley in response to an increase in nitrogen levels. In another study done in India, it was also reported that wheat grain yield increased with an increase addition of N levels (Sabir *et al.,* 2002). The results are also in agreement with those of Zhu *et al.* (2017) who reported an increased in yield of japonica soft super rice with an increment with nitrogen levels in Nainjing China. In another study by Zhou *et al.* (2017), it was reported that rice and nitrogen levels established a positive relationship in the increment of the grain yield.

4.3 Nitrogen partitioning in different plant organs as affected by nitrogen forms, rates and methods of application at different phenological stages

4.3.1 Vegetative Stage

The nitrogen partitioning in the rice plant organs was different across all sources and levels of N at this initial stage of plant growth, and this was observed in the two sites. In Ahero both Ammonium sulphate and urea at 50 kgha^{-1} had the highest N concentration partitioned to the roots, with each treatment recording 34% (figure 4.10). However, in Mwea urea at 50 kgha^{-1} partitioned the highest amount of N (47.5%) to the roots (Fig. 4.11). The roots were followed by the stems in terms of N partitioning, while leaves had the least N partitioned to them at this initial stage of plant growth. Similar trends were observed with the control (Appendix 4).

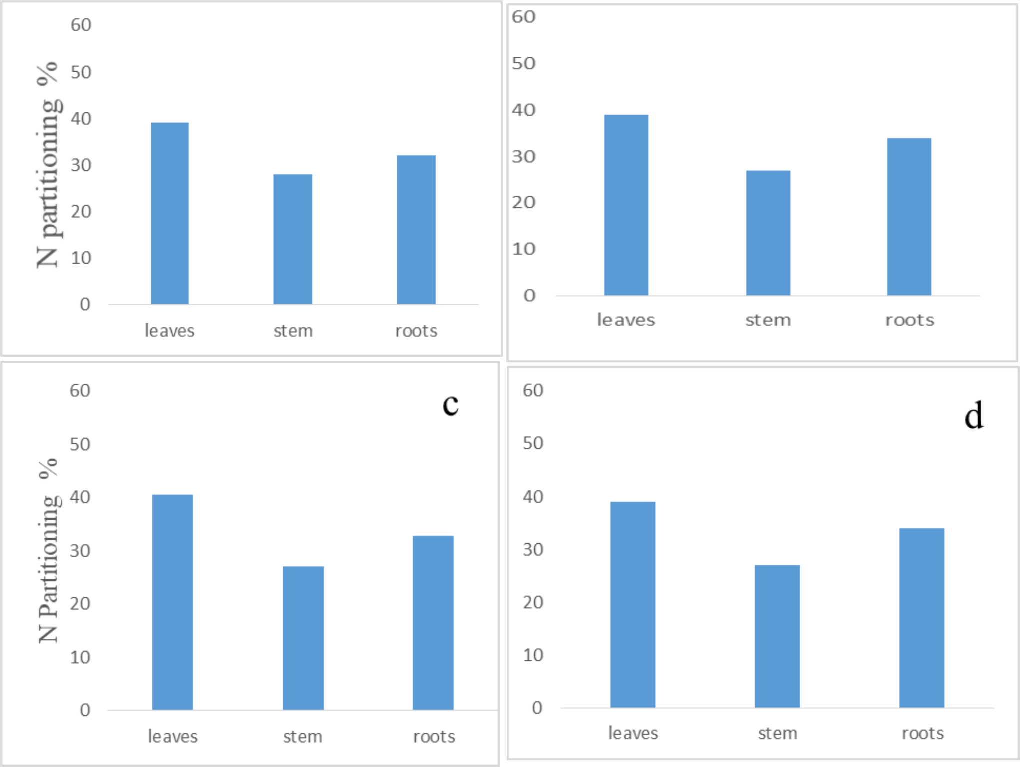

Figure 4.10: Mean nitrogen partitioning percentage in Ahero at vegetative stage (60 DAT) a- AS25kg ha^{-1}, b-AS 50kg ha^{-1} , c-urea 25kg ha^{-1} , d-urea 50 kg ha^{-1}

