EFFECT OF ORGANIC AND INORGANIC FERTILIZER REGIMES ON GRAIN SORGHUM GROWTH AND YIELD

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

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DEDICATION

I dedicate this work to my dear parents Mr. Joseph Riungu and Mrs. Celina Riungu for their financial, spiritual and moral support throughout my study. To my lovely sister Cecilia Riungu for her love and council. To my husband Sebastian Tom for his relentless support and love. Lastly to Pastor Roy Muriuki for encouraging me to walk this journey, for his prayers and spiritual guidance.

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LIST OF ABREVIATIONS AND ACRONYMS

AAS	Atomic absorption spectrophotometer
ADP	Adenosine diphosphate
ADS	Anglican Development Services
AEZ	Agro ecological zone
AMP	Adenosine monophosphate
ANOVA	Analysis of Variance
ASALs	Arid and Semi-Arid Lands
ATP	Adenosine triphosphate
Ca	Calcium
CAN	Calcium ammonium nitrate
CIDP	County Integrated Development Plan
CIMMYT	International Maize and Wheat improvement Center
CV	Coefficient of Variance
DAP	Diammonium phosphate
DNA	Deoxyribonucleic acid
DTPA	Diethylenetriamine pentaacetic acid

Fe	Iron
FGD	Focus group discussion
FYM	Farmyard Manure
GHGs	Greenhouse gasses
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IPNI	International plant Nutrition Institute
ISFM	Integrated Soil Fertility Management
KALRO	Kenya Agricultural and Livestock Research Organization
KIHBS	Kenya Integrated Household Budget Survey
KII	Key informant interview
LM	Lower mid land
LSD	Least Significant Difference
Mg	Magnesium
NGO	Non-governmental organization
NPK	Nitrogen, Phosphorus and Potassium
pH	potential of Hydrogen
SPSS	Statistical package for social sciences
SSA	Sub Saharan Africa

USAID	United States Agency for International Development
USDA	United States Department of Agriculture

GENERAL ABSTRACT

Productivity of sorghum has been below potential in arid and semi-arid lands (ASALs) of Kenya, mainly due to poor agronomic practices, especially nutrient deficiency. Although sorghum crop is fairly drought tolerant, resistant to water logging and yields are reasonably better on infertile soils compared to other crops, increasing its nutrition would significantly increase the yields as well as the nutrient loads to the grains and the crop residues used for livestock feed. The objective of this study was to determine the farmers' existing sorghum production practices and the effect of using organic and inorganic fertilizers on the growth and yield of grain sorghum.

A survey involving 90 farmers from sorghum producing areas in Makueni County was conducted in February 2017. The survey focused on; farmer's sorghum production objectives, the size of land used for sorghum production, source of information on sorghum production, challenges and constraints in sorghum production, source of sorghum seeds used by farmers, varieties of sorghum produced and preferred, intercropping in sorghum production, cropping system and fertilizer use in sorghum production, sorghum yield, sorghum use and conservation as animal feed in Makueni County. The data was analyzed in a Statistical Package for the Social Sciences (SPSS) program version 20.The survey results showed that most farmers (70%) used uncertified seeds from own saved sources, and the commonly grown variety was Seredo (47.2%) due to resistance to birds' damage. Most (31.7%) of farmers recorded very low yield of sorghum grain of between 0.151 to 0.25 t/ha which is below the potential yields of 10.5t/ha. Most farmers (66.6%) used farmyard manure in sorghum production while 30.9 % of the farmers did not use any fertilizer. All farmers indicated that their greatest challenge in sorghum production was inadequate rainfall. Bird damage to sorghum crop was a chronic problem to most (71.6%) farmers. Most (56.8%) of the farmers conserved sorghum residue for feed as hay

A field experiment was conducted in a randomized complete block design with split plot arrangement, to evaluate the effects of two fertilizer sources (Organic and inorganic) on productivity of three sorghum varieties (Gadam, Kari Mtama 1and Macia) as main crop and ratoon crop under supplemental irrigation. The fertilizer treatments levels were: 5tFYM/ha, 15tFYM/ha, 25kgN/ha NPK + 25kgN/ha Urea, 50kgN/ha NPK + 50kgN/ha Urea, 5tFYM/ha +25kgN/ha NPK+ 25kg Urea, 15tFYM/ha + 50kgN/ha NPK + 50kgN/ha Urea. The crop growth parameters measured were; number of productive tillers per plant, panicle length, time to 50% flowering, 1000-grain weight, plant stand at harvest, number of panicles, number of grains per panicle, threshing percentage, stover yield and grain yield. The data obtained was subjected to analysis of variance using GENSTAT© statistical package.

