EFFECT OF INORGANIC AND ORGANIC NITROGEN SOURCES ON THE YIELD, AGRONOMIC EFFICIENCY AND LAND EQUIVALENT RATIO OF SORGHUM - GROUNDNUT CROPPING SYSTEMS IN MIGORI COUNTY, KENYA

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This thesis is my original work and has not been presented for the award of a degree at any other University.

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DEDICATION

This work is dedicated to my God who has granted me great favours throughout my study and research period and my beloved parents Mr. and Mrs. Manoah Khaguli who have always wanted the best for me as their daughter.

ABSTRACT

Persistent droughts, soil infertility and reduced land sizes are major limitations to agricultural productivity in Migori County. Intercropping drought tolerant legumes with cereals such as sorghum and groundnuts is one of the coping strategies that have been proposed but the effectiveness of these systems particularly under various sources of nitrogen (N) is not clear. A study was therefore conducted at Nyabisawa and Piny Oyie in Migori County during the long rains of 2019 to establish the effect of inorganic and organic N sources on the yield and yield components, land equivalent ratio (LER) and agronomic efficiency (AE) of sorghum - groundnut cropping systems. A Randomised Complete Block Design (RCBD) replicated thrice was used. Treatments included: sole sorghum, sole groundnut and sorghum - groundnut intercrop supplied with N from two sources, that is, organic (farmyard manure (FYM)) and inorganic (urea). Crops in the sole sorghum and sorghum - groundnut intercrop received N at rates of 40 and 80 kg/ha from each source and 40 kg N/ha provided by urea combined with FYM in equal amounts (20 kg N/ha from each source). Sole groundnuts received at 20 kg N/ha from each source and 20 kg N/ha provided by urea combined with FYM in equal proportions (10 kg N/ha from each source). There was a zero N input treatment for each cropping system. Sowing was at the onset of the rains and harvesting done at physiological maturity. The effectiveness of intercropping was determined using LER while the agronomic efficiency was determined using AE. All data were subjected to analysis of variance and the significant treatment means were separated using LSD ($p \leq 0.05$.) Synergism was observed where use of 40 kg N/ha from combined sources significantly increased the sole sorghum plant heights above the unfertilized sole sorghum and also gave the tallest plants at 4, 6 and 8 WAP and the highest sorghum grain and stover yields at Nyabisawa and Piny Oyie. In the intercrop however, the use of N from urea at 40 and 80 kg N/ha from urea and 80 kg N/ha from FYM became important considering the higher demand for minimal resources available in the intercrop. The unfertilized intercropped sorghum had the shortest plants and lowest grain and stover yields in both sites due to the N deficiency which had not been managed thus the need to supply N to the crops so as to improve their yields. In groundnuts, the yields of sole groundnuts to which 20 kg N/ha from urea was applied were significantly superior compared to those supplied with 20 kg N/ha from FYM. Only FYM applied at 20 kg N/ha on sole groundnuts significantly increased the groundnut pods per plant and the biomass yields above the unfertilized sole groundnuts at Nyabisawa. Intercropping was beneficial (LER>1) where 0 kg N/ha, 80 kg N/ha from urea and 80 kg N/ha from FYM were applied. The AEs decreased with increasing N rates in the sole sorghum, while in the intercrop, they increased with increasing N rates. This was observed where sole sorghum that received 40 kg N/ha from urea and the combined sources had significantly higher AEs than those that received 80 kg N/ha from urea and FYM at Nyabisawa and those that received 80 kg N/ha from FYM at Piny Oyie. In the intercrop, it was noted that where 80 kg N/ha from urea and FYM was supplied, the AEs were significantly higher than those which received 40 kg N/ha from combined sources at Nyabisawa and Piny Oyie. In sole groundnuts however 20 kg N/ha from urea had a significantly higher agronomic efficiency compared to all the other treatments since the crops needed N before they were well established to start fixing their own N. In conclusion, the application of 40 kg N ha^{-1} from combined sources in sole sorghum, 20 kg N ha^{-1} from urea in sole groundnuts and either 80 kg N ha^{-1} from urea or FYM on the intercropped sorghum and groundnuts gave the best yields and could be recommended to farmers for adoption especially when production is done under similar conditions.

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ABBREVIATIONS

AE	Agronomic efficiency
a.s.l	above sea level
ATER	Area time equivalency ratio
CAN	Calcium ammonium nitrate
CEC	Cation Exchange Capacity
CPR	Crop Performance Ratio
CPRT	Time corrected Crop Performance Ratio
CRE	Crop Removal Efficiency
CV	Coefficients of Variation
EC	Electrical Conductivity
FYM	Farmyard manure
ISFM	Integrated Soil Fertility Management
LER	Land Equivalent Ratio
LSD	Least Significant Differences of means
LM	Lower Midlands
MBILI	Managing Beneficial Interactions in Legume Intercrops
NPK	Nitrogen - Phosphorus - Potassium
PE	Physiological Efficiency
PFP	Partial Factor Productivity
RE	Apparent Recovery Efficiency
uS/cm	Micro Siemens per centimeter
WAP	Weeks after planting

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CHAPTER ONE

INTRODUCTION

1.1 Background

Sorghum, a drought tolerant crop, is an important staple food crop used in maintaining a productive agro - ecosystem and in the provision of various nutritional requirements in a stable way (Ashiono et al., 2006; Tonitto and Ricker - Gilbert, 2016). There is a renewed interest in the crop in Kenya following the increased number of persistent droughts and reduced reliability of rainfall as a result of climate change which adversely affects most staple crops grown such as maize (Mwadalu and Mwangi, 2013; Ogolla et al., 2016). Migori County, which experiences regular droughts and consequently food insecurity, is one of the regions in western Kenya where sorghum is increasingly being cultivated. Its production is however limited by the low soil fertility status particularly of nitrogen in most farmer fields (Kisinyo et al, 2014).

Sorghum is reported to be able to grow in harsh conditions and poor soils in some studies done by researchers such as Belay (2018). This has however been disputed by others such as Gebremariam and Assefa (2015) who observed low yields in such conditions due to lack of nutrients such as nitrogen which is among the important elements that enhance the drought resistance trait of most sorghum varieties. This therefore created a need to study the response of sorghum to supply of N which is deficient in most soils in Migori County. Many management practices have been recommended to help alleviate the problem of N deficiency. These include use of inorganic N fertilisers whose use by smallholder farmers is minimal because they are expensive (Jama et al., 2000; Gichangi et al., 2006). Although organic N inputs such as animal manures are available on most farms, most have low N levels and are not available in adequate quantities (Lekasi et al., 2003). Attention has therefore shifted to integrated nutrient management approaches where organic and inorganic nitrogen fertilizers are used in combination thus their efficiencies in nutrient supply should also be observed. Nutrient use efficiency is an essential aspect that should be considered when supplying these nutrient elements but is often not regarded as of importance by most farmers. Factors such as fertilizer source and rates, soil physical and chemical properties such as soil texture, pH among other factors may affect uptake of nutrients by plants and in turn affect the efficiency in utilising the nutrients supplied thus should be factored in when supplying nutrients to crops (Roberts, 2008). For instance, most soils in Migori County have a high sand percentage which may possibly cause high leaching of most nutrients such as nitrogen resulting to low nutrient use efficiency as the nutrients become unavailable for uptake by the crops. Use of most organic farm inputs have been reported to be more advantageous when compared with inorganic inputs because they enhance the nutrient use efficiency by improving soil aggregation thus reducing the leaching capacity but it depends on the type and quality of organic material used (Diacono and Montemurro, 2010). In addition, combining use of these organic inputs with inorganic fertilizers has been reported by researchers like Mucheru - Muna et al (2007) and Endris (2019) as having the ability to improve the nutrient use efficiency considering the synergistic advantages such as increasing the soil pH and improvement of nutrient uptake from the inorganic nutrient source.

The problem of food insecurity in Migori County is exacerbated by the ever-growing population that has reduced land sizes per household and hence the total agricultural output as the total area of land used for agricultural production is as well reduced. Intercropping is among the strategies that have been used to help maximize the total output from the small land sizes used for agricultural production (Ananthi et al., 2017). Most farmers have adopted intercropping systems with preference to those where cereals are intercropped with legumes due to benefits attached to it such as high total output and reduced risks of total crop failure as in cases of calamities like drought or specific crop disease outbreak (Ananthi et al., 2017; Kinama and Pierre, 2018). One of the important legumes preferred by farmers in Migori County for such systems is groundnut. Groundnuts are relatively drought tolerant, have high market value and fix more N nitrogen when compared to other legumes such as common beans which are being cultivated by most farmers (Franke et al., 2018; Witcombe and Tiemann, 2022). The effectiveness of intercropping as compared to planting the crops as sole crops should however be evaluated using the land equivalence ratio (LER) so as to determine their effectiveness.

1.2 Problem statement

Increased frequency of droughts limits agricultural production in Migori County. Sorghum, a well adapted crop to these harsh conditions, is among crops cultivated in the County but has its productivity limited by N deficiency (Gichangi et al., 2006; Matusso, 2014). Nitrogen deficiency can be overcome by use of the recommended rates of organic and/or inorganic fertilizers. However, most organic sources have low N levels and are not available in adequate amounts while commercial fertilizers are expensive (Jama et al., 2000; Lekasi et al., 2003). The efficiency of the N fertilizers may also be low mainly because of the sandy nature of most soils in Migori which encourages leaching though this could be mitigated by use of organic materials but as earlier mentioned, are available in small quantities (Sitthaphanit et al., 2009: Alshankiti and Gill, 2016). Furthermore, the ever-growing population in the County has led to reduced land sizes per household. The smaller land sizes are reported to result to reduced total output per land area hence aggravating the food insecurity status (Ananthi et al., 2017). Intercropping legumes with cereals is one of the copping strategies adopted by most farmers in Migori County to maximize land use; however, common bean which is used in the intercrop has low productivity (Matusso et al., 2012).

Consequently, groundnut, which has ability to relatively tolerate drought and high N fixation rate when compared to other legumes such as common bean, is being promoted (Franke et al., 2018; Witcombe and Tiemann, 2022). However, there is inadequate information on the effectiveness of the sorghum - groundnut cropping systems when subjected to various N sources and at varying rates in Migori County.

1.3 Objectives

The general objective was to determine the effect of inorganic and organic nitrogen sources on the yield, agronomic efficiency and land equivalent ratio of sorghum - groundnut cropping systems in Migori County.

The specific objectives were:

i. To assess the effect of inorganic and organic N sources and their combination on the yield and yield components of sorghum - groundnut cropping systems.
ii. To determine the agronomic efficiencies of sorghum - groundnut cropping systems under inorganic and organic N sources and their combination.
iii. To determine the effect of inorganic and organic N sources and their combination on the land equivalent ratios of sorghum - groundnut cropping systems.

1.4 Null hypotheses

i. Inorganic and organic N sources and their combination have no significant effect on the yield and yield components of sorghum - groundnut cropping systems.
ii. The agronomic efficiencies of sorghum - groundnut cropping systems are not significantly affected by inorganic and organic N sources and their combination.
iii. Inorganic and organic N sources and their combination have no significant effect on the land equivalent ratios of sorghum - groundnut cropping systems.

1.5 Justification

Migori County is among the regions in the western region of Kenya that are affected by frequent droughts and therefore sorghum, a drought tolerant crop is a popular crop in the County. However, sorghum has to be supplied with N in appropriate quantities required to support its growth because N is deficient in most soils in the region. Considering the limited ability of most smallholder farmers to access fertility inputs, it is necessary to find strategies that can utilize the little inputs accessed while maximizing the outputs. The combined use of inorganic and organic nitrogen sources together with appropriate intercropping systems where a high nitrogen fixing legume such as groundnut is included with crops that tolerate drought such as sorghum are some of the promising strategies in Migori. However, there is inadequate information on how effective these strategies are.