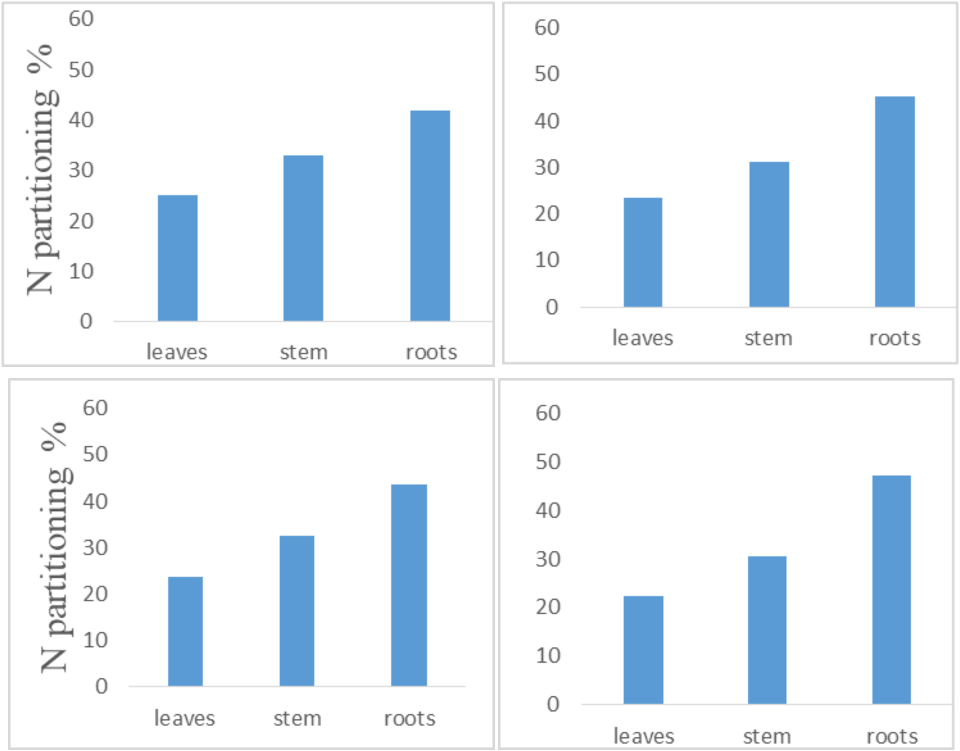

Figure 4.11: Mean nitrogen partitioning percentage in Mwea at vegetative stage (60 DAT) a- AS25kg ha^{-1}, b-AS 50kg ha^{-1} , c-urea 25kg ha^{-1} , d-urea 50kg ha^{-1}

The concentration of N partitioned to the roots at this stage could probably be due to high demand of nitrogen during this stage by younger and actively developing organs hence exerting greater demand for nutrients, consequently triggering roots to absorb more. These findings are in agreement with those of Dogan *et al.* (2007), who reported that at vegetative stage roots absorbs considerable amount of supplied nitrogen to cater for the demand of the rapidly multiplying young plant organs at this particular stage. It has also been reported that plants also acquire sufficient amount of nitrogen during vegetative stages to enhance growth of strong stems to avoid lodging that may result to greater economic losses (Pinheiro *et al.*, 2001).

4.3.2 Reproductive Stage

At reproductive stage, there was also variability observed in the concentration of N partitioned to the different rice plant organs. Irrespective of N sources and levels, the results from Ahero had higher N content partitioned to their leaves as compared to other organs. Furthermore, the results revealed that urea at 25 kgha^{-1} had the highest N partitioned to leaves (53%), while the stems and roots had 20 and 24% respectively (Figure 4.12). The trends were similar with urea at 50 kgha^{-1} as well as ammonium sulphate at both 25 and 50 kgha^{-1}. The increase in partitioning to the leaves could be attributed to high uptake in the roots and higher translocation to the leaves for reproductive processes. On the contrary, the trend in Mwea site was different with higher amount of N being channeled towards the roots than in stems and leaves. For instance, urea at 50 kgha^{-1} channeled 45.2% of its N to the roots compared with 19 and 23% to the stems and roots respectively (Figure 4.13). This implied that there was higher uptake of N from the soil and less was being translocated to the reproductive organs. The control had the lowest partitioned to the leaves compared to other treatments in the two sites (Appendix 5).

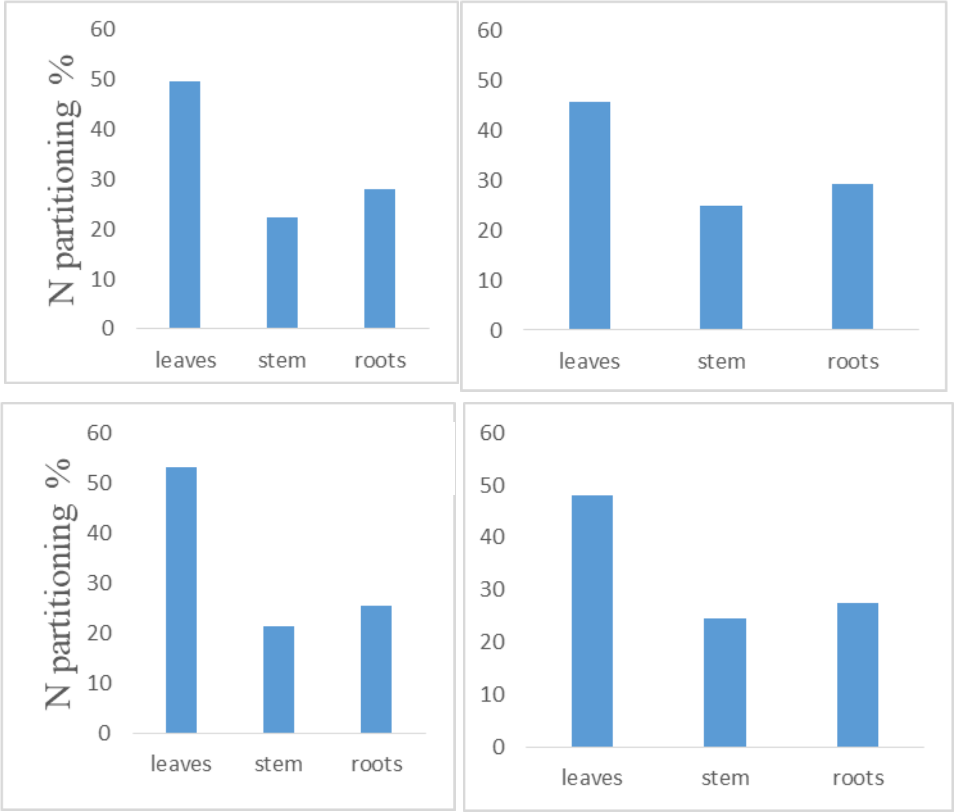

Figure 4.12: Mean nitrogen partitioning percentage in Ahero study site at reproductive stage (90 DAT) a- AS25kg ha^{-1} , b-AS 50kg ha^{-1} , c-urea 25kg ha^{-1} , d-urea 50kg ha^{-1}