The field experiment showed number of productive tillers increased with increase in fertilizer level used in both the main crop and the ratoon crop. Gadam variety had the highest number of productive tillers per plant compared to Kari Mtama 1 and Macia, in the ratoon crop with2.19, 1.81 and 0.667 tillers, respectively. The panicle length and days to 50% flowering was affected by the levels of fertilization in both main and ratoon crop. Macia had the highest panicle length (28.5 cm main crop; 26.76 cm ratoon crop) compared to the other varieties (Gadam 22.8cm main crop; 20.01cm ratoon crop and Kari Mtama124.73cm main crop; 22.7cm ratoon crop). Gadam took fewer days (50days) to 50% flowering in the main crop and 36 days in the ratoon crop. The highest number of panicles was observed in Gadam followed by Kari Mtama 1 and Macia with 156.9 panicles in main crop; 136.5 panicles in the ratoon crop, 102 panicles in main crop; 96 panicles in the ratoon crop, 85.3 panicles in main crop; 80.4 panicles in the ratoon crop, respectively. Different fertilization levels had no significant ($p \leq 0.05$) effect on 1000-grain

weight for the three varieties in both main and ratoon crop seasons. However, there was significant differences in 1000-grain weight amongst the varieties with Kari Mtama 1 having the highest 1000-grain weight of 36.05g in main crop; 34.19g in ratoon crop, followed by Gadam with 31.43g in main crop; 30.9g in ratoon crop and lastly Macia with 29.43g in main crop; 26.67g in ratoon crop. There was significant difference in the stover and grain yield in t/ha among the sorghum varieties. Gadam had the highest grain yield of 5.54t/ha in main crop; 4.5t/ha in ratoon crop, Kari Mtama 1 recorded 4.81t/ha in main crop; 3.96t/ha ratoon crop and Macia recorded the least grain yield of 4.79t/ha in main crop; 3.96t/ha in ratoon crop. Macia had the highest stover yield of 16.47t/ha in main crop; 17.7t/ha in ratoon crop, while Gadam had the least stover yield of 12.6t/ha in main crop and 13.15t/ha in ratoon crop.

The findings show there is need to provide technical information and guidance to farmers on sorghum varieties to grow, agronomic practices for soil fertility management and proper use and conservation of sorghum residue as animal feeds in Makueni County. Use of both organic and inorganic fertilizer can highly influence yield and the yield attributes of grain sorghum. Gadam variety proved to be better than Kari Mtama 1 and Macia across all fertilizer levels and the highest yields were obtained where fertilizer and manure application was done at the rate of15t/ha FYM+100kgN/ha. Macia does well as a dual purpose because it has a high residual yield than Gadam and Kari Mtama 1 across all the fertilizer levels.

Key words: Dual purpose, Gadam, ratoon crop, stover yield, uncertified seeds

CHAPTER ONE

INTRODUCTION

1.1Background information

Generating a sustainable food and feed supply that to match the increasing demand is, by far, the most formidable challenge facing sub-Saharan Africa (SSA) agriculture (Hounkonnou*et al*., 2012; Jayne and Shahidur, 2013). Enormous increases in human and livestock populations are projected to occur in the decades to come, coupled with massive increase in levels of urbanization. The anticipated population growth is also projected to generate heightened competition for land and increased scarcity of cropland (Strassburg *et al*, 2014; Mueller and Binder, 2015) and especially in the rangelands. This may in turn induce agricultural intensification, in particular, integrated crop/livestock production (Baudron *et al*, 2014; Kindu *et al*. 2014; Castellanos-Navarrete *et al*, 2015). This is already happening in Kenyan arid rangelands. Thus, crop residue is becoming the dominant feed resources for livestock in these Eco zones as more rangeland is converted into cropland.