CHAPTER TWO

LITERATURE REVIEW

2.1 Sorghum

2.1.1 General information

Sorghum (*Sorghum bicolour* L. Moench) is a cereal produced in the tropical and semitropical parts of the world (Mwadalu and Mwangi, 2013). It is a member of family Poaceae, genus *Sorghum* Moench and species *Sorghum bicolour* Moench (Dahlberg, 2000). Sorghum was first domesticated in Africa but its use declined when maize became a preferred staple crop (Chepng'etich et al., 2014). In Kenya, sorghum comes third after wheat and maize in terms of cereal production and is mostly cultivated in Nyanza, Western, Eastern and Rift valley (Onono, 2018). It is more tolerant to drought as compared to most other cereals (Saputro et al., 2021). Its production is majorly by smallholder farmers and is mostly used for subsistence (Léder, 2004). Some of the common varieties of sorghum grown in Kenya are Serena, Seredo, Gadam and E1291 mainly used as food; the brown Gadam and Serena are also used in brewing (KFSSG, 2008: Karanja et al., 2014).

Sorghum grains are used in various ways by different communities which range from *ugali*, porridge, *githeri,* baked goods, as a beverage to being malted with its main consumers being human beings (Kulamarva et al, 2009). Selling of the surplus may also make sorghum to be a source of farm income (Robert et al., 2013). Although sorghum production can be used to alienate food insecurity, most smallholder farmers still have poor harvests of about 300 - 1000 kg/ha instead of 3000 to 4500 kg/ha due to factors such as poor soil fertility which becomes a limiting factor (FAOSTAT, 2014; Oyier et al., 2016).

Sorghum is among the many crops studied by most researchers who have reported the various responses of the crop according to the treatments applied. Most treatment effects are usually reported using the observations made on the plant parts as the plant grows. Sorghum plant parts commonly mentioned include the panicles (height, weight and in some cases color); plant height; stem thickness; biomass weight; leaf broadness and grain weights among many other parts. Different studies use different plant parts or attributes of that plant part measured at specific times to determine the effects of these treatments. Reddy et al (2010) and Moi (2021) are among the many studies on sorghum but measured different attributes according to their objective of study; Reddy et at (2010) focused on the sorghum grain and stover quality while Moi observed the leaf senescence, grain yield, fertile tillers, panicle weight and many other attributes. Some measurements could be done progressively. An example is the plant heights which could be measured at 4, 6 and 8 weeks after planting. These are critical growth points of the crop where nutrients and moisture are needed considering that at 4 weeks, sorghum is undergoing differentiation of their growing points; at 6 weeks, booting initiation begins while at 8 weeks, half boom (anthesis) of the crop is observed (Plessis, 2008). Most other parameters especially those related to yield such as grain weight are measured at physiological maturity of the crop. In sorghum, physiological maturity is attained when a dark spot is observed on side opposite to the embryo of the grain and the grain has about 30% moisture content (Moore et al., 2014).

2.1.2 Ecology and nitrogen requirements

Sorghum has an ability to grow in harsh conditions such as drought due to both the physiological mechanisms and morphological characteristics that enable it to survive in such conditions. Some of the physiological mechanisms common in most arid and semiarid sorghum varieties are leaf rolling and osmotic adjustment (Amelework et al., 2015). The morphological aspects such as leaf waxing and root system also boost sorghum's adaptability (Fracasso et al., 2016).

For instance, sorghum's roots are usually dense and grow up to about 3 cm per day depending on the variety. Their roots can reach a depth of 2 meters by booting stage which makes it efficient for extraction of water laterally in distances that are over 1 meter away from the plant (Routley et al., 2003; Kidanemaryam, 2019). However, despite these adaptations, yield loses of about 60 - 90% due to drought have been reported although the effect is determined by the severity of the drought (Kole, 2015). The effect of drought on the yield is higher when the sorghum crops are exposed during anthesis and grain filling considering that the impact on yield loss is also dependent on the stage of growth in which sorghum was exposed (Kidanemaryam, 2019).

Sorghum grows well in altitudes of up to 2500 m a.s.l. It requires a minimum annual rainfall of 250 mm and temperature of 10°C (Chemonics, 2010). It can grow in a variety of soils of pH of 5.5 - 8.5 (Plessis, 2008). Most sorghum varieties are usually early maturing as an adaptation to adverse conditions and hence require large supplies of the essential nutrient elements such as N which has been recommended to be supplied at 75 kg/ha (KARI, 1994).

2.2 Groundnut

2.2.1 General Information

Groundnut (*Arachis hypogaea* L.*)* is in the family of Fabaceae, genus Arachis (Settaluri et al., 2012). It originated from Bolivia in eastern South America and the adjoining countries but is currently widespread and its major producers worldwide are China, India and the USA (Campos - Mondragon et al., 2009). In Kenya, groundnut production is common in former Western and Nyanza provinces (Masira, 2017). Some of the common varieties grown in Kenya include ICGV 99568, ICGV 90704, Homa Bay local and Valencia Red (Mutegi et al., 2013). Groundnuts can be grown as a pure stand or in space intensive cropping systems such as intercropping so as to cater for the problem of reduced land sizes (Langat et al., 2006).

As a legume, groundnut fixes about 86 - 92% of the N for its uptake through biological nitrogen fixation (BNF) (Kabir et al., 2013).

Groundnut is mainly produced for the extraction of edible oils and for use as food and has been ranked as the 13th crop among food crops in the world (Janila et al., 2013). Apart from having a high potential to fix N, groundnuts are highly nutritious since they have proteins, carbohydrates, vitamins, lipids, minerals, organic acids and purines making them an important food crop in solving many malnutrition problems (Settaluri et al., 2012). Groundnut also has higher oil content than other legumes making it to be a very important crop (Kabir et al., 2013). In many countries groundnuts are used for commercial oil production but are also locally consumed either when they are raw, boiled or in roasted form, pounded and mixed into maize porridge or vegetable relish or as peanut butter (Munsaka, 2013). When used for oil extraction, their residues are taken and used in the production of livestock feeds as good sources of protein (Adinya, 2009). Their shell and skin are also used as silage (Jenkins et al., 2009). Groundnuts are relatively resistant to drought thus can withstand unreliable rainfall patterns (Kihaga, 2011; Desmae and Sones, 2017).

Like sorghum, groundnuts have also been studied by many researchers and their response to treatments given by a measure of the changes observed in the parts of the plants. Common parts of the crop mentioned are the biomass, number of pods per plant, number of seeds per pod, grain weight (per a thousand grains or per hectare) among many other parts. The choice of which parts to capture, in what state (dry or actual) and at what stage of growth to be measured in a study is however limited to objective the researcher has for their study.

2.2.2 Ecology and nitrogen requirements

Groundnut grows well in altitudes of up to 1500 m a.s.l. and requires an optimum annual temperature of 25 - 30° C; deep, loose soils that are well - drained and of pH ranging between 5.5 to 7.0 and receive an annual rainfall of about 400 - 1200mm depending on variety grown (Desmae and Sones, 2017). Despite the fact that groundnuts can fix their own nitrogen, application of 20 kg N/ha at planting is important for the crop during the early developmental stages before the root system establishes (FAO, 2006). Groundnuts also need adequate phosphorus as it is important in root formation thus is essential in nodule formation and fixation of atmospheric nitrogen (Mitran et al., 2018).

2.3 Intercropping

2.3.1 General information

Intercropping is largely practiced by small-holder farmers in the tropical regions (Kinama and Pierre, 2018). It is a cropping system that involves the cultivation of crops of dissimilar species simultaneously on the same field or piece of land in combinations that are distinct (Katyayan, 2005). Intercropping revolves around intensification of space, time and competing for resources among and between components in the system and the appropriate management of their interactions (Tajudeen, 2010). Some of the important factors considered in this system therefore are plant population, time of sowing, the time it takes for each crop to mature and the farmers' and region's socio-economic conditions when choosing the components of the intercropping system (Aziz et al., 2015). These factors help in determining whether the crops selected are complementary in growth patterns, systems of the root, above ground canopy and critical times of high nutrient and water need by the crops so as to enable efficiency in utilization of photosynthetically active radiation (PAR), water and nutrients (Patson et al., 2017).

Intercropping could either be practiced as additive intercropping whereby additional crops of other species are added into the already existing population of the sole crops or replacement intercrop whereby the intercrops have the same population as the sole they are composed of attained by replacing each plant species with the other (Azam - Ali and Squire, 2002). The major types of intercropping practices recognized are; mixed, alternate, strip and relay intercropping (Mousavi and Eskandari, 2011). Intercropping can be done using various types of crop species but cereal-legume intercropping is one of the common practices by most smallholder farmers because of the added advantage of N fixation (Chandra et al., 2013; Matusso et al., 2014).

Intercropping ensures better utilization of resources, reduced weed competition and pest infestation and in turn minimizes food insecurity (Uddin and Adewale, 2014; Ananthi et al., 2017). In addition, the legume in the intercrop, for instance groundnut, may fix the atmospheric N thus improving soil fertility (Kabir et al., 2013). Most of the legumes in such systems also act as false crops to parasitic weeds such as striga hence are beneficial in its control (Dereje et al., 2016). The higher population in these cropping systems also results to an increase in soil conservation through greater ground cover and as well high soil organic matter when their leaves fall and decompose among many other advantages (Ananthi et al., 2017). Studies have also shown some increase in the LER and returns to labour and other inputs where intercropping with legumes was used hence making them suitable for smallholder farmers who have smaller land areas for agricultural production (Maingi et al., 2001). However, reduced PAR reaching the shorter plants (which in most cases are the legumes) usually results to suppressed yields (Liu et al., 2010; Matusso, 2014). There is therefore need to select appropriate crops and spatial arrangements that cater for the above ground canopies (Matusso, 2014; Kermah et al., 2017).

Intercropping can be done in various patterns/arrangements, among them being planting crops on same rows and alternating one or more rows (Roholla and Hamdollah, 2011). These patterns affect the relative competitiveness of the crops; for instance, those that allow shading of the leguminous crops may significantly reduce nitrogen fixation by the legumes hence development of improved intercropping systems. MBILI system is one of the improved intercropping patterns that allow good penetration of light especially where shorter legumes are involved (Mucheru - Muna et al., 2010). In MBILI, the crops are planted in such a way that two rows of one crop species are followed by two rows of the other crop species (Tungani et al., 2002). Suleman et al (2022) observed that planting two rows of sorghum alternated with two rows of groundnuts (basically refereed to MBILI system) had the best land use efficiency thus the most excellent combination when it comes to maximum use of land.

There is also inter-specific competition between the crops of different species for the limited resources such as nutrients resulting to reduced yields for each crop (Gao et al., 2013). This notwithstanding, intercropping is thought to be better than the sole cropping since the total output of both crop species from the same area of production is often higher than that from sole crops (Maingi et al., 2001; Lithourgidis et al., 2011). For productive intercropping systems, challenges such as the selection of correct crop types and planting densities, additional labour in the management practices on the crops from preparation and planting to harvesting experienced when setting up an intercropping system should be well handled (Lithourgidis et al., 2011).

2.3.2 Sorghum - groundnut intercropping

Sorghum - groundnut intercropping is among the cereal-legume intercropping systems practiced by smallholder farmers. Both crops can grow well in regions with relatively lower rainfall amounts, an important aspect during this era of climate change (Kihaga, 2011;

Mwadalu and Mwangi, 2013). There are many advantages attached to the cropping system as mentioned by most researchers. For instance, Dereje et al. (2016) found that sorghum - groundnut intercropping was an efficient cropping system in controlling striga weed leading to an increase in the yields throughout the growing seasons when compared with other cropping systems under study. They reported higher yields ranging from 1873.g kg/ha to 2476.1 kg/ha sorghum yields and LER values of between 1.39 – 2.05 where sorghum and groundnuts were intercropped at different ratios (Dereje et al., 2016). Other studies have also been done with focus on other aspects such as cropping patterns, crop densities, crop varieties and crop combinations used as intercrops among many other aspects which affect the productivity of the systems. Information on the effect of using different sources of nitrogen to supply the nutrient to the crops and at different rates considering that the crops have been assumed to grow in poor conditions is inadequate.