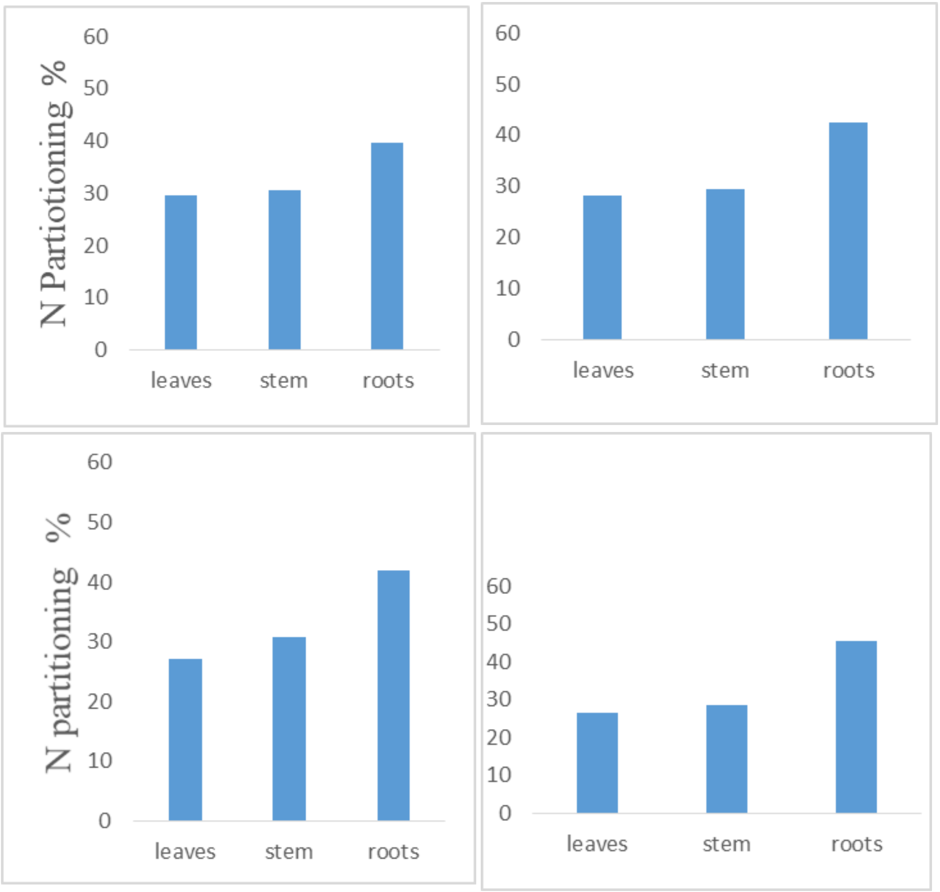

Figure 4.13: Mean nitrogen partitioning percentage in Mwea study site at Reproductive stage (90 DAT) a- AS25kg ha^{-1}, b-AS 50kg ha^{-1} , c-urea 25kg ha^{-1} , d-urea 50kg ha^{-1}

Nitrogen is also readily translocated within the plants moving from older to younger tissues to promote growth in those sections more so in the shoot tips especially during reproductive stage. Supply of nitrate to leafy vegetables promotes metabolic pool and storages in the leaf blade pools to enhance productivity potential (Chen *et al.*, 2004).

These results are inconsistent those of Ye *et al.,* (2014) who reported that leaf N content decreased during the reproductive stages in cereal crops. In another study done by Linquist *et al.*, (2006), most of the nitrogen is concentrated in the leaves during the productive stage due to the higher photosynthetic processes that the plants taking place. Therefore, there is increased recovery of N during reproductive stages due to efforts to achieve maximum production. These findings are in agreement with those of Gallais *et al.* (2006) who reported that in maize low nitrogen concentration was experienced at the second phase of reproductive stage upon application of nitrogen levels however, due to some climatic conditions a higher concentration would be experienced in the roots at this stage than any other organs. This was due to the hydrolization of nitrogen that is transported to the reproductive organs to cater for the flowering and grain filling processes (Gallais *et al.,* 2006).

4.3.3 Harvesting Stage

At harvesting stage, the amount of N partitioned to plant organs exhibited some variations. In both study sites, at harvesting stage, the greatest amount of N was partitioned to the grain compared the other organs. The leaves followed this and the trend was the similar in all treatments. For instance, at Ahero site, Urea at 25 kgha^{-1} had highest N partitioned towards grain and leaves 33.3% and 32% respectively) (Figure 4.14). In Mwea, Ammonium sulphate 25 kgha^{-1} had highest N partitioned to grain and leaves (36.6% and 31.6% respectively) (Figure 4.15). In both sites, the control had the lowest N partitioned to the grain although the trend was similar with the N treatments (Appendix 6).