Sorghum *bicolor* L. Moench commonly known as sorghum is a grass species cultivated for its grain, which is used for human food and feed for animals, and for ethanol production (Rhodes*et al*, 2015). The United States is the world's largest producer of grain sorghum followed by India, Nigeria, and Mexico, while the leading exporters are the United States, Australia and Argentina (Rao *et al*, 2014). Sorghum provides human dietary calories fromdirect cereal consumption or from livestock products from animals fed with sorghum grains and their byproducts (Taylor, 2003). It is likely that sorghum will continue to account for the bulk of the future human food supply because it produces higher yields of human edible grains, easily growneven under low rainfall areas, easy to store and transport and requires less fuel and labor for processing and cooking than other food crops.

Sorghum is an under-utilized crop and one of the most important cereals in semi-arid tropics (Muui *et al*, 2013; Jacob *et al*, 2013). In Kenya, sorghum is grown in the often drought prone marginal agricultural areas of Eastern, Nyanza and coast provinces (Muui *et al*, 2013). Most people in these regionsregard sorghum as a poor man's crop and some still prefer to grow maize even in areas where it does not do well and as a result, there is increasing food insecurity (Gregory et al, 2005). A wide range of naturally occurring biotic and abiotic constraints including poor soils, water scarcity, crop pests, diseases, weeds and unsuitable temperatures are well known to reduce the productivity of sorghum leading to low efficiencies of input use, suppressed crop output and reduced food security (Strange and Scott, 2005). Nitrogen losses through gaseous plant emissions, soil denitrification, surface runoff, volatilization and leaching are increasing with time, especially in nutrient poor soils. This results to a minimal amount of nitrogen available for cereal crops such as sorghum, which cannot do nitrogen fixation leading to low yields (William *et al*, 1999). Other constraints in sorghum production include; water logging, water runoff and soil erosion, which represent major yield constraints (Murty *et al*,2007). Low temperatures, low soil P and N, Fe toxicity, acid soils, and wind damage (blown sand) also hinder crop yields, while downy mildew, insect pests, and weeds such as Striga also cause severe losses (Clay, 2013).

Although many producers view sorghum as a low maintenance crop, with its deep fibrous root system, sorghum responds well to nutrient applications especially in soils that are low in fertility. Nitrogen is the most often limiting in sorghum production, hence if managed efficiently, significant increase in the yields may be realized (Vanlauwe, 2014; Potgieter *et* *al*,2016). This study therefore, focused on the use of both organic and inorganic fertilizers in sorghum production for increased yields and improved quality of grains for human food and residues for quality livestock feed.

1.2 Problem statement

Productivity of sorghum has been below potential in ASALs of Kenya, mainly due to poor agronomic practices, particularly nutrient deficiency (Chepkemoi *et al*, 2014; Janeth *et al*, 2014; Mwadalu, 2014). Nitrogen is the element most frequently lacking for optimum sorghum production (Barthélémy *et al*, 2014;Paiva *et al*, 2017). Although sorghum crop is fairly drought tolerant, resistant to water logging and yields are reasonably better on infertile soils compared to other crops (Rurinda *et al*, 2014), increasing its nutrition would significantly increase the yields as well as the nutrient loads to the grains and the crop residues used for livestock feed. Sadly, many sorghum farmers are traditionally known to be producing sorghum without the use of inorganic or organic fertilizers, which has contributed to very low yields (Kagwiria *et al*, 2019).This is due to the high costs of commercially produced fertilizers, and low adoption of organic fertilizer use. In areas where inorganic fertilizers are used, farmers poorly manage in terms of rates of application, time of application and method of application. This also has contributed to low sorghum yields even among large-scale producers. The current sorghum yields in small scale farming ranges from 0.5-1.5 tons/ha compared to the potential yield of 4tons/ha (Muui *et al*, 2013).

Sorghum, which is closely related to maize in utilization and is an alternative staple food crop in arid areas, with a competitive edge over maize due to drought resistance and better nutrient use efficiency, even under poor soils. As an indigenous Kenyan crop, sorghum could provide food security and become a suitable alternative in ASALs of Kenya. Despite its suitability in these areas, the area under sorghum production is still low and farmers attain low yields. Most farmers still opt to grow maize that is disadvantage by frequent crop failures (Muui *et al*, 2013). Many farmers also do not practice ratooning, which may be another agronomic practice to increase feed yield and reduce new crop establishment costs hence increased benefit to farmers.