2.3.3 Measures of effectiveness of a cropping system

Productivity of a cropping system is measured through yield, sunlight, water-use and nutrient use comparisons (Anders et al., 1996). These give an estimate of how the resources were competed for and as well as how it reflected on the crop yields. Various indices can be used to measure the efficiency of a cropping system using yield comparisons. The most commonly used standardized index is land equivalent ratio (LER) which is defined as the relative area the sole crop requires to give a yield similar to that of the crops in the intercrop (Mead and Willey, 1980). Being an important tool for studying and evaluating intercropping systems, it is used to measure the advantage in the yield from crops in an intercropping system compared to that from the same crops in a mono-cropping system (Rana and Rana, 2011). For instance, an LER of 1 denotes no difference in yield between the cropping systems while a value > 1 signifies that intercropping was advantageous (Wahla et al. 2009).

The LER however has some drawbacks such as ignoring of the relative time of each crop within the cropping system hence is said to often exaggerate the intercropping performance (Yahuza, 2011). Therefore, other indices were developed to help cater for these gaps. These include the area time equivalency ratio (ATER) which takes into account the time taken by components in the system; the crop performance ratio (CPR) which is an index adjusted to describe the physical or physiological basis of the performance of the crops in comparison with the component sole crops; and the time corrected CPR (i.e. CPRT) (Gebru, 2015). The ATER and CPRT were developed to help cater for the time deficient factor in LER and CPR respectively but very few studies have adopted them (Yahuza, 2012). These indices though important, cannot fully replace LER since they also have limitations. For instance, most of them are not used in cropping systems where the growth components differ in their length of growing periods unless factors such as time are incorporated as in the case of CPRT (Yahuza, 2011).

2.4 Soil fertility Management in Sorghum and groundnut production

2.4.1 General information

Soil fertility is important in agricultural production. It therefore requires a holistic farming approach to be employed with an aim of sustaining soil fertility and improving land productivity (FAO, 2016). Most soils within the western parts of Kenya, including Migori County, have been reported to be deficient of nutrients particularly in N (Ashiono et al., 2005). Nitrogen is an important nutrient element that is vital in the normal growth of crops as it forms a basic part of chlorophyll and amino acids (Ganajax et al., 2016). Its deficiency negatively affects the dry matter, crude protein and the grain yield (Ashiono et al., 2005). Mahama et al., 2014 noted that its deficiency affects the plants more than the other nutrient elements.

It is therefore recommended that appropriate management of the soil should be done so as to ensure that N removed from the soil during cultivation is replaced (Von, et al, 1841). Some of the strategies that are used by farmers to supply nitrogen are outlined next.

2.4.2 Use of inorganic fertilisers

Inorganic fertilisers are important fertility inputs since they are able to supply the required N in a readily available form for immediate plant use and have been reported to improve the crop yields by over 60% when applied at optimum rate (Ashiono et al., 2005; Rashid and Iqbal, 2011). Some of the commonly used inorganic N fertilizers in Kenya are urea, CAN and NPK (26:5:5, 25:5:5:5S, 23:23:0, 17:17:17) (Oseko and Dienya, 2015). Application of N through such fertilizers increases production of plant biomass and organic matter which when incorporated in soil results to higher organic matter accumulation, increased biological activity and enhancement of some soil physical properties (Manna et al, 2005). However, despite the fact that such inorganic N fertilisers can be used singly to supply the nitrogen requirements for the crop, their use by smallholder farmers has still remained low because of their high cost (Jama et al., 2000). Most smallholder farmers have also not been well convinced to use them due to the low yields observed despite fertilizer use with claims that they give no promising returns to their investment in fertiliser purchase (Kaizzi et al., 2012; Rware et al., 2016). This may however be as a result of other limiting factors such as low soil pH which have not been put under consideration yet they negatively affect the nutrient use efficiencies of nutrients supplied.

2.4.3 Use of organic fertilisers

Use of organic inputs such as FYM to supply nutrients has been a common traditional practice (Babbu et al., 2015). Most of them have been shown to improve various physical soil properties by enhancing aggregation of soil particles and aggregate stability, reducing the volume of the micro-pores while increasing that of the macro - pores and improving the water holding capacities (Shukla et al., 2003; Behera et al., 2007; Diacono and Montemurro, 2010). Farmyard manure is among the valuable organic nitrogen sources utilized for soil fertility maintenance (Malle et al., 2017). It is usually used in crop production as a substitute or with chemical fertilizers as it also improves soil chemical properties by providing macro and micro nutrient elements, increase pH of acid soils and calcareous soils with no negative residual effects on soil in addition to the physical properties mentioned above (Ashiono et al., 2006). When well decomposed, it tends to result to higher soil organic carbon content which is important in the enhancement of these soil biophysical properties (Batiano et al., 2006; Järvan et al., 2017). Enhancement of such soil properties in turn result to higher nutrient use efficiencies when other fertility inputs such as inorganic fertilizers are used as more nutrients will be used up by the plants rather than being lost through factors such as leaching or fixation of nutrients (Diacono and Montemurro, 2010).

Although organic inputs such as FYM tend to be cheaper because they are locally available most of them have low nutrient content mainly due to the poor manure preparation practices and the fact that they take quite a longer time to fully decompose (Lekasi et al., 2003; Mwadalu, 2014). Their low nutrient levels require that they are supplied in large quantities so as to cater for the nutrients required by the crops but are rarely available in such quantities on most smallholder farms thus making it less efficient when used singly by farmers (Lekasi et al., 2003).

2.4.4 Integrated soil fertility management

The current status of food security calls for use of more than one strategy so as to meet the food demands of this ever growing population. For instance, use of the above methods singly is untenable to most smallholder farmers as they are unable to raise the recommended rates of application because they are costly as in case of inorganic fertilizers or not readily available in adequate quantity and quality for organic materials (Lekasi et al., 2003; Jama et al., 2000). The need to consider a combined use of fertility inputs from both organic and inorganic sources has thus been advocated as they increase crop yields due to aspects such as synergism (Ganajax et al., 2016; Patson et al., 2017). For instance, the yields of the crops are enhanced by the high total N accumulated in the soils as a result of synergism when the N inputs from both sources are applied (Huang et al., 2007). Their combination has shown some level of effectiveness with the benefits from both sources experienced thus deal with limitations such as reduced quantities and high costs (Redda and Abay 2015). In addition, when combined, the N input could be supplied in micro – doses at the time when the crop needs it most thus increasing the fertilizer – use efficiency, stimulate the increase of soil microorganisms and as well play an important role in the maintenance of ecological balance of rhizosphere (Khaim et al., 2013). Use of space intensive cropping systems such as intercropping the cereal with high nitrogen fixing legumes can also be used to help increase the total output of the small land sizes per household thus increasing the efficiency of the fertility inputs applied as an integrated soil fertility management (ISFM) approach (Tajudeen, 2010).

2.5 Nutrient use efficiency

There are several ways of expressing the NUE of a crop such as agronomic efficiency (AE); physiological efficiency (PE); apparent recovery efficiency (RE); crop removal efficiency (CRE) and partial factor productivity (PFP) (Fixen et al., 2015). The choice of a mode of expressing the NUE is best determined by the data that is available and the objectives of the study; for instance, AE can be used in this experiment to determine the amount of sorghum and groundnut yields that increase per kilogram of N added in each experimental unit and calculated in units of yield increase per unit nutrient (kg/kg N) applied, considering the zero N inputs present for each cropping system (Terry, 2008). The advantage of using AE when compared to other methods is that it reflects the effect of the fertilizer applied more closely and is easily calculated as long as a record of farm inputs and outputs is kept (Norton, 2017). The ultimate NUE value expressed may however be greatly influenced by the management of fertilizer application practices and the relationships that exist between the soil, plants and water hence should be put into consideration whenever applying nutrient elements from the respective sources (Roberts, 2008; Fixen et al., 2015). The critical AE level as described by Dobermann (2007) is 10 - 30 kg yield per kg nutrient supplied. Fixen et al (2015) however later gives a higher minimum value of 15 kg yield per kg nutrient making the range to be between 15 - 30 kg yield per kg of nutrient supplied.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental sites

The experiment was done during the long rains season (March to July) of 2019 on farmer fields at two sites (Nyabisawa and Piny Oyie) in Migori County. The Nyabisawa field is in Suna East constituency at an altitude 1286 m above sea level lying along latitude 1° 1’ 24.04” S and longitude 34° 22’ 4.8” E. The Piny Oyie field is in Suna West constituency lying on latitude 1° 4’ 10.56” S and longitude 34° 24’ 32.2” E at an altitude of 1735 meters a.s.l. Nyabisawa is in LM 2 while Piny Oyie is in LM 3. The Piny Oyie field had a sloping landscape. Migori County has an annual temperature range of 24 - 31 degrees Celsius and a mean rainfall of 700 to 1800 mm annually (County Government of Migori, 2018). The sites were selected in the previous season. The farmers at both sites grew maize and beans in the previous season.

3.2 Soil and manure characterization

The samples of soils to be used for determination of the characteristics of the sites were taken before application of treatments from a depth of 0 - 20 cm in a stratified arrangement. Composite samples were obtained and taken to the laboratory where they were prepared for appropriate analysis by procedures described by Okalebo et al. (2002). The soil parameters determined were soil pH, total N, organic C, total P, available P, exchangeable acidity, K, Ca, Mg and the percentage clay, sand and silt (soil textural classification). For manure characterization, a sample 1kg of well mixed FYM from the Rongo University farm was used for analysis so as to determine the total N, P and other properties. The manure had been prepared from cow dung obtained from the animal sheds in the university, heaped and turned after every 3 weeks for 3 months before being taken for analysis.

The moisture content of the FYM was also determined during the analysis. These were then used calculate the amount of FYM required to apply in the respective treatments.

Soil and manure samples were analysed in the laboratory as follows (Okalebo et al., 2002). Soil particle size analysis was determined using the Bouyouscos method where sand, silt and clay distribution were measured and thereafter assigned the textural classes using the textural triangle. The pH was measured potentiometrically from a soil: water suspension. Total nitrogen was determined by the Kjedhal method. Available P was obtained by the Sodium bicarbonate method (Olsen et al., 1954 cited in Okalebo et al., 2002). This involved extracting of a soil extract using 0.5 M $NaHCO_3$ at pH 8.5 then determining the P colometrically. The exchangeable acidity was determined through the differential potentiometric titration method which involves preparation of the 1 M KCl solution used to prepare the solution used for titration with 0.05 M NaOH (from a burette) to a permanent pink end point. Flame photometry was used to determine the exchangeable sodium and potassium while atomic absorption spectrophotometry was used in determining the exchangeable calcium and magnesium. Manganese, copper, zinc and iron levels were also determined through atomic absorption. The sulphur in the soil was determined through measuring of the absorbance at 420 nm on a UV/Visible spectrophotometer of the soil extract after adding 2 ml of Gelatin-Barium chloride solution. The total organic C was determined through a digestion with 1N Potassium dichromate ($K_2Cr_2O_7$) solution and concentrated sulphuric acid. The produced digest was back-titrated using Ferrous ammonium sulphate ($(NH_4)_2Fe(SO4)_2{\cdot}6H_2O$) solution and the determination of organic C percentage was done.

3.3 Experimental design and treatments

An RCBD design replicated thrice was applied in the experiment. The treatments were three cropping systems; sole sorghum, sole groundnut and an intercrop of sorghum and groundnut each planted with different rates of nitrogen from organic fertilizers, inorganic fertilizers and their combination (Table 1).