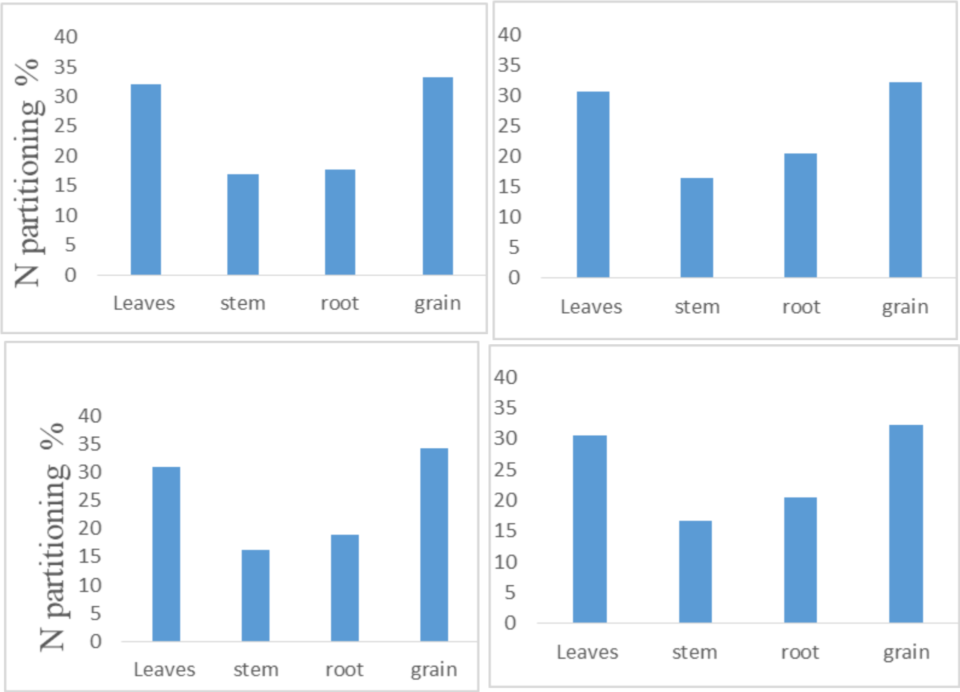

Figure 4.14: Mean nitrogen partitioning percentage in Ahero study site at harvesting stage (120 DAT) a- AS25kg ha^{-1}, b-AS 50kg ha^{-1} , c-urea 25kg ha^{-1} , d-urea 50kg ha^{-1}

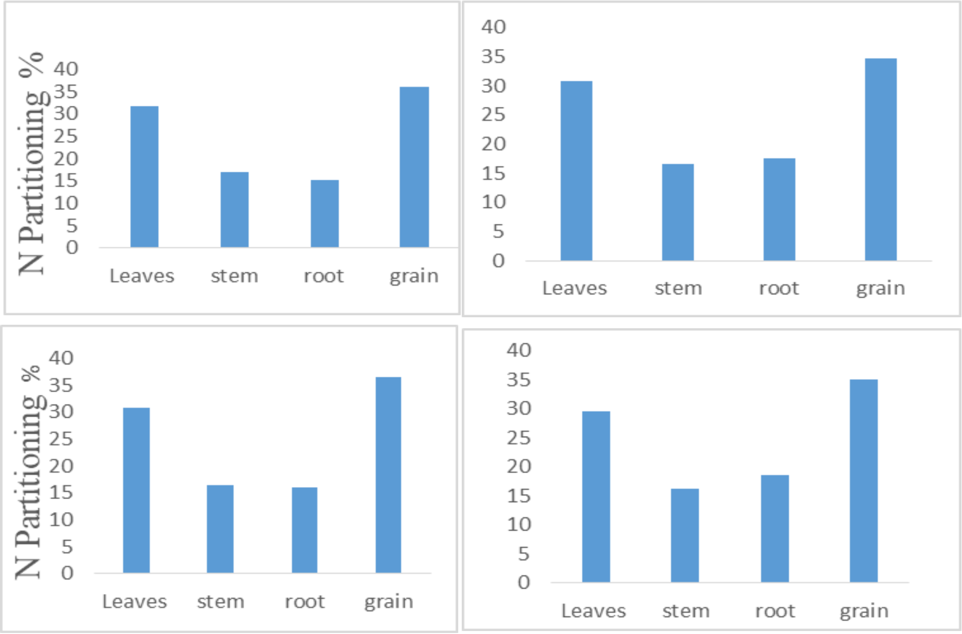

Figure 4.15: Mean nitrogen partitioning percentage in Mwea study site at harvesting stage (120 DAT)

The high nitrogen content partitioned to the leaves at ripening stage could be due to a greater accumulation of nitrogen by the plant during ripening as a mechanism of maintaining a high photosynthetic rate that would enhance grain-filling process. The nitrogen is also reported to be very crucial in translocation of carbohydrates from the source to the sink. This study results agrees with the findings of Qsaki, *et al.* (1995) who reported that potato tuber showed higher concentration of nitrogen at ripening stages when supplied with ammonium. The IR variety of rice that was used in this experiment is reported to have capacity of exhibiting considerably higher nitrogen contents in the leaves due to its inherent genotypic characteristics due to high nitrogen responsive receptors (Garnett *et al.* 2015). In the grain, high N could be attributed to remobilization from mature organs e.g. leaves and stems through degradation of all nitrogen compounds and consequently accumulated for grain maturation (Yoneyama *et al.* 2016). The high nitrogen percentage is an indication of large portion of nitrogen getting exported from the farm hence indicating one of the sources through which applied nitrogen is exported from the growing field. These arguments are in tandem with those of Fageria and Baligar, (2005), who demonstrated that grain N in cereals was always higher than those of the shoots due to remobilizations and translocation of nitrogen from vegetative parts of the plants soon after the anthesis stage. In another study by Iqbal *et al.* (2006), it was reported that ammonium sulphate contributed to higher nitrogen concentration in the grain when compared to other sources of N. These results are also supported by findings of Bertheloot *et al.* (2008) who showed that grain N accumulation is usually regulated by nitrogen sources, is in accordance to the kinetics of Rubisco biosynthesis and content as well as grain N accumulation; suggesting that during grain filling, N translocation from the vegetative organs is mainly limited by the availability of the substrate in the source organs. The concertation of N in the stem and leaves is also another indication of losses of nitrogen from the farm for the case where farmers use it as hay or even burn. However, in most of the farming systems roots are lefts in the field, hence enhances recycling of the nitrogen partitioned in the roots. These findings are also in agreement with those of Cao *et al*. (2018) who reported that that in rice crops more nitrogen is partitioned to the grain at harvesting stage.

4.5 Nitrogen Uptake by rice as affected by N sources and levels

Significant differences ($P \leq 0.05$) were observed on the plant nitrogen uptake at vegetative, reproductive and harvesting/maturity stages at the two study sites as shown in Table 4.10. During vegetative stage, ammonium sulphate at 50 kgha^{-1} resulted into highest nitrogen uptake per plant 13.93 kgha^{-1} while the control had the least of 4.08 kgha^{-1}. The same trend was observed in Mwea where Ammonium sulphate at 50 kgha^{-1} recorded 20.07 kgha^{-1} and the control had the lowest uptake of 7.02 kgha^{-1}. Significant differences were observed at stage in ahero study between full dose and split method of N application. Full dose method was superior with 10.15 kgha^{-1}(Table 4.10).