1.3 Justification

Sorghum like any other crop requires good agronomic practices such as application of fertilizers at the right time and in right amounts to ensure vigorous plant growth and high yields. Absence of these nutrients such as nitrogen, magnesium, phosphorous, potassium, zinc, iron may lead to crop failure. It is likely that sorghum will continue to account for the bulk of the future human food supply because it produces greater yields of human edible food and this increases food security (Gruen and Loo, 2014). High sorghum yields will also reduce costs of sorghum imports from countries such as Uganda, Tanzania, United States and other European countries. (Kilambya *et al*, 2013). Nutrients such as nitrogen are subject to many losses for instance losses through gaseous plant emissions, soil denitrification, surface runoff, volatilization and leaching and hence should be efficiently managed to optimize on the yields (William *et al*, 1999). Use of organic fertilizers such as the farmyard manure may increase sorghum yield compared to the use of inorganic fertilizers alone. This is because organic manure contains other nutrients such as the micronutrients (iron, zinc, boron) which are absent in inorganic fertilizers and contribute to improved soil fertility and soil structure. Organic manures are also cheaper compared to the inorganic fertilizers and are readily available even to small-scale farmers. Use of both organic and inorganic fertilizers may greatly increase the yield of sorghum in the semiarid areas of Kenya.

1.4 Objectives

1.4.1 General objective

To determine the existing farmers' production practices with respect to sorghum production and to evaluate the effects of different fertilizer regimes on the growth and yield of grain sorghum.

1.4.2 Specific objectives

1. To investigate the existing farmers' production practices with respect to sorghum production and uses for both food and feed
2. To evaluate the effect of organic and inorganic fertilizer regimes on the growth and yield of grain sorghum from main crop and ratoon crop of three varieties in dry lands of Kenya

1.5 Hypotheses

1. Different farmers do not carry out different production practices with respect to sorghum production and use for both food and feed
2. Organic and inorganic fertilizers does not improve the growth and yield of grain sorghum varieties for the main crop and ratoon crop

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and history of sorghum

Sorghum is a tropical cereal whose origin is Africa with the primary source believed to be Ethiopian Highlands and Southern Sudan (Klein *et al*, 2015). Sorghum spread from Ethiopia into Eastern Africa regions around 200 AD, and was carried to many countries of Eastern and Southern Africa by the Bantu people (Taylor, 2003). It spread to India during the first millennium BC and the spread along the coast of Southeast Asia to China may have taken place about the beginning of the Christian era. Sorghum is the world's fifth most important cereal crop after rice, wheat, maize and barley (Akram *et al*, 2007).

2.2 Importance of sorghum as food crop

Worldwide, sorghum is a food grain for humans (Carter *et al*, 1989). Grain sorghum is used in many parts of Africa to make semi-leavened bread, fermented and non-fermented porridges, brewing traditional beers and has been proven as the best alternative to barley for lager beer brewing because of good malting quality (Basnet, 2003; Taylor, 2003). Sorghum is also used as feed and a pasturage crop for livestock as well as to make ethanol (Hariprasanna, 2016). It has protein levels of around 9−12%, enabling dependent human populations to subsist on it in times of famine (Basnet, 2003).

2.3 Sorghum ecology and botany

Sorghum*bicolor* is typically an annual crop although some cultivars are perennial (Prasad, 2009). It grows in clumps that may reach over 4 m high. The grain is small, ranging from 3 to 4 mm in diameter.

Grain sorghum is a grass similar to maize in vegetative appearance, but sorghum has more tillers and more finely branched roots than maize. Growth and development of sorghum is similar to maize, and other cereals. Sorghum seedlings are smaller than maize due to smaller seed size (Carter *et al,* 1989). Grain sorghum goes through three distinct stages of development after emergence – seedling development, panicle initiation and reproduction. The time required for the plant to go through each stage is dependent upon variety, hybrid maturity and temperatures encountered during the growing season (Gerik, 2003). Grain sorghum takes 90 days from planting time to maturity, 0-30 days being the vegetative growth, 30-60 reproductive stage and 60-90 grain filling and physiological maturity.