Table 1: Experimental treatments

Treat No.	Cropping system	*Inorganic N source (kg/ha)	**Organic N source (kg/ha)	Total N (kg/ha)
1.	Sole sorghum	0	0	0
2.	Sole sorghum	40	0	40
3.	Sole sorghum	0	40	40
4.	Sole sorghum	20	20	40
5.	Sole sorghum	80	0	80
6.	Sole sorghum	0	80	80
7.	Sole groundnut	0	0	0
8.	Sole groundnut	10	10	20
9.	Sole groundnut	20	0	20
10.	Sole groundnut	0	20	20
11.	Sorghum - groundnut intercrop	0	0	0
12.	Sorghum - groundnut intercrop	40	0	40
13.	Sorghum - groundnut intercrop	0	40	40
14.	Sorghum - groundnut intercrop	20	20	40
15.	Sorghum - groundnut intercrop	80	0	80
16.	Sorghum - groundnut intercrop	0	80	80

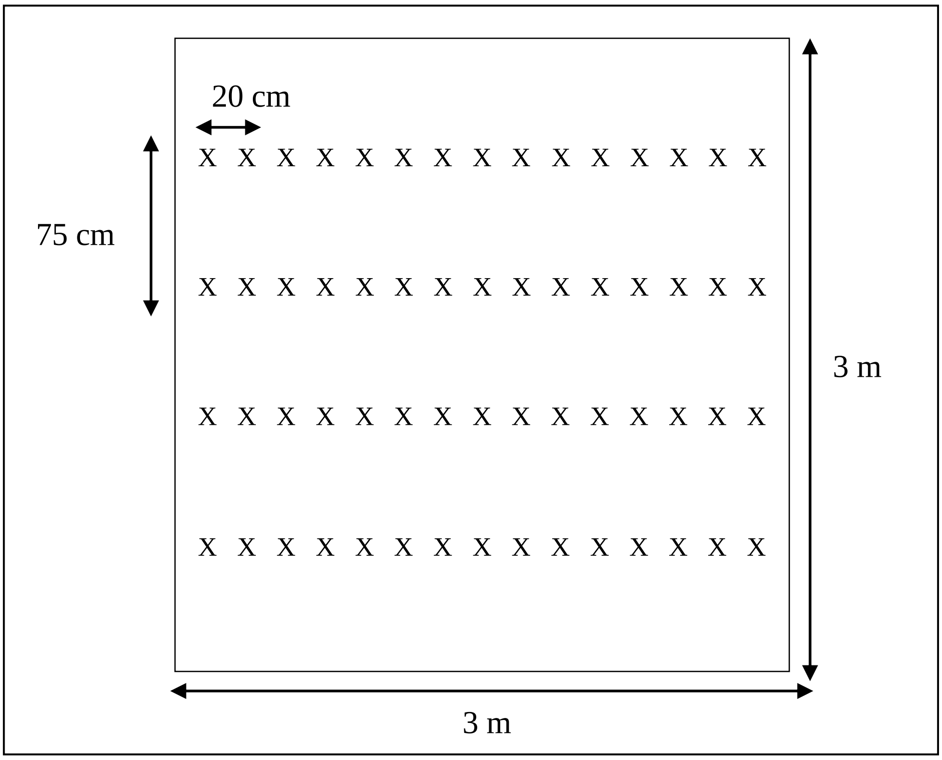
Key: The recommended N rate is 75 kg/ha approximated to 80 kg/ha while 40 kg/ha is the 50% of this 80 kg/ha; The soil P level was low hence the recommended rate (30 kg P/ha) was applied to all the treatments; *Inorganic N source - Urea, and **Organic N source - Farmyard manure (FYM).

3.3.1 Treatment Rationale

Treatment 1, 7 and 11 were the unfertilized treatments in the sole sorghum cropping system, sole groundnut cropping and sorghum - groundnut intercrop respectively. They were used to assess the effect of not applying fertilizer and a basis of determining response to N when compared with the other treatments. Treatment 2, 3 and 4 were compared to establish the effect of N source (organic, inorganic or combined) on yield of sole sorghum at same N rate (40 kg/ha). These were also compared to treatments 1, 5 and 6 to evaluate the effect of N rate (40 and 80 kg/ha) on yield of sole sorghum. They were also compared with sorghum in the intercrop at the same N rate (treatments 11 to 16) to obtain the effect of intercropping on growth and yield of sorghum. Treatments 7, 8, 9 and 10 were compared to establish the effect of source and rate of N on sole groundnut yields. They were also compared to intercropped groundnuts in treatment 11 to 16 so as to assess the effect of source and rate of N with intercropping on the yield of groundnuts.

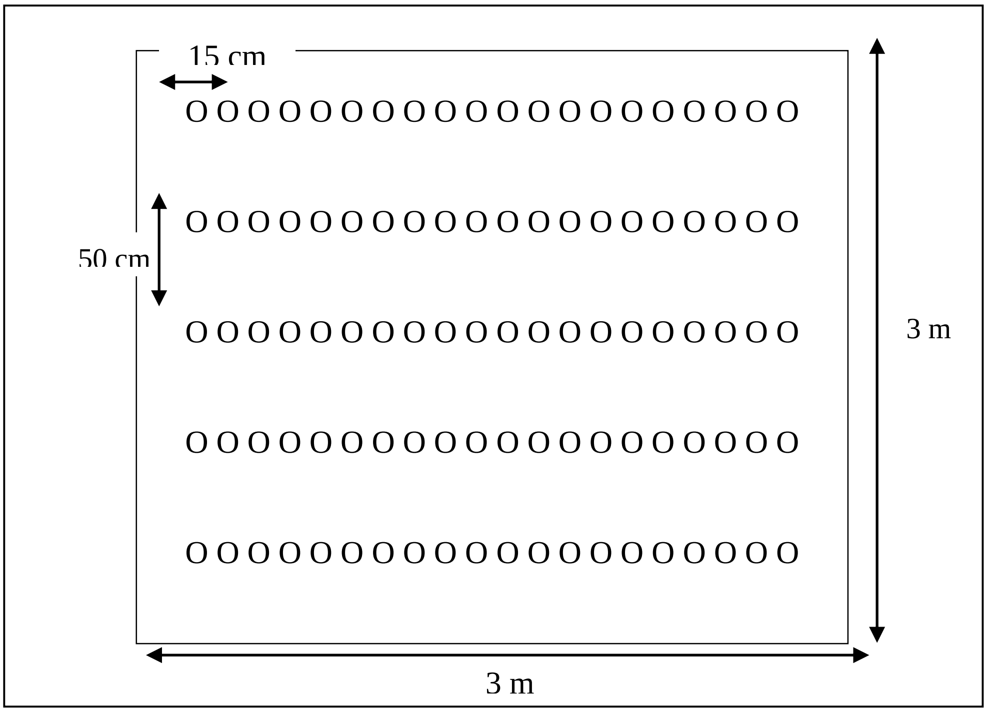
3.3.2 Experimental layout

Each plot area was 9 m^2 (3 m by 3 m) in size. The sole sorghum cropping system plots had 4 rows of sorghum at a spacing of 75 cm by 20 cm giving a total population of 66,666 sorghum plants per hectare (Figure 1).



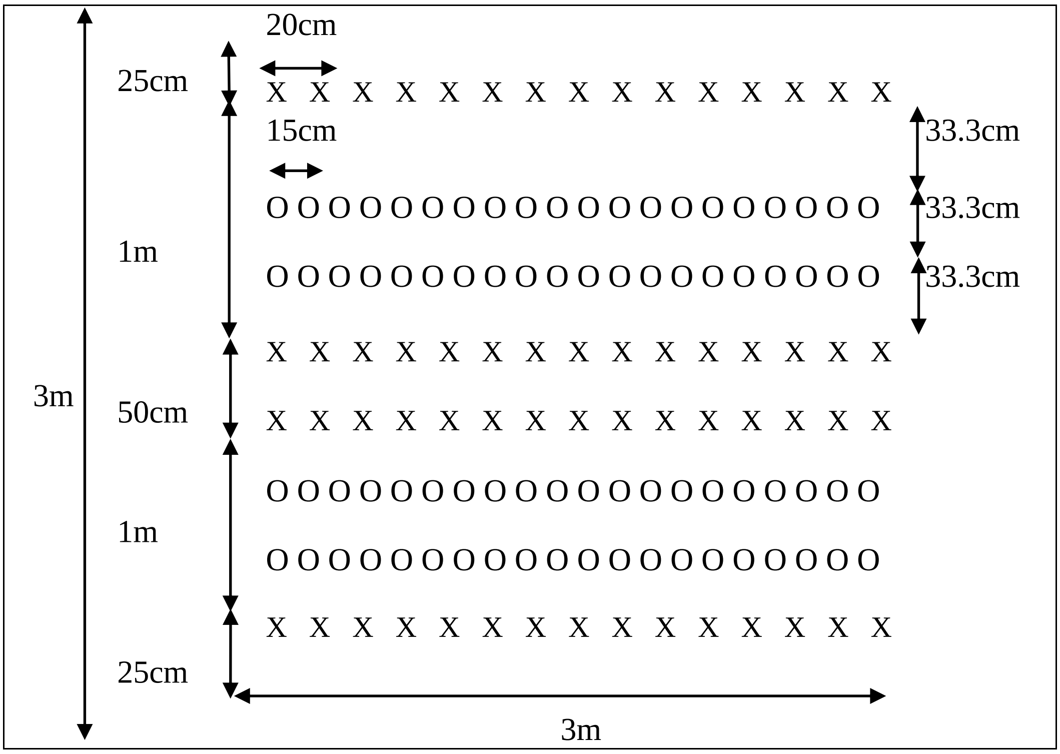
Key: X represents the sorghum plants
Figure 1: Sole sorghum plot layout

The sole groundnut cropping system plots had 6 rows of groundnut planted at a spacing of 50cm by 15cm giving a total of 133,333 groundnut plants per hectare (Figure 2).



Key: O represents the groundnut plants
Figure 2: Sole groundnut plot layout

In the intercrop however, the plots had 6 rows of sorghum and 4 rows of groundnuts with a similar plant population to that of the sole cropping systems of each crop as the "MBILI" intercropping system was used (Figure 3). The two outer rows of sorghum were treated as boarder rows and were not used in yield determination.



Key: X represents the sorghum plants and O represents the groundnut plants
Figure 3: Sorghum – groundnut intercrop (MBILI system) plot layout
The experiment as laid out in the field at each sites is illustrated in Figure 4.

101 T1	102 T14	103 T8	104 T13	105 T5	106 T7	107 T9	108 T2	109 T12	110 T4	111 T10	112 T11	113 T3	114 T15	115 T16	116 T6	Rep 1
201 T15	202 T16	203 T7	204 T4	205 T12	206 T8	207 T14	208 T9	209 T11	210 T1	211 T5	212 T2	213 T13	214 T6	215 T3	216 T10	Rep 2
301 T2	302 T9	303 T12	304 T15	305 T10	306 T16	307 T3	308 T1	309 T8	310 T5	311 T13	312 T14	313 T6	314 T11	315 T7	316 T4	Rep 3

Key:
T1 - Sole sorghum (0 kg/ha N)
T2 - Sole sorghum (40 kg/ha N - I)
T3 - Sole sorghum (40 kg/ha N - O)
T4 - Sole sorghum (40 kg/ha N - I+O)
T5 - Sole sorghum (80 kg/ha N - I)
T6 - Sole sorghum (80 kg/ha N - O)
T7 - Sole groundnut (0 kg/ha N)
T8 - Sole groundnut (20 kg/ha N - I+O)
T9 - Sole groundnut (20 kg/ha N - I)
T10 - Sole groundnut (20 kg/ha N - O)
T11 - Sorghum - groundnut intercrop (0 kg/ha N)
T12 - Sorghum - groundnut intercrop (40 kg/ha N - I)
T13 - Sorghum - groundnut intercrop (40 kg/ha N - O)
T14 - Sorghum - groundnut intercrop (40 kg/ha N - I+O)
T15 - Sorghum - groundnut intercrop (80 kg/ha N - I)s
T16 - Sorghum - groundnut intercrop (80 kg/ha N - O)
I – inorganic source, O – Organic source and I+O – organic and inorganic source in equal proportions.

Figure 4: Experimental layout for both sites

3.4 Establishment and management of the crop

Preparation of the land was done before planting. The inorganic (urea) and organic (FYM) fertility inputs were then broadcasted and thoroughly mixed with soil in the appropriate plots. The urea was however applied twice; at planting and as a top dress (21 days after planting so that 7 days later, plant height determination would begin) in the sole sorghum and the sorghum - groundnut intercrop plots. The amount of inorganic (urea) fertilizer to be used was calculated using the formula described by Carol (2004) as follows:

$$\text{Amount of fertilizer in kg/ha} = \frac{\text{kg/ha of nutrient required}}{\text{\% nutrient in the fertilizer}} \times 100 \quad \text{..................Equation 1}$$

For FYM, the quantity obtained is corrected to the present moisture content. That is, if the quantity X of FYM required was calculated at 5% moisture content, then the present moisture content is determined using a moisture meter and the values corrected as follows:

$$\text{Amount of FYM to be used in kg/ha} = \frac{\text{P\% MC x Y kg of FYM}}{\text{C\% MC}} \quad \text{.......................Equation 2}$$

Where:
MC = Moisture content
P% = present/current percentage MC in FYM at the time of planting
C% = Percentage MC of FYM at the time of nutrient analysis in the lab
X = quantity of FYM needed to supply the nutrient needed (calculated as per the MC given during soil analysis in the lab)

In the sole groundnut plots, N from both sources was applied at planting. The groundnut seeds used were a local variety in Migori (Valencia red) which is large seeded and red in color. An improved early maturing sorghum variety (MUK 27) developed by the Sorghum Project Eastern and Western Regions which is red seeded was used. It takes up to 90 days to mature and grows up to a height of 130 - 150 cm. Furrows were made 4 cm deep and 3 sorghum seeds dropped at an interval of 20 cm and later reduced to one plant while for groundnut, two seeds were planted in each hole and also later reduced to one plant per hole.