Table 4.10 Mean nitrogen uptake by plants affected by N sources and levels at vegetative, reproductive and harvesting stages

			Nitrogen Uptake Kg ha^{-1}			
Method		**Ahero**			**Mwea**	
	VS	**RS**	**HS**	**VS**	**RS**	**HS**
Full dose	10.15^{a}	25.79^{a}	112.50^{a}	11.76^{a}	65.73^{a}	355.00^{a}
Split	7.60^{b}	27.30^{a}	116.50^{a}	12.72^{a}	60.85^{a}	360.00^{a}
LSD	2.209	4.55	24.83	2.68	9.01	6.30
N rates kg ha $^{-1}$						
Control	4.08^{d}	15.47^{c}	61.33^{c}	7.02^{c}	43.84^{c}	162.18^{c}
AS25	7.7^{bcd}	28.37^{bc}	113.57^{b}	10.97^{bc}	74.91^{ab}	346.54^{b}
AS50	13.92^{a}	38.06^{a}	186.95^{a}	20.07^{a}	90.18^{a}	549.55^{a}
UR25	9.10^{bc}	20.96^{c}	94.66^{bc}	12.34^{bc}	53.60^{bc}	328.36^{b}
UR50	12.25^{ab}	39.46^{a}	161.02^{a}	15.92^{ab}	67.95^{abc}	559.57^{a}
LSD	4.51	11.17	39.34	7.49	25.17	163.55
M*NR	NS	NS	NS	NS	NS	NS

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$). VS- Vegetative stage (60 DAT), RS- Reproductive stage (90 DAT), HS- Harvesting stage (120DAT) M- method of application, NR- Nitrogen rates As25-Ammonium sulphate 25 kgha^{-1} AS50-Ammonium sulphate 50 kgha^{-1}, Ur25-Urea 25 kgha^{-1}, Ur50- Urea 50 kgha^{-1}

The uptake at vegetative stage depends on the rate of crop growth, which is also affected by other environmental factors as well as the amount of nitrogen applied. Additionally, during the vegetative stage there is great biomass accumulation due to extensive growth of organs such as roots leaves and stems/tillers. These findings are in agreement with those of Arkoun *et al.,* (2012) who reported that ammonium sulphate resulted to higher nitrogen uptake in oil seed due to its potential of mobilizing N during vegetative stages. At reproductive stage, there was an increase for uptake by the plants across all the treatments in the two sites. The trend observed at reproductive stage was the same for the vegetative phase, with ammonium sulphate 50 kgha^{-1} exhibiting the highest uptake of N recording 38.06 kgha^{-1} and 90.18 kgha^{-1} for Ahero and Mwea respectively, while the unfertilized plants had the lowest recording 15.47 kgha^{-1} and 43.84 kgha^{-1} in Ahero and Mwea respectively. This increase in nitrogen could be attributed to the high demand of nitrogen by plants during this stage to initiate flowering as well as to enhance grain formation and filling.

At reproductive stage, there is the remobilization of nitrogen from the other organs, which is majorly concentrated in the reproductive organs hence resulting to higher intake of nitrogen during this period. These findings agree with those of Kamekawa *et al.* (1990) who reported that urea had the potential of having a higher nitrogen uptake compared to ammonium sulphate at reproductive stages of rice due to its slow release of nitrogen during the initial stages of growth and later promoting increased growth during the later stages. At ripening stage ammonium sulphate 50 kgha^{-1} had a high nitrogen uptake while control (no additional N) had the lowest, with each recording 186.95 and 61.33 kgha^{-1} respectively at Ahero (Table 4.10). In Mwea urea at 50 kgha^{-1} had the highest uptake with 559.57 kgha^{-1}. The increase at this stage was probably due to a considerable amount of nitrogen that was accumulated in the grain and which was not the case during the other growth stages (Awan, 2002). At harvesting, there is translocation of nitrogen absorbed during vegetative and reproductive to the grain to enhance maximum yields. Urea applications results to lower efficiency during the early growth stages when the plants are not actively in need of N nutrition since its losses to atmosphere depending on the weather conditions is assumed to between 7% to 40% especially in flooded rice field where it is not incorporated to the soil, resulting to poor utilization of applied N (Dobermann, 2000). In a study done Awan, (2002) similar results were reported that ammonium sulphate was better in terms of total nitrogen uptake at harvesting stages compared to urea in rice fields.

4.6 Nitrogen Use and Agronomic Efficiencies

Significant differences ($P \leq 0.05$) were observed in nitrogen use efficiencies in the two sites at various growth stages. At reproductive and harvesting stages, there was an increase in the NUE at both Ahero and Mwea study sites. Ammonium sulphate at 50 $kgha^{-1}$ showed superiority in Ahero having a NUE of 31.96 while in Mwea had 134.39 at reproductive stages. Method of N application did not show any significant differences ($p \leq 0.05$) in the two study sites. (Table 4.11). In Mwea the 134.96 exceeds the normal range of the NUE, which is normally expressed as percentage. This is an indication of increased N recovered in the plant compared to what was applied. In this case, there is an indication of soil degradation and declining fertility and hence the plants mines the soil in the aim of satisfying its need at this critical stage of growth. At the harvesting stage, urea at 50 $kgha^{-1}$ recorded a NUE of 146.53, which was also an indication of soil.