2.4 Agronomy and growth requirements of sorghum

Early planting of sorghum can help to avoid harsh weather condition and increase productivity. The earlier the planting date just before the first rains the better for the crop by ensuring a compromise between soil temperatures for good sorghum emergence and trying to get the crop in early to result in avoiding heat and achieving better water use efficiency (Peter, 2008). A large number of row spacing and population studies in sorghum have failed to establish optimum row spacing and plant population estimates (Myers and Foale, 1981). However, some past research has resulted in estimating desirable plant population in sorghum. Thomas *et al*(1981) suggested a plant population of 60,000 to 80,000 plants per hectare. Maximum yield for a range of hybrids at each yield level did not differ significantly from yield at a density of 75,000 plants/ha (Wade and Douglas, 1990). They suggested highest grain yields would be obtained with a plant population between 50,000 and 100,000 plants/ha under dry land conditions. Sorghum sowing should consider available moisture and the prevailing temperature. Planting should be as shallow as possible (about 5cm) under cool soil temperatures, with depth increasing under hot, dry conditions. Sorghum has been observed to have better emergence from 8 to 10cm depth under high temperatures, which rapidly dry out the soil surface (Orchard et al, 1984). Sorghum is known to have a well-developed root structure and possesses the ability to roll up its leaves in hot weather and this makes the crop drought tolerant. Sorghum does well in areas that are below 1500m above the sea level. It requires 420mm-630mm of rainfall per annum for growth and production (Orchard et al, 1984).

2.5 Nitrogen requirement in sorghum production

Nitrogen is the most limiting nutrient in grain sorghum production. Crops do not use as much nitrogen during the first 20 days of development but at 6o days, the plant will have used up to 60% of the total nitrogen applied hence it is necessary to apply N fertilizers in splits (Espinoza *et al*, 2003). Nitrogen element is a major component of chlorophyll, hence very crucial in the process of photosynthesis. It is also a major component of amino acids, the building blocks of proteins. Nitrogen is a component of energy-transfer compounds, such as ATP (adenosine triphosphate). Nitrogen is a significant component of nucleic acids such as DNA. Soil nitrogen can be found in three forms: organic nitrogen compounds, ammonium ions (NH_4+) and nitrate ions (NO_3-). 95 to 99% of potentially available nitrogen is in organic forms (IPNI, 2013).

2.6 Potassium in sorghum production

Potassium just like other nutrients like nitrogen and phosphorous, is required for normal plant growth and development in any crop. It plays the role of translocation of carbohydrates, water relations, photosynthesis, resistant against insects and diseases and sustains balance between divalent and monovalent cations (Brar *et al*, 2004). Potassium uptake is greater in the early part of sorghum growth than that of nitrogen and phosphorus and most of potassium is contained in the crop at harvest is present in straw (Kemmler, 1980). Potassium can be applied in one dose or in splits, however, according to Manzoor *et al*, (2008), potassium fertilizer application in splits lead to more yields than when it was applied as a single dose. In sandy, light and waterlogged soils, potassium is applied as foliar spray (Sarkar *et al*, 2001). Factors such as soil moisture, soil aeration and oxygen level, soil temperature and tillage system affect potassium plant uptake (Kaiser *et al*, 2018).

2.7 Phosphorus in sorghum production

Phosphorus is one of the most limiting nutrient for plant growth after nitrogen (Holford, 1997) because most soil total P is in organic form which is not directly available to crops (Smith *et al*, 2003). It contains high energy bond molecules such as adenosine monophosphate (AMP), adenosine diphosphate (ADP) and adenosine triphosphate (ATP) which release energy in plant cells hence phosphorus is essential in providing the energy required for growth and development crops (Tisdale *et al*, 1985). Phosphorus is a vital component of the substances that are building blocks of genes and chromosomes. Large amount of P is present in seeds and in fruits because p is essential for fruit development and that is why plants mostly take up phosphorus from the seedling stage up to grain filling stage especially in sorghum. Phosphorus availability increases efficiency of nitrogen use by plants because p compounds provide the needed energy for movement of nutrients within the plant (Sharpley *et al*, 1999). A study by Razaq *et al*, 2017 shows that the use of nitrogen and phosphorus at the rate of 10g/plant and 8g/plant respectively resulted in maximum plant height, root collar diameter and chlorophyll content hence P uptake has been reported to increase with increased availability of nitrogen. The method of application of phosphorus can be furrow placement or side dressing because phosphorus is not lost due to leaching and this minimizes the fixation of phosphorus in the soil (Bharati, 2009).