Agronomic practices such as weeding and the top dress of urea in plots where it was required were done to manage the crops until they were harvested.

3.5 Data collection

Data collection was done within the harvest area of 2.8m by 1.5m in each plot since the outer rows and plants at the furthest ends of the inner rows were not used so as to cater for the boarder effect. Sorghum plant height was determined at the 4^{th}, 6^{th} and 8^{th} week after planting (WAP) by measuring the above ground height of six plants randomly selected per plot (three plants: 5^{th}, 8^{th} and 11^{th} plant from each of the 2 inner rows). These six plants were selected at the first time of measurement (4^{th} week), tagged and used for measurement all through the subsequent times of height measurement. The crops were harvested at physiological maturity. Yield data was collected on the various parameters for each crop. In sorghum, the data collected was for the grain and stover yields. For the grain yields, the panicles were cut off from the main plants and dried for one week under direct sunlight. The dried panicles were then threshed then the grains separated from the empty panicles. The dried sorghum grains were then weighed and the data obtained was used to determine the grain yield. The moisture content of these sorghum grains at the time of weight determination was 13.5%. It was determined using a moisture-meter. The above ground stovers (without the panicles) were chopped and dried under direct sunlight for one week. These dry stovers were then weighed to determine the stover yield.

In groundnuts the data on the yield and yield components was collected on; pods per plant, the seeds per pod, grain and biomass yields. The pods per plant were counted from twenty-four randomly selected plants from each plot (six plants: 3^{rd}, 6^{th}, 9^{th}, 12^{th}, 15^{th} and 18^{th} plant from each of the four inner rows). The data obtained was then averaged to determine the mean number of pods per plant. The number of seeds per pod was obtained by counting the total number seeds from each of the five randomly picked pods (the five pods were picked from each of the six plants previously counted in the determination of the number of pods per plant). The totals obtained were then averaged to determine the means. This was done after air drying under direct sunlight for one week. This was done to ensure that the pods were completely dry. All the pods from the plants harvested were then shelled and the groundnut grain weight was measured to determine the grain yield. The biomass weight for groundnut plants were obtained after the pods had been removed from the plants. The remaining plant material was dried whole and directly in the sun for one week to ensure that the material was completely dry. The dry plant material was then weighed to determine the biomass yield.

The yields of both crops were calculated and displayed in kilograms per hectare. The grain yield data obtained for both crops was then used to determine the AE and the LER as described below.

3.5.1 Agronomic efficiency

The AE was computed using the formula in equation 2 as follows (Rajendra, 2009);

$$AE = \frac{Y_f - Y_c}{Na} \quad \text{.....Equation 3}$$

Where:
AE = Agronomic Efficiency (kg grain/kg nutrient applied);
Y_f = Yields in fertilized crops (kg/ha);
Y_c = Yields in unfertilized crops (controls) (kg/ha);
Na = amount of nutrient applied (kg/ha).

3.5.2 Land Equivalent Ratio

The formula of Mead and Willey (1980) in equation 1 was used to calculate the LER as follows:

$$LER = L_a + L_b = \frac{Y_a}{S_a} + \frac{Y_b}{S_b} \quad \text{.....Equation 4}$$

Where:
LER = Land Equivalent Ratio;
L_a and L_b = Partial LERs of crops a (sorghum) and b (groundnut);
Y_a and Y_b = Individual crop yields in intercropping;
S_a and S_b = Individual crop yields in sole crop.

3.6 Data analysis

All yield, LER and AE data were analysed by analysis of variances. The Genstat Statistical Package (7^{th} edition - version 7.2.2.222; 2008) was used and significant treatment means separated using the LSD values ($p \leq 0.05$).

CHAPTER FOUR

RESULTS

4.1 Initial manure and soil characteristics

The properties of the FYM used were as illustrated in Table 2. The manure had all nutrient elements in optimum to high levels apart from sulphur which was low.

Table 2: The properties of farmyard manure

Elements		Value
Macronutrients (%)	C	14.50
	N	1.60
	P	0.29
	K	1.05
	Ca	0.91
	Mg	0.35
	S	0.16
Micronutrients (ppm)	Mn	1310
	Fe	47700
	Zn	133
	Cu	32.2
	B	113
	Na	1390
Other	pH	8.9
	EC (S) (mS/cm)	2.19
	C:N	9.06
	DM (%)	55.7

The initial soil chemical and physical properties for Nyabisawa and Piny Oyie were as illustrated in 3. The soils for both sites were acidic and had low nitrogen and carbon levels. The levels for other elements including the macro and micro nutrients in the soil were also low. The sand percentages in both sites were also high.

Table 3: Initial soil chemical and physical properties

		Nyabisawa	Piny Oyie
pH (H_2O):1:2.5 (soil:water)		4.94	5.28
Electrical conductivity	uS/cm	68.3	18.3
Phosphorus (Olsen)	Ppm	4.47	6.58
Potassium		74.4	89.8
Calcium		411	322
Magnesium		70.0	68.4
Sulphur		5.01	4.58
Total Nitrogen	%	0.088	0.083
Organic Carbon		0.87	0.96
Manganese	Ppm	89.6	23.4
Copper		1.92	0.70
Boron		0.14	0.10
Zinc		0.71	0.73
Iron		111	240
Sodium		4.37	4.77
C.E.C	meq/100g	6.15	4.30
Exchangeable Acidity		0.60	0.30
Acid Saturation	%	17.4	11.0
Sand		67.0	85.0
Silt		8.56	4.42
Clay		24.4	10.6
Textural class		Sandy loam	Loamy sand

4.2 Sorghum plant heights at Nyabisawa and Piny Oyie

A site analysis to test for the homogeneity of error variance using an unpaired t test for plant heights of sorghum at 4, 6 and 8 WAP at Nyabisawa and Piny Oyie was done and the sites differed significantly ($p \leq 0.05$) hence the results are presented per site. Table 4 shows the plant heights for sorghum at Nyabisawa and Piny Oyie at 4, 6 and 8 WAP. At 4 WAP, the plant heights ranged from 15.4cm (unfertilized intercropped sorghum) to 19.6cm (sole sorghum to which N was provided from 40 kg N/ha from urea combined with FYM) at Nyabisawa. At Piny Oyie, the plant heights ranged from 18.1 cm (sole sorghum to which N was provided from 40 kg N/ha from FYM) to 22.9 cm (sole sorghum to which N was provided from 40 kg N/ha from combined sources).

Treatment effects on plant heights were only significant at Nyabisawa. In the sole sorghum, use of 40 kg N/ha from combined sources lead to plants that were significantly taller compared to those to which 80 kg N/ha from FYM was supplied to. In the intercrop, supply of 40 kg N/ha from combined sources and 80 kg N/ha from urea gave significantly taller plants than the unfertilized intercropped plants. No other significant differences were noted among the sources and the N rates within the intercrop. When compared between cropping systems, only unfertilized sole sorghum had significantly taller plants compared to the unfertilized intercropped sorghum.

At 6 WAP, the plant heights at Nyabisawa ranged from 49.7 cm (unfertilized intercropped sorghum) to 60.3 cm (sole sorghum to which N was provided from 40 kg N/ha from combined sources). At Piny Oyie, the plant heights ranged from 39.8 cm (unfertilized intercropped sorghum) to 72.2 cm (intercropped sorghum to which 80 kg N/ha from urea was provided). No significant treatment differences on the plant heights at both sites in the sole sorghum were noted.

Table 4: Sorghum plant heights at Nyabisawa and Piny Oyie at 4, 6 and 8 WAP

Treat no.	Treatment	Height in centimeters (cm) 4 WAP Nyabisawa	4 WAP Piny Oyie	6 WAP Nyabisawa	6 WAP Piny Oyie	8 WAP Nyabisawa	8 WAP Piny Oyie
1	Sole sorghum (0 kg N/ha)	18.7	22.7	51.5	65.8	85.6	114.1
2	Sole sorghum (40 kg N/ha - I)	19.4	22.1	57.9	63.4	103.6	110.5
3	Sole sorghum (40 kg N/ha - O)	16.9	18.1	52	48	86.6	96.3
4	Sole sorghum (40 kg N/ha - I+O)	19.6	22.9	60.3	65.9	111.9	118
5	Sole sorghum (80 kg N/ha - I)	18.4	20.4	57.8	67.7	103.8	118.3
6	Sole sorghum (80 kg N/ha - O)	15.8	19.9	53.3	57.5	93.4	109.2
11	Sorghum - groundnut intercrop (0 kg N/ha)	15.4	18.7	49.7	39.8	81.7	84
12	Sorghum - groundnut intercrop (40 kg N/ha - I)	17.4	21.1	56.9	69.8	111.8	116.1
13	Sorghum - groundnut intercrop (40 kg N/ha - O)	15.6	20.7	51	68.4	87.1	111.1
14	Sorghum - groundnut intercrop (40 kg N/ha - I+O)	18.5	21.5	50	64.2	93.5	101
15	Sorghum - groundnut intercrop (80 kg N/ha - I)	19.3	21.6	63	72.2	112.9	122.7
16	Sorghum - groundnut intercrop (80 kg N/ha - O)	18.1	22.3	57.1	58	98.2	107.3
	Mean	17.76	21.01	55	61.7	97.5	109
	LSD	3.1	NS	10.3	23.1	22.8	32.3
	CV%	10.4	15.4	11	22.1	13.8	17.5

Key: I – inorganic source, O – Organic source and I+O – organic and inorganic source in equal proportions; WAP - Weeks after planting.

At 6 WAP in the intercrop, only use of 80 kg N/ha from urea enhanced the plant heights significantly above the unfertilized intercropped plants at Nyabisawa. At Piny Oyie, only supply of 40 kg N/ha from urea, FYM and combined sources and 80 kg N/ha from urea increased the plant heights above the unfertilized intercropped plants significantly. Among the rates, sorghum that received 80 kg N/ha from urea had plants that were significantly taller when compared to those which received N at 40 kg/ha from combined sources at Nyabisawa. No other significant treatment differences were observed among the sources and the N rates in the intercrop at both sites. When compared between cropping systems, only sole sorghum where 40 kg N/ha from combined sources was provided had plants that were significantly taller compared to the similar treatment in the intercrop at Nyabisawa. At Piny Oyie, only unfertilized sole sorghum and sole sorghum supplied with 40 kg N/ha from urea had significantly taller plants than similar treatments in the intercrop.

At 8 WAP, the height of plants at Nyabisawa ranged from 81.7cm (unfertilized intercropped sorghum) to 112.9 cm (intercropped sorghum to which 80 kg N/ha from urea was provided). At Piny Oyie, the plant heights ranged from 84 cm (unfertilized intercropped sorghum) to 122.7 cm (80 kg N/ha from urea in intercropped sorghum). Significant treatment effects on sole sorghum were only noted at Nyabisawa. 40 kg N/ha from combined sources increased the plant heights above the unfertilized sole sorghum significantly when applied on sole sorghum. Among the sources, applying 40 kg N/ha from combined sources led to significantly taller plants in comparison to where 40 kg N/ha from FYM had been supplied. No other significant differences were noted on treatments of sole sorghum. In the intercrop, only the plant heights of intercropped sorghum supplied with 40 and 80 kg N/ha from urea were increased significantly above the unfertilized intercropped plants at Nyabisawa. At Piny Oyie, intercropped sorghum supplied with N at 80 kg/ha from urea had significantly taller plants when compared with the unfertilized intercropped plants. Among the sources, a significant treatment effect was only observed where use of 40 kg N/ha from urea lead to plants that were significantly taller compared to where 40 kg N/ha from FYM had been supplied in the intercrop at Nyabisawa. No other treatment effects were observed to significantly affect the plant heights at Nyabisawa and Piny Oyie. Among the cropping systems, no significant treatment effects amidst the sole sorghum and the intercrop at both sites were noted.