Table 4.11 Mean Nitrogen use efficiency (NUE) and as affected by N sources, levels and methods at vegetative, reproductive and harvesting stages

	NUE					
Method			**Ahero**		**Mwea**	
	VS	**RS**	**HS**	**VS**	**RS**	**HS**
Full dose	18.20^{a}	40.80^{a}	159.00^{a}	20.00^{a}	96.50^{a}	54.60^{a}
Split	12.80^{a}	46.70^{a}	182.00^{a}	20.00^{a}	90.40^{a}	60.80^{a}
LSD	5.89	11.11	74.8	8.00	17.50	17.70
N rates kg ha^{-1}						
As25	22.15^{a}	20.86^{ab}	73.15^{b}	27.00^{a}	20.77^{a}	90.10^{a}
AS50	20.03^{a}	31.96^{a}	120.60^{a}	34.70^{b}	134.39^{b}	86.65^{a}
Ur25	27.48^{a}	13.41^{c}	54.24^{bc}	35.50^{a}	122.70^{b}	82.84^{a}
Ur50	23.38^{a}	30.95^{a}	146.53^{a}	24.00^{a}	89.00^{b}	87.50^{a}
LSD	13.01	11.17	39.44	20.00	45.60	42.70
M*NR	NS	NS	NS	NS	NS	NS

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$). VS- Vegetative stage (60 DAT), RS- Reproductive stage (90 DAT), HS- Harvesting stage (120DAT), M –Method of N application, NR-Nitrogen rates As25-Ammonium sulphate 25 kgha^{-1} AS50-Ammonium sulphate 50 kgha^{-1}, Ur25-Urea 25 kgha^{-1}, Ur50- Urea 50 kgha^{-1}

The NUE is a considered as an indicator to measure the potential of the plants to convert the applied nitrogen to potential yield hence improve global food production (Rahimizadeh *et al.*, 2010). NUE also provides a real measure on harmful control of excess nitrogen based compounds to environment. Soil mining at reproductive and vegetative stages implies that there was a higher risk of N losses during the initial stages of application and thus leading to deficiency of N during times of demand at reproduction and ripening. These findings are in agreement with Raun and Johnson, (1999) who reported that NUE of cereal crops is high during the reproductive due to increased translocation of N uptake N from the roots to other organs. According Brentrup and Pallière, (2010), the range of 75-90% was essential in NUE in enhancing productivity, since it showed a balance between the inputs and the output of N. In this particular study, it was clear that for Mwea at harvesting stage the NUE was within the recommended range hence minimal mining of N compounds to the environment was incurred. The crop to initiative flowering as well as grain filling process uses the higher demand for nitrogen nutrition during this stage. A balance in yield implies that the plant was capable of meeting the demand of the straw, grain and roots (Ying *et al.*, 1998). These findings also agree with those of Peng, *et al.*, (1996), who reported that in irrigated rice there is a higher NUE at reproductive stage.

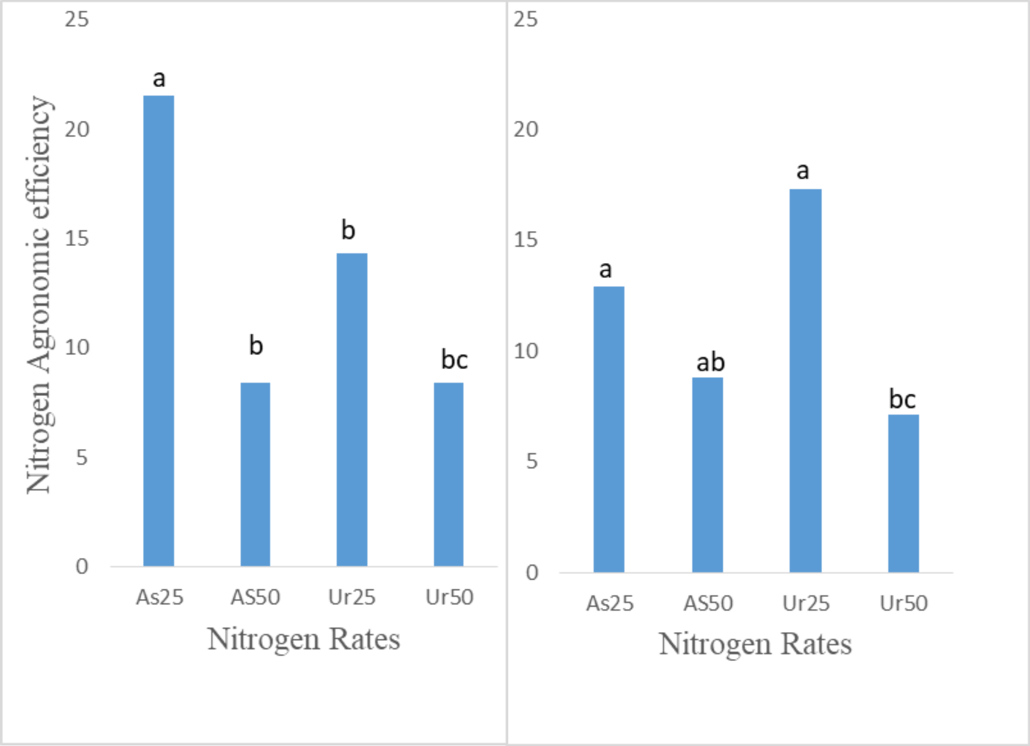

Figure 4.16: Mean nitrogen agronomic efficiency as affected by Nitrogen rates at Ahero (a) and Mwea (b) study sites. As25-Ammonium sulphate 25 kgha^{-1} AS50-Ammonium sulphate 50 kgha^{-1}, Ur25-Urea 25 kgha^{-1}, Ur50- Urea 50 kgha^{-1}

The NAE was also significantly ($P \leq 0.05$) affected by N sources and levels in the two sites. In Ahero, Ammonium sulphate 25 kgha^{-1} had the highest nitrogen agronomic use efficiency with recording 21.53 while in Mwea urea at 25 kgha^{-1} resulted in a higher NAE with 17.30(figure 4.16). This implied that at lower rate there was greater returns in the grain as a function of the nutrient applied. These findings are in agreement with those of Sandoval *et al.* (2017*)* who reported that lower rates of N results to higher NAE.