2.8 Secondary nutrients in sorghum production

Calcium, Magnesium and Sulfur are the most important secondary nutrients in sorghum production. They are generally considered adequate in soils unless plant and soil tests reveal otherwise (Espinoza *et al*, 2003). They are considered secondary because they are needed by plants in smaller amounts than N, P and K. on the other hand, plants require the secondary nutrients in larger amounts than the micronutrients such as Boron and Molybdenum. The secondary nutrients affect the soil pH when applied. Calcium and magnesium are known to increase the soil pH while sulfur decreases the soil pH. Calcium serves to provide structural support to cell walls. Magnesium is absorbed as Mg^{+}ion and it is involved in photosynthesis. Sulfur is absorbed by plants in form of the sulfate ion and it is an essential building block in chlorophyll development and protein synthesis (Larry, 2017). Use of the common inorganic fertilizers does not supply the secondary nutrients which leads to their deficiencies and reduced sorghum yields. The need of application of these nutrients can be attained through soil testing. Well decomposed farmyard manure, compost manure and green manure provides most of these plant nutrientsas well as using fertilizer sources from organic compounds containing some of these nutrients.For instance, applying super phosphate will not only supply phosphorus but also calcium and sulfur. Deficiency of these secondary nutrients in many sorghum-growing areas is very rare (Bharati, 2009).

2.9 Importance of micronutrients in sorghum production

Some essential elements are required in very small amounts. They are regarded as trace elements and they include; Iron, Zinc, Boron, Molybdenum, Manganese, Copper, Chlorine and Cobalt. They are needed in sorghum production for plant growth, development and reproduction.

Availability of these micronutrients is greatly influenced by soil pH. At the pH of 6 to 6.5, most of these nutrients are moderately available for plants (Larry, 2017).The traditional continued use of inorganic fertilizers, which do not supply these nutrients, is leading to their deficiencies resulting in reduced yields. Application of organic manures like well decomposed farmyard manure, compost manure and green manure s provides most of these plant nutrients. Among the micronutrients, Zinc and Iron are the most commonly deficient in sorghum growing areas (Bharati, 2009).

2.10 Farmyard manure in sorghum production

The organic manures have the advantage of contributing to soil fertility through addition of organic matter, which improves soil structure, reduces soil erosion, helps to store moisture, provides fixation sites for plant nutrients and does not have negative impact on the environment (Kurual *et al*, 1990). Farmyard manure is traditional manure which is cheap and mostly readily available to the farmers but it is rarely used (Waarts *et al*, 2012).Farmyard manure is a decomposed mixture of Cattle dung and urine with straw and litter used as bedding material and residues from the fodder fed to the cattle. On average, farmyard manure contains 0.53% nitrogen, 0.22% phosphorous, 0.59% potassium, 2100mg/kg Iron, 61mg/kg Zinc, 2.2mg/kg Boron and 0.75mg/kg Molybdenum(Parihar *et al*, 2012). In addition to releasing nutrients, farmyard manure improves the soil structure, increases water holding capacity, it is slow in action hence very difficult to over fertilize plants, there is no risk of forming toxic buildup of chemicals which reduces soil and water pollution by acting as chelating agent for inorganic nutrients and it is renewable, biodegradable and eco-friendly (Bayu *et al*, 2006., Mukhtiar *et al*, 2018., Sahoo *et al*, 2013). It is difficult to establish the exact recommended rate of application of farmyard manure for optimum output but studies have shown that application of farmyard manure at the rate of

5t/ha to 20t/ha can lead to high yields in various crops (Nasiri,2016., Upadhyay *et al*, 2012., Mukhtiar *et al*, 2018).