4.3 Sorghum yield and yield components at Nyabisawa and Piny Oyie

An analysis to test for the homogeneity of error variance between the sites (Nyabisawa and Piny Oyie) using an unpaired t test for the yield components, that is, the grain and stover yields of sorghum was done and the sites were significantly different ($p \leq 0.05$) hence results presentation were done per site.

4.3.1 Grain yields

The sorghum grain yields were as illustrated in Table 5. The CV percentages were high for both sites (Table 5). At Nyabisawa, grain yields varied between 0.11 t/ha (unfertilized intercropped sorghum) and 0.55 t/ha (sole sorghum to which 40 kg N/ha from combined sources was provided) while at Piny Oyie, they varied from 0.17 t/ha (unfertilized intercropped sorghum) to 0.97 t/ha (sole sorghum to which 40 kg N/ha from combined sources was supplied). In sole sorghum, only the supply of 40 kg N/ha from combined sources increased the yields above the unfertilized sole sorghum significantly at Nyabisawa and Piny Oyie.

Table 5: Grain and stover yields for sorghum at Nyabisawa and Piny Oyie

Treat no.	Treatment	Yields in tons per hectare (t/ha)			
		Grain yields		Stover yields	
		Nyabisawa	Piny Oyie	Nyabisawa	Piny Oyie
1	Sole sorghum (0 kg N/ha)	0.23	0.38	2.87	7.44
2	Sole sorghum (40 kg N/ha - I)	0.35	0.7	3.66	7.83
3	Sole sorghum (40 kg N/ha - O)	0.28	0.31	3.06	4.06
4	Sole sorghum (40 kg N/ha - I+O)	0.55	0.97	5.06	8.76
5	Sole sorghum (80 kg N/ha - I)	0.33	0.79	3.82	8.65
6	Sole sorghum (80 kg N/ha - O)	0.24	0.47	4.61	5.2
11	Sorghum - groundnut intercrop (0 kg N/ha)	0.11	0.17	2.15	3.43
12	Sorghum - groundnut intercrop (40 kg N/ha - I)	0.15	0.64	4.53	6.31
13	Sorghum - groundnut intercrop (40 kg N/ha - O)	0.14	0.41	3.36	5.65
14	Sorghum - groundnut intercrop (40 kg N/ha - I+O)	0.18	0.21	4.4	5.85
15	Sorghum - groundnut intercrop (80 kg N/ha - I)	0.23	0.67	4.66	5.3
16	Sorghum - groundnut intercrop (80 kg N/ha - O)	0.18	0.62	3.38	5.25
	Mean	0.24	0.53	3.8	6.18
	LSD	0.14	0.43	1.55	2.23
	CV%	33.2	46	23.8	16

Key: I – inorganic source, O – Organic source and I+O – organic and inorganic source in equal proportions.

Among the sources, the use of 40 kg N/ha from combined sources led to grain yields that were significantly higher than sole sorghum where N was applied at 40 and 80 kg/ha from urea at Nyabisawa. Use of 40 kg N/ha from combined sources in the sole sorghum also lead to significantly superior grain yields compared to sole sorghum to which 40 and 80 kg N/ha from FYM were supplied at the two sites.

In the intercrop, significant effects of these treatments were only noted at Piny Oyie. Use of N at 40 and 80 kg/ha from urea and 80 kg N/ha from FYM had a significantly higher yield than the unfertilized intercropped plants. Among the sources, 40 kg N/ha from urea gave a significantly better yield than where N was supplied at 40 kg/ha from combined sources in the intercropped sorghum. Among the rates, 80 kg N/ha from urea had a significantly superior yield compared to where 40 kg N/ha from combined sources in the intercropped sorghum was supplied. When compared between cropping systems, N applied at 40 kg/ha from either urea, FYM or combined sources in the sole sorghum at Nyabisawa and sole sorghum to which 40 kg N/ha from combined sources at Piny Oyie had better yields compared to their equivalent in the intercrop.

4.3.2 Stover yields

The stover yields are presented in Table 5. At Nyabisawa, the stover yields were from 2.15 t/ha (unfertilized intercropped sorghum) to 5.06 t/ha (sole sorghum where 40 kg N/ha from combined sources was provided). At Piny Oyie, the stover yields from 3.43 t/ha (unfertilized intercropped sorghum) to 8.76 t/ha (sole sorghum supplied with 40 kg N/ha from combined sources)). In the sole sorghum, only sorghum that 40 kg N/ha from combined sources and 80 kg N/ha from FYM were provided to significantly increased the stover yields above the unfertilized sole sorghum at Nyabisawa. At Piny Oyie, yields from sole sorghum supplied with FYM both at rates of 40 and 80 kg N/ha had significantly lower yields than the unfertilized sole sorghum. Among the sources, use of 40 kg N/ha from combined sources had a significantly higher stover yield when compared to sole sorghum to which 40 kg N/ha from FYM had been supplied at Nyabisawa. At Piny Oyie, a similar effect was observed where sorghum supplied with 40 kg N/ha from urea and combined sources had significantly higher stover yields than those obtained from sorghum supplied with 40 kg N/ha from FYM. Those that 80 kg N/ha from urea was supplied to also had a significantly better stover yield than those at 80 kg N/ha from FYM at Piny Oyie. Among the rates, significant treatment differences were observed at Piny Oyie only whereby 40 kg N/ha from combined sources resulted to a significantly higher yield when compared to those that 80 kg N/ha from FYM was supplied to.

In intercropped sorghum, use of N at 40 and 80 kg N/ha from urea and 40 kg N/ha from combined sources caused a significant yield increase over the unfertilized intercropped plants at Nyabisawa. At Piny Oyie, only supply of N at 40 kg N/ha from urea and combined sources increased the sorghum stover yields significantly over the unfertilized intercropped plants. No other significant effects of the treatment were eminent in the intercrop at both sites. Among the cropping systems, significant treatment differences were only observed at Piny Oyie where only stover yields of the unfertilized sole sorghum and sole sorghum where 40 kg N/ha from combined sources and 80 kg N/ha from urea were supplied had significantly higher stover yields than those of similar sources and rates in the intercrop.

4.4 Yield and yield components of groundnuts at Nyabisawa

The yield components measured in groundnuts were the biomass yields, grain yields, seeds per pod and number of pods per plant are presented in Table 6. Due to disease attack at Piny Oyie, groundnut growth was adversely affected and therefore no yields were recorded. Only data for Nyabisawa is therefore presented herein.

Table 6: The yield components of groundnuts at Nyabisawa

Treat No.	Treatment	Pods per plant	Seeds per pod	Grain yield (t/ha)	Biomass yields (t/ha)
7	Sole groundnut (0 kg N/ha)	17	2.1	0.79	1.3
8	Sole groundnut (20 kg N/ha - I+O)	20	1.8	0.89	1.74
9	Sole groundnut (20 kg N/ha - I)	18	2.2	1.03	1.81
10	Sole groundnut (20 kg N/ha - O)	24	1.9	0.78	2.18
11	Sorghum - groundnut intercrop (0 kg N/ha)	10	2.4	0.68	1
12	Sorghum - groundnut intercrop (40 kg N/ha - I)	11	1.9	0.45	0.78
13	Sorghum - groundnut intercrop (40 kg N/ha - O)	14	1.9	0.49	0.8
14	Sorghum - groundnut intercrop (40 kg N/ha - I+O)	12	1.9	0.49	0.81
15	Sorghum - groundnut intercrop (80 kg N/ha - I)	13	1.8	0.44	0.82
16	Sorghum - groundnut intercrop (80 kg N/ha - O)	12	2	0.51	0.95
	Mean	15.1	2	0.66	1.22
	LSD	4.87	NS	0.25	0.61
	CV%	18.8	17.5	21.7	29.2

Key: I – inorganic source, O – Organic source and I+O – organic and inorganic source in equal proportions.

The number of pods per plant were between 10 (unfertilized intercropped groundnuts) and 24 pods (sole groundnuts supplied with 20 kg N/ha from FYM). In sole groundnuts, only use of 20 kg N/ha from FYM significantly increased the groundnut pods per plant above the unfertilized sole groundnuts. When compared between cropping systems, all treatments in the sole groundnuts had significantly greater numbers of pods per plant compared to those from treatments of similar sources in the intercrop. The treatment effects on the number of seeds per pod were however not significant from each other.

The groundnut grain yields varied between 0.44 t/ha (intercropped groundnuts where 80 kg N/ha from urea was provided) and 1.03 t/ha (sole groundnuts to which 20 kg N/ha from urea was supplied). In the sole crop, no treatment increased the yields above the unfertilized groundnuts significantly. A significant treatment effect among the sources was only observed where use of 20 kg N/ha from urea gave a significantly greater yield increase when compared to that from groundnuts supplied with 20 kg N/ha from FYM. Significant effects of the treatments were not noted on the grain yields of the intercropped groundnuts.

When compared between cropping systems, all treatments in the sole groundnut except the unfertilized ones had significantly higher grain yields than those from similar sources in the intercrop.

The groundnut biomass yields were as presented in Table 6. At Nyabisawa, the biomass yields ranged from 0.78 t/ha (intercropped groundnuts where 40 kg N/ha from urea was applied) to 2.18 t/ha (sole groundnuts where 20 kg N/ha from FYM was provided). In the sole groundnut, only groundnuts supplied with 20 kg N/ha from FYM significantly raised their biomass yields above the unfertilized sole groundnuts. No treatment significantly affected the biomass yields in the intercrop. When compared between cropping systems, all treatments except the unfertilized groundnuts in the sole groundnuts had significantly higher biomass yields than those from treatments of similar sources in the intercrop.

4.5 Agronomic Efficiency

Table 7 shows the AE values for sorghum at Nyabisawa and Piny Oyie. At Nyabisawa, the AE values were ranging between -15.19 kg/kg N (sole groundnuts where 20 kg N/ha from FYM was applied) and 10.64 kg/kg N (sole groundnuts to which 20 kg N/ha from urea had been provided). At Piny Oyie, the AE values were between -2.98 kg/kg N (sole sorghum that received 40 kg N/ha from FYM) and 16.64 kg/kg N (sole sorghum that got 40 kg N/ha from combined sources). Among the sources, sole sorghum which was provided 40 kg N/ha from urea and combined sources had significantly higher AEs than that to which 40 kg N/ha from FYM was supplied at Nyabisawa and Piny Oyie. Sole sorghum supplied with 80kg N/ha from urea also had a significantly higher AE than those supplied with 80 kg N/ha from FYM at Piny Oyie.

Table 7: The Agronomic efficiency (AE) values for sorghum - groundnut cropping systems at Nyabisawa and Piny Oyie

Treat No.	Cropping system	Nyabisawa	Piny Oyie
2.	Sole sorghum	6.94	7.2
3.	Sole sorghum	2.91	-2.98
4.	Sole sorghum	7.4	16.64
5.	Sole sorghum	2.62	5.83
6.	Sole sorghum	1.29	0.79
8.	Sole groundnut	-7.38	0
9.	Sole groundnut	10.64	0
10.	Sole groundnut	-15.19	0
12.	Sorghum - groundnut intercrop	-7.35	14.33
13.	Sorghum - groundnut intercrop	-3.83	15.15
14.	Sorghum - groundnut intercrop	-4.52	1.67
15.	Sorghum - groundnut intercrop	-1.91	13.12
16.	Sorghum - groundnut intercrop	-1.76	11.52
	Mean	-0.78	6.4
	LSD	2.586	4.903
	CV%	179	42.1

Among the rates, sole sorghum that received 40 kg N/ha from urea and 40 kg N/ha from combined sources had significantly higher AEs that those that received 80 kg N/ha from urea and FYM at Nyabisawa. At Piny Oyie, sole sorghum that was provided 40 kg N/ha from combined sources had significantly higher AEs than that which 80 kg N/ha from urea and FYM were supplied to. Sole groundnuts that were supplied 20 kg N/ha from urea had a significantly higher AE than those from sole groundnuts to which 20 kg N/ha from FYM and combined sources had been supplied at Nyabisawa.