4.7 Nitrogen Harvest Index (NHI)

Significant differences ($p \leq 0.05$) were observed in NHI in Mwea study site but it was not significant in Ahero study site. In Mwea Urea 50 kgha^{-1} had the highest NH1 with 0.66 (Table 4.12). This could be due to high efficiency of utilization of N applied by the plant. Split and full doses method of application were insignificant ($p \leq 0.05$) in both Ahero and Mwea study sites. According to Yesuf, and Balcha, (2014), a higher level of NHI is a measure of the nitrogen acquired and transformed in the grains due to high efficiency of the N rate applied.

Table 4.12 Mean Nitrogen Harvest Index as affected by N sources methods and levels in the study sites

	Nitrogen Harvest Index	
Method	**Ahero**	**Mwea**
	NHI	
Full dose	0.42^{a}	0.62^{a}
Split	0.42^{a}	0.59^{a}
LSD	0.06	0.05
N kg/ha		
Control	0.36^{a}	0.51^{b}
As25	0.44^{a}	0.64^{a}
AS50	0.43^{a}	0.61^{ab}
Ur25	0.39^{a}	0.65^{ab}
Ur50	0.44^{a}	0.66^{ab}
LSD	0.13	0.11
M*NR	NS	NS

Means followed by the same letter within the same column are not significantly different ($P \leq 0.05$). M-methods of N application, NR-Nitrogen rates As25-Ammonium sulphate 25 kgha^{-1} AS50-Ammonium sulphate 50 kgha^{-1}, Ur25-Urea 25 kgha^{-1}, Ur50- Urea 50 kgha^{-1}

In the grain N derived from vegetative parts after anthesis is remobilized and relocated in the grain hence contributing to high proportion on the applied N in the grain than any other part of the plant. Additionally, the higher concentration of N in the grain is as a result of decreases in the pools of N reserves soon after anthesis and thus a considerable amount is translocated to the grain (Fergusson, 1999). The findings of this study are however in disagreement with those of Tana et al. (2015) who reported a decline on NHI because of higher application N levels in wheat. Therefore, having a higher NHI is an economical indication than the amount of N applied is recovered back in the grain, which contributes to nutrition of proteinous compounds to humans. Also, the higher the efficiency of utilization of the N applied the less the loss hence promoting improved management of N fertilizers in rice fields.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study demonstrated that farmers widely used SA and urea fertilizers in production of rice. A number of the farmers are also aware of nitrogen losses but a few demonstrated to have knowledge on nutrient pollution aspects. Straw management practices are the key factors leading to high losses of nitrogen hence leaving the agricultural field depleted of nutrients. Burning, feeding to livestock and selling out to neighbours were some of the common practices embraced by farmers.

The results also illustrated that ammonium sulphate performed better in rice as depicted in the findings of various growth and yield parameters such as number of tiller, height, shoot and root dry biomass, straw weight, grain yield and harvest index. When ammonium sulphate was applied in full dose it resulted to better yield than when applied in split in Ahero.

There were significant differences observed in nitrogen partitioning with the highest being observed in the grains harvested with ammonium sulphate at 50 kgha^{-1} showing the higher nitrogen concentration in both Mwea and Ahero. A highest nitrogen uptake and partitioning data was during reproductive stage, probably due to the process of flowers initiation and grain formation.

Nitrogen use efficiency varied significantly across vegetative, reproductive and ripening stages with the harvesting stage having the highest efficiency of nitrogen which was attributed to the grain formation that required a considerable amount of nitrogen to complete the ripening stage to economic factors. Additionally, Nitrogen agronomic efficiency varied significantly with the lower rates giving a higher value.

5.2 Recommendations

- Through the findings of this study, it is recommended that the county and national policy makers sensitize the farmers on nitrogen losses, and nutrient pollution practices that affect production of rice through use of fertilizers. There is also need to embark on good agricultural management practices of straw as way of reducing exportation of potential and available nitrogen to non-reproductive areas.

- Due to the fact that Ammonium sulphate fulldose at 50 kgha^{-1} gave the highest yield, farmers can be encouraged to use this dose for rice production to maximize yield hence achieving the food security goals.

- Farmers need to apply N at reproductive stage as one of the effective stage to increase the nitrogen recovery in the plants, minimize losses, and promote economic yield and most importantly improve nitrogen management practices.

- Further studies need to be carried out to evaluate the associations of nitrogenous compounds on NUE and NAE as an indicator of agricultural sustainability and environments factors management in a long term farming system.

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Appendices

Appendix 1: Study Questionnaire for rice farmers

Objectives of the questionnaire

1. To evaluate nitrogen use, application and management methods adopted by rice farmers in both Kisumu and Siaya.

Interview data (to be filled – in by the interviewer)

Name of interviewer	
Duration of the interview (min)	
Interview date	
Interviewee gender	Male ☐ Female ☐

Personal details (farmer)

Farmers name (optional):

____

Age: 20-30 (1) 30-40 (2) 40-50 (3) 50-60 (4) 60-100 (5)

County:______

GPS coordinates:____

Education level: primary-1, secondary-2, college- 3, and none-4

B 1. Which different rice varieties do you grow in this region? _________________

B 1.1 why do you prefer the variety?

(a) Affordable

(b) Commonly used in the region

(c) Particular seed characteristics

(d) High yielding

B2. How many years of experience do you have in rice production?

B3. How have been the returns from production? (A)High (b) moderate (c) low

B4: what is the size of your field is under rice production?

(a) 0-5 acres

(b) 6- 10 acres

(c) Above 10

B5. How many bags of rice do you produce per season?