In the intercrop, among the sources, the crops supplied with 40 kg N/ha from FYM and combined sources had significantly higher AEs than those that received 40 kg N/ha from urea at Nyabisawa. At Piny Oyie however, the crops that 40 kg N/ha from urea and FYM were supplied to had significantly higher AEs than those that were provided 40 kg N/ha from combined sources. Among the rates the crops in the intercrop that 80 kg N/ha from urea and FYM were supplied to had significantly higher AEs than those which received 40 kg N/ha from combined sources at Nyabisawa and Piny Oyie. Supply of 80 kg N/ha from urea and

FYM also led to significantly higher AEs than those from the crops supplied with 40 kg N/ha from urea at Nyabisawa.

4.6 Land Equivalent Ratio

The LER values for Nyabisawa are presented in Table 8. Intercropping sorghum and groundnut was beneficial (LER > 1) where there a there was no nitrogen application (0 kg N/ha) and where 80 kg N/ha from urea and 80 kg N/ha from FYM were used.

Table 8: The Land Equivalent Ratio (LER) for Nyabisawa

N rate	LER
0 kg N/ha	1.5
40 kg N/ha – I	0.767
40 kg N/ha – O	0.859
40 kg N/ha - I+O	0.759
80 kg N/ha – I	1.3
80 kg N/ha – O	1.061

Key: I – inorganic source, O – Organic source and I+O – organic and inorganic source in equal proportions.

CHAPTER FIVE

DISCUSSION

5.1 Manure and soil properties

The manure had a low C:N ratio (9.06) which infers its ability to easily mineralize and release N for plant use (Table 2). The high pH in the manure was important following the acidic nature of the soils and the optimum levels of nutrient elements in the manure which are necessary for plant growth and should be able to provide the plant with other vital elements in addition to N and C (Table 2, Table 3). However, despite these, the manure is classified either the intermediate class III or low quality following the <2.5 % of N it contains (Palm et al., 2001). Chivenge et al (2011) recommended that organic resources within such classes be supplied with a combination of inorganic fertilizers so as help deal with the low N present.

The soils had nitrogen levels which were below the critical level of 0.25% as they had lower percentages thus N supply using various sources was needed for growth of the crops (Okalebo et al., 2002). Their carbon levels were equally low as they were below 3% which is the critical level (Okalebo et al., 2002). This necessitates the use of FYM as one way of supplying N which has been reported in several occasions as not only important for N supply but also increases the C levels in the soil (Batiano et al., 2006; Järvan et al., 2017). The low pH in the sites which was either due to the parent material, leaching of the cations or continuous use of materials such as fertilizers that increased the acidity levels in the soil (Kisinyo et al., 2014). These could act as factors limiting the availability and uptake of most nutrients thus negatively affecting the efficiency of nutrient use and in turn result to poor yields (Kisinyo et al., 2019). The high sand percentages in the soil were also a point of concern as such textures directly affect the ability of the soil to retain water and nutrients for uptake by plants (Zhang et al., 2008; Arora et al., 2011)

5.2 Plant height

At 4 WAP, the crop was still at its early development stages and not many significant treatment effects are observed. At this stage however, it was noted that synergism was important as the plant heights of sole and intercropped sorghum supplied with N at 40 kg N/ha from combined sources were significantly taller than sole sorghum supplied with 80 kg N/ha from FYM and the unfertilized intercropped sorghum respectively (Table 4). The synergistic effects of supplying N using combined organic and inorganic sources observed in other studies have been attributed to higher nutrient use efficiencies, accumulation of more nutrient elements such as total N, C and P in the soils, increased yields, lowered emissions of greenhouse gases, better synchrony of the release and uptake of nutrients by the crops (Huang et al., 2007; Kassahun et al., 2010; Schoebitz and Vidal, 2016; Musuya, 2017).

At 6 WAP, the crop was at its critical stage of growth where booting is almost initiated and the N supply is critical (Bean, 2019) and therefore more treatment effects were observed as all treatments except supply of 80 kg N/ha from FYM significantly increased the plant heights above the unfertilized intercropped sorghum (Table 4). The plant heights increased with increasing N rates as observed in Nyabisawa where use of 80 kg N/ha from urea gave significantly taller plants than those supplied with 40 kg N/ha from combined sources (Table 4).

At 8 WAP, not much growth is expected as the plant was on the reproductive phase thus minimal treatment effects on the plant height are observed (Bean, 2019; Table 4). For instance, some of the outstanding treatment effects at 6 WAP such as significant plant height increases where N was supplied with 40 and 80 kg N from urea as compared to the unfertilized intercropped sorghum were still observed (Table 4). At this stage, nutrient uptake may have minimal effects on the plant height, however, other conditions such as droughts during the flowering stage could affect the crop and in turn affect the yield thus is equally and important stage of the sorghum plant (Burke et al., 2010).

The increased population in the intercrop that caused an increased intra and interspecific competition for the available resources among the intercrops affected the growth of the individual crops (Gao et al., 2013). This resulted to significantly taller plants in the sole sorghum treatments as compared to their similar treatments in the intercrops (Table 4).

5.3 Sorghum yield and yield components

5.3.1 Grain yields

In the sole sorghum, increase of yield where 40 kg N/ha was supplied as compared to most other grain yields in the respective sites was observed which was attributed to synergism due to use of N from combined organic and inorganic sources (Table 5). Increased yields of other different crops as a result of synergism where similar or different organic and inorganic nutrient inputs other than urea and FYM were used when supplying various nutrient elements have also been reported by other researchers. For instance, Kassahun et al (2010) also observed that a combination of FYM with 50% dose of inorganic N and P fertilizers increased the tef grain and straw yields and also resulted to an increase in the organic carbon and available nitrogen and phosphorus. In addition, Dhamala et al (2020) recorded the highest biological and economic yield of 9.63 Mt/ha and 6.16 Mt/ha respectively from cabbage that had been supplied with 50% urea and 50% FYM.

In the intercrop however, the higher demand of N by the larger crop population became more important than the synergistic effects as in the case of the plant heights mentioned earlier (Table 5). This also explains the lower grain yields observed in the intercrop as compared to the sole crop (Table 5).

The high percentage CVs were noted on the grain yields in both sites are explained by the large number of treatments which resulted to larger blocks and in turn increased heterogeneity among the treatments (Dafaallah, 2019). In general, despite some of the treatments giving higher yields, the sorghum yields were lower than 3 - 4.5 t/ha which is expected under such nutrient management practices (FAOSTAT, 2014; Oyier et al., 2016). Chivenge et al (2009) reported that using combined organic and inorganic sources to supply nutrients to crops could increase the grain yields by over 400% when compared to the control which was not the case for this study. This could be explained by the low pH levels in the soils for these sites (Table 3). According to Kihara et al (2017) and Kisinyo et al (2019), soil acidity is among the factors that affect crop productivity. It therefore calls for use of liming materials and or larger quantities of FYM so as to increase the pH and allow the crops a favourable environment for growth which may then boost their response to nutrient inputs by giving higher yields (Fageria and Baligar, 2008).

5.3.2 Stover yields

The significantly higher stover yields of sole sorghum supplied with 40 kg N/ha from combined sources and 80 kg N/ha from FYM when compared to those from the unfertilized sole sorghum at Nyabisawa were attributed to synergism and to the larger amount of N in released respectively. Chaudhari et al (2017) also observed an increase in the dry matter (inclusive of stover yield) above the unfertilized crops where FYM was applied and attributed it to the improvement of the soil physical and chemical properties which for this study were not measured thus could not be concluded as such. At Piny Oyie however, supply of N at 40 and 80 kg N/ha from FYM gave significantly lower stover yields than the other treatments including the unfertilized sole sorghum. This was unexpected especially when compared with the unfertilized sorghum as the soils were already deficient of N at the time of planting thus would not surpass the yields obtained from crops fertilized from whichever source (Table 3).

As in the grain yield, the observations in the intercrop revolved around the higher N demand that had to be met by supplying the nutrients through use of urea, FYM or combined sources as was done in the study. It is however important to note that the stover yields may not always correlate positively to the grain yields. For instance, higher stover yields may however not necessarily lead to higher grain yields especially due to other factors such as diseases, droughts and pests like midge at critical times of growth for instance panicle formation (Tandzi and Mutegwa, 2020). Increased plant height may however affect the stover yields as the tall stems have an increased number of internodes formed which allow more room for leaves to form and in turn increase the stover/biomass yields (Gasim, 2001; Olson et al., 2012).

5.4 Groundnut yield and yield components

The readily available N in the 20 kg N/ha from urea at the initial stages enabled good crop establishment, formation of the plant parts responsible for certain vital roles such as N fixation and in the long run better yields (Table 6). This implied that the 20 kg N/ha recommended by FAO (2006) was essential for the early stages of growth and was to be applied, but a readily available form would supply the N better. These observations were however different in the case of the number of pods per plant and biomass yields where use of FYM recorded significantly better performance (Table 6). As opposed to the inorganic N source, organic materials such as FYM are known to improve the soil chemical and physical properties leading to a good environment for beneficial microorganisms and good growth of the plants as aspects such as improved uptake of minerals are enhanced (Karunakaran et al., 2010). These could then boost the formation of the other plant parts and in turn significantly increase the yield components such as pods per plant and biomass as in the case of this study. These findings are in line with reports by Madhiyazhagam et al (2001) and Ravichandra et al (2015) that use of FYM could increase the yield and yield components of groundnuts. The number of pods per plant may however not correlate to the grain yield in some cases. This is in agreement with Pathak (2010) who reported that the number of pods per plant can be negatively correlated to the seed formation as in the cases where deficiency of one of the elements such as calcium at the critical time of seed formation can result to poor filling of pods thus higher numbers of pods but lower grain yields.

5.5 Agronomic Efficiency

All the AEs obtained from the two sites except that from the sole sorghum that received 40 kg N/ha from combined sources (16.64 kg/kg N) at Piny Oyie were lower than the expected range (15 – 30 kg grain yield per N input) (Fixen et al., 2015). This inferred that use of combined sources to supply nutrients could increase the efficiency of nutrient uptake although this could be affected by other factors such as the cropping system, soil properties and rainfall amounts as it is only observed in Piny Oyie on the sole sorghum. Muflahi and Basuaid (2017) are among researchers who also recorded a low nitrogen efficiency of 12.78 kg/kg N. The low AEs can be explained by the low soil pH which could inhibit availability and uptake of nutrients from the soil as well as the poor rainfall patterns within the season which resulted to instances such as poor grain filling as explained earlier.

Significant treatment effects were observed despite the low AEs. In sole sorghum, it was observed that use of 40 kg N/ha from urea and combined sources gave a significantly higher AE as compared to use of 40 kg N/ha from FYM. Efthimiadou et al mentioned that 2010 mentioned in his study that manure may not be sufficient alone to maintain the levels of most high yielding varieties. Some studies have also noted less effect of manure applied within the first season but recorded more yields in the subsequent seasons due to its residual effects. These could explain the poor performance of crops that received FYM at 40 kg N/ha but further research can be done to establish this as it was also observed in several other treatments in this study. For instance, sole sorghum supplied with 80 kg N/ha from urea had a significantly higher AE than those supplied with similar rates of N from FYM at Piny Oyie (Table 7). A similar case was observed at Nyabisawa in the sole groundnut to which 20 kg N/ha from urea was supplied had a significantly higher AE as compared to where 20 kg N/ha from FYM supplied (Table 7). It is also important to note that ready availability of N from the inorganic source and aspects of synergism enhanced these observations as most of the mentioned treatments were either that that received N from urea or combined sources. The significantly higher AE in the sole groundnuts supplied with 20 kg N/ha from urea as compared to 20 kg N/ha from FYM and combined sources at Nyabisawa likely due to the fact that the crops needed about 20 kg N/ha so as to facilitate their growth during early stages before the nodule bacteria are established to enable the start the fixing of their own N (FAO, 2006).

It was also observed that the AEs decreased with increasing N input in the sole crops where the crops that received 80 kg N had from both sources had significantly lower AEs than those that received 40 kg N from FYM, urea ad combined sources as in Nyabisawa (Table 7).

This was due to the lower populations in the sole crops as thus a lower demand for nutrients as compared to the higher populations in the intercrops which not only creates a higher need for resources but also exposes the crops to higher competition for these resources. Akdeniz et al (2006), Buah and Mwinkaara (2009), Muflahi and Basuaid (2017) and Zang et al (2020) also observed lower efficiencies of nitrogen use as N input increased. Roberts (2008) and other researchers attributed such low efficiencies on higher rates of nutrients to loses such as leaching, erosion, run offs of soluble N fertilizers. In the intercrop however, the AEs increased with increasing rates of N applied (Table 7). This is explained by the increased N demand with the increased plant population thus a need for higher N supply as earlier mentioned.

5.6 Land Equivalent Ratio

The yield advantages of 130% (LER = 1.3) and 106.1% (LER = 1.061) obtained from intercropped plants supplied with N at 80 kg/ha from urea and FYM respectively were due to the higher N rates supplied to meet the higher N demand posed by the dense population of the crops in the intercrop. The yields of the individual crops were enhanced thus giving higher total outputs as compared to those grown as sole crops. Studies have reported in intercropping sorghum and groundnuts as beneficial although the yield advantages are not expressed with regard to the rates of nutrient provided. Berhanu and Hunduma (2017) are among the researchers who in their study observed an LER of 1.3 where sorghum and groundnuts were intercropped at a spacing of 30 cm by 20 cm but their focus was on plant density for intercropping sorghum and groundnuts.

The other yield advantage of 150% (LER=1.5) observed in the unfertilized intercropped plants was however unexpected. This because the soils were deficient of N and thus due to lack of N supply, were expected to give poor yields both as individual crops which would then lower the total output. The condition was to be exacerbated by the high population in the intercrop thus a higher N demand that was not met by not supplying N. Biological nitrogen fixation could explain this as lack of N in the soil is an encouraging factor to N fixation but the acidic nature of the soils in both sites was not conducive (Table 3: Mohammadi et al., 2012). Nonetheless, the high total output value obtained from the unfertilized intercropped plants could be explained by the high groundnut yield obtained in the intercrop as opposed to that in the sole crop (Table 8). This is one of the factors that attract farmers to intercropping as it gives security where one crop could fail as the other crop in the intercrop could also give them some yield

(Ananthi et al., 2017, Kinama and Pierre, 2018). The high N demand in the intercrop however could also not be met by the lower N rates hence the yield disadvantages (LER < 1) observed where N was supplied at 40 kg/ha from urea, FYM and combined sources

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

Objective 1: To assess the effect of inorganic and organic N sources and their combination on the yield and yield components of sorghum - groundnut cropping systems.

In the sole sorghum, use of 40 kg N/ha from combined sources significantly increased the sole sorghum plant heights above the unfertilized sole sorghum. They also gave the tallest plants at 4, 6 and 8 WAP and the highest sorghum grain and stover yields at Nyabisawa and Piny Oyie which inferred that synergism was important in the sole sorghum as it boosted the productivity of the crops. In sole groundnuts, use of 20 kg N/ha from a readily available source, that is, urea, is important for the growth of groundnuts as it led to grain yields that were significantly higher than all the other treatments in the sole groundnuts. In the intercrop however, considering the increased number of crops which posed a higher demand for minimal resources available, the use of N from readily available resources and at higher rates, that is, 40 and 80 kg N/ha from urea and in some cases 80 kg N/ha from FYM became important. The unfertilized intercropped sorghum gave the shortest plants and the poorest yields in both cropping systems due to the N deficiency which had not been managed thus proved the need to supply N to the crops so as to improve their yields. It was observed that despite the ability of sorghum and groundnut to tolerate drought, it is important that timely planting be observed to prevent exposing the crops to stress during the critical growth stages as in sorghum and also help escape disease cycles that result to loses as in the case of groundnuts at Piny Oyie.

Objective 2: To determine the AEs of sorghum - groundnut cropping systems under inorganic and organic N sources and their combination.

Sole sorghum that received 40 kg N/ha from urea and the combined sources had significantly higher AEs than those that received 80 kg N/ha from urea and FYM at Nyabisawa and those that received 80 kg N/ha from FYM at Piny Oyie. In the intercrop, crops supplied with 80 kg N/ha from urea and FYM had significantly higher AEs than those which received 40 kg N/ha from combined sources at both sites. In sole groundnuts, just like in the grain yields, use of 20 kg N/ha from a readily available source resulted to a significantly higher agronomic efficiency compared to all the other treatments since the crops needed N before they were well established to start fixing their own N.

Objective 3: To determine the effect of inorganic and organic N sources and their combination on the LERs of sorghum - groundnut cropping systems.

Intercropping was beneficial (LER > 1) in the unfertilized plots and those supplied with 80 kg N/ha from either urea or FYM. The 80 kg N/ha from either urea or FYM provided the large amount of N needed by the crops following the higher population in the intercrop which posed a higher N demand.

Recommendation for further research

The observation where intercropping was beneficial in the unfertilized intercrops however requires further research as factors such as the low N levels in the soil where the crops were grown, the low pH which hindered N fixation to some extent and also the higher N demand from the densely populated intercrop which was not supplied.

6.2 Practical Recommendations

1. When sorghum is to be planted as a sole crop, use of 40 kg N/ha from combined inorganic (urea) and organic (FYM) sources can be recommended for good yields.

2. When sorghum - groundnut intercropping is practiced, a higher rate of N (80 kg N/ha) from either inorganic (urea) or organic (FYM) sources is recommended as it caters for the nutrient demand of both crops and may result to give higher yields.
3. When groundnuts are grown in a pure stand (sole groundnut), application of 20 kg N/ha from urea at planting is recommended for better groundnuts yields

6.3 Suggestions for further studies

- Economic analyses to determine the economic viability for each strategy for soil fertility management and cropping systems in this study should be conducted before recommending them to farmers
- This study was only done for one season at both sites; therefore, it is recommended that it is done for several cropping seasons so as to determine the response of the cropping systems under varied conditions.
- Soil acidity was suspected to have affected the response of the crops to the treatments leading to very low yields even where higher N rates were applied. This calls for intervention or inclusion of an acid correction treatment so as to determine whether and to what extent acidity was able to inhibit crop response to the treatments applied.
- The large distance between the sites of study and the weather stations resulted to generation of rainfall data that could not give an actual picture of how dry or wet the sites were. Therefore, installation of a simple weather station for important parameters such as a rainfall within the area of study could be of importance if this study was repeated or in any other study of similar kind.
- The soil nutrient dynamics and the factors affecting it such as leaching in sandy soils could be important in explaining some treatment effects in this study were not explored. In other studies, nutrient dynamics could be studied too and certain related parameters measured so

as to give a clearer picture of the nutrient input and its use all through the critical growth stages rather than just giving the final outputs only.

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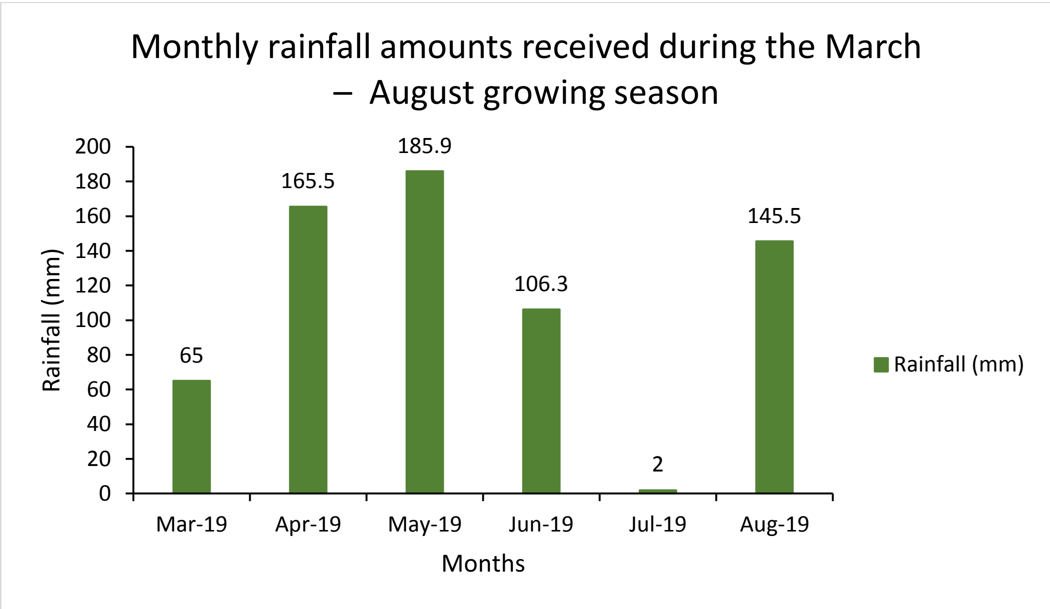
APPENDICES

Appendix I: Rainfall Data

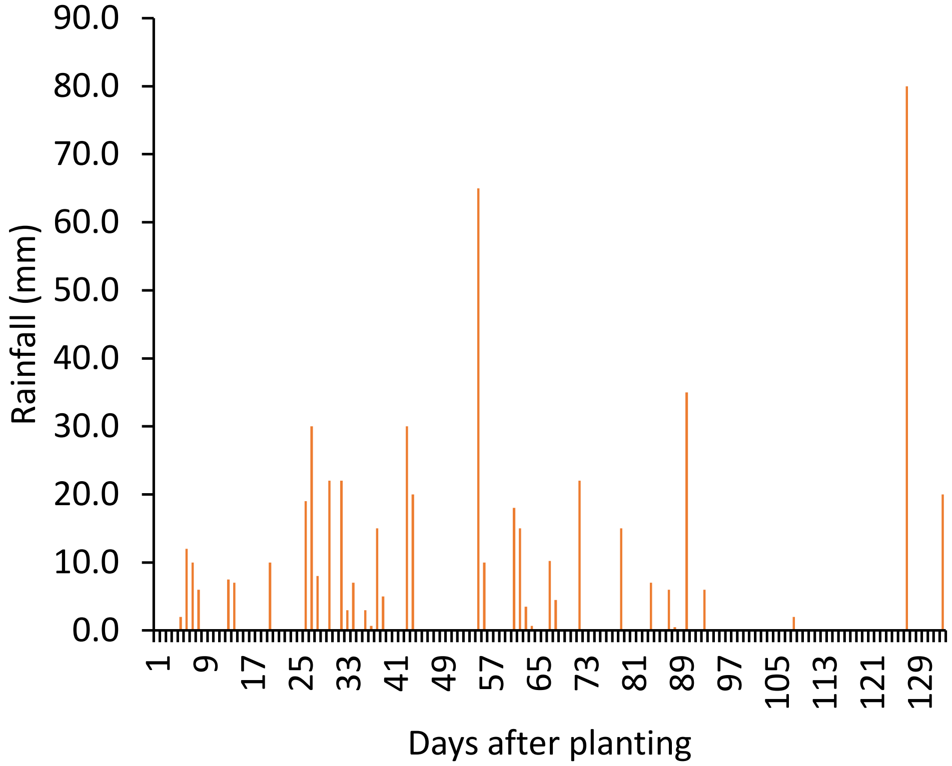
Suba weather station was the nearest meteorological station to the sites of studies and thus was used to give a view of the rainfall received during the cropping season. Figure 5 illustrates the monthly rainfall received during the March - August growing season of 2019. The rainfall amounts received varied throughout the season. The wettest month in the season was May (185.9 mm) which had the highest rainfall amounts while the driest smonth was July (2 mm) which had the least rainfall amounts. The total ammount of rainfall received throughout the season was 670.2 mm.



(Source: Suba weather station)

Figure 5: Monthly rainfall received during the March - August growing season

Figure 6 illustrates the pattern of daily rainfall amounts received from the time the crops were planted to the time they were harvested. The pattern of the rainfall amounts was irregular throughout the growing season with several days having very low rainfall amounts.



(Source: Suba weather station)
Figure 6: Daily rainfall received from the day of planting to the day of harvesting