B6. How often do you irrigate your field? A once a week, (b) twice a week, (c) thrice a week (d) every day

B7.Do you use nitrogen fertilizers for production of rice Yes-1, No- A5.1? If NO, why?

____

B7.1. If Yes. Which time of planting do you apply the fertilizers in the rice fields

____

B 7.2. Do you top-dress your rice (a) Yes (b) No

B 7.3 If YES, which form do you use?

B 7. 4. If yes at what stage (a) vegetative (b) Flowering – this similar question should be clearly asked in part 1 above.

B 7.5 If No, why______________________

B 7.6 what is the sources of the N fertilizers you use in your farm?

B8. What is the rate of fertilization do you use in the field?

(a) 40 kg/ha

(b) 50kg/ha

(c) 60 kg/ ha

(d) Not sure

____

B9. How many seasons of rice do you have in a year? (1) or (2)

B9.1 If two do you use fertilizers during both season_______________ why____________________

B 10. Which method of fertilizer application do you use (1) full dose (2) split.

B 10.1.Give a reason for each method of use (a) ___________________ (b)_________________

B11. What is the source of N used in production? (a) Commercial purchase (b) given by the board

B12. What is your annual budget for fertilizers N?

B13. Do you have any other source of agricultural income apart from rice?

B: 13.1 If yes, which are they (a) livestock, (b) employed, (c) business

B: 14. What are the key challenges that you encounter in production of rice (a) accessibility of seeds and fertilizers, (b) shortage of irrigation water, (c) marketing (d)

B: 15. Are you aware of nutrient pollution?

B 16: Are you aware of nitrogen losses mechanism such as leaching, or emissions

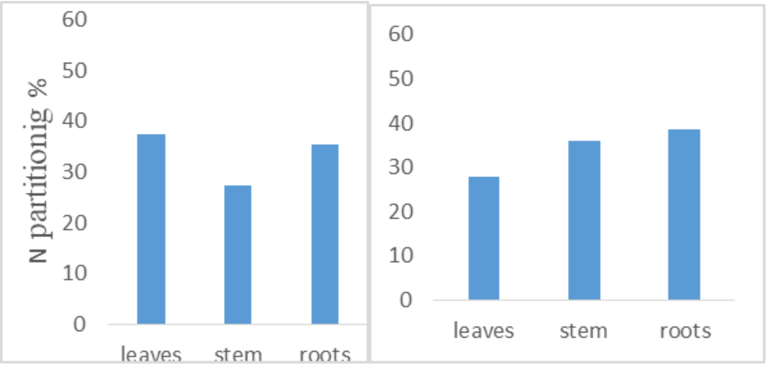
Appendix 2: Mean Root dry weight as affected by sources and levels of N and methods of application in Mwea and Ahero study site

N kg/ha	VS	RS	RS
Control	1.54a	2.98a	15.17a
Ursp25	1.55a	3.25a	17.88a
Ursp50	1.62a	4.91a	17.16a
Urf25	1.97a	4.21a	21.28a
Urf50	2.43a	4.71a	21.46a
Assp25	0.97	4.92a	27.72a
Assp50	1.22a	3.63a	17.50a
Asf25	1.49a	3.63a	26.43a
Asf50	1.22a	4.11a	24.59a
LSD	0.93	2.16	12.60

Appendix 3: Mean grain yield as affected by N sources, levels and method of application in Mwea study site

N rates kgha^{-1}	Yield kgha^{-1}
Control	657a
Ursp25	828a
Ursp50	877a
Urf25	729a
Urf50	742a
Assp25	757a
Assp50	800a
Asf25	757a
Asf50	770a
LSD	204

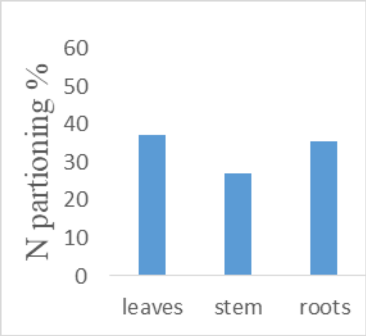
Appendix 4: Control N partitioning percentage in Mwea and Ahero at vegetative stage



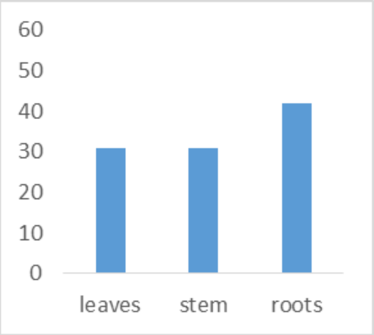
Ahero

Mwea

Appendix 5: Control N partitioning percentage in Mwea and Ahero at reproductive stage

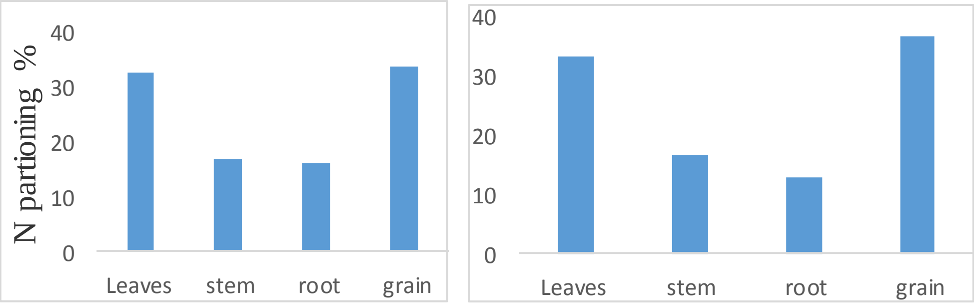


Control Ahero



Mwea

Appendix 6: Control N partitioning percentage in Mwea and Ahero at harvesting stage



Ahero Mwea