2.11 Constraints in sorghum production

For all food crops, farming decisions including the choice of crop or variety to plant, the types and amounts of inputs and their management is directly a factor of availability and quality of cropland. Land availability is a challenge in sub Saharan Africa, which limits production of crops. As a result, people convert forests, grasslands and other non-agricultural land to crop production. Land constraints also has led to intensification system of production which involves multiple cropping (Byerlee, *et al*, 2014). Once crops have been selected and planted, various environmental factors such as inadequate access to and use of soil nutrients, water shortages and drought, and direct damage from pests, weeds and diseases can substantially compromise sorghum production (Muui *et al*, 2013). At the same time, common responses to these production constraints such as applying chemical fertilizers, water extraction and irrigation, and applying pesticides and herbicides often pose significant environmental risks and costs for crop production, with sometimes-significant negative impacts to wildlife and human populations. Specific environmental impacts in post-production include the introduction of environmental or human health toxins in crop storage either from storage chemicals, or from contaminants of biotic origin such as aflatoxin (Gnonlonfin *et al*,2013), as well as the emission of GHGs from the burning of crop residues. Cereal crops such as sorghum also suffer significant losses in traditional storage from various pests and diseases (Melaku *et al*, (2017). Though relatively drought-tolerant, grain sorghum still yields far less under drought conditions. As the rainfall season is frequently short and intense in sorghum growing regions and soil cover sparse, problems such as water logging, water runoff and soil erosion represent major yield constraints (Murty *et al*,2007). Low temperatures, low soil P, Fe toxicity, acid soils, and wind damage (blown sand) also hinder crop yields, while downy mildew, insect pests, and weeds such as Striga cause severe losses (Clay, 2013).

Sorghum plants typically have a thinner stalk than corn and are more prone to lodging. Lodging in sorghum is caused by the interaction between internal plant stress during the grain filling period and invasion of the stem by two common soil pathogens *Fusarium*spp and *Macrophomina phaseolina* (charcoal rot). However, this interaction is complex and the importance of the pathogenic organisms is unclear. The internal plant stress is usually caused by water deficit during the grain fill, which limits photosynthesis and causes plants to transport reserves from the stem and leaves to fill the developing grain. A range of factors including; varietal susceptibility, environmental conditions, physical factors, and the presence of disease-causing organisms impact the severity of lodging. (Xu *et al*, 2000)

2.12 Experimental variety origin and characteristics

Gadam sorghum is a semi-dwarf sorghum variety with specific market traits, including white color. It is an early maturing sorghum variety (flowers in about 45-52 days and matures in 85-95 days depending on altitude). The variety matures earlier than the other sorghum varieties and any of the maize varieties making it an ideal variety for areas receiving low and unreliable rainfall. It has been reported to survive and produce grain with approximately 200 mm of rainfall in Machakos area of eastern Kenya. The grain is high in starch, low in protein and tannin making it suitable for malting. Gadam grain has 75% carbohydrate compared to 67% in barley and 66% in maize making it a good alternative source of starch. Further analysis showed that Gadam had low levels of oil and proteins, which makes it good for industrial processing. Through tests for enzymatic digestion of starch, Gadam was reported to have high levels of fermentablesugars hence suitable for preparation of local and introduced recipes due to its high fermentable starch and its favorable taste (Kavoi *et al*, 2013).

KARI Mtama-1 is a sorghum variety. The plant height ranges from 50 to 170cm tall depending on the altitude. It has one main erect tiller and sometimes has 2-3 straight tillers. The grain color is white with a hard endosperm and has no testa. It flowers in 58-65 days and matures in 95-100 days. The variety has a potential yield of 4t/ha with an average yield of 2.5tha or 1t/acre. KARI Mtama-1 is highly tolerant to stalk borers and aphids and it recovers from drought very fast. It is also highly palatable and sweet making it attractive to birds. In order to minimize the losses due to birds, a cluster of farmers should plant or cultivate the variety to increase the acreage in a location (Karanja *et al*, 2014).

Macia is a dual-purpose sorghum variety that was released in Tanzania in Dec 1999. It has an average of 3-4 months growing period. It is a short plant which makes bird scaring convenient. The variety has a large head size and the yields are relatively high (up to 4.6 t/ha). It has a low dehulling losses and good eating quality. The variety also has a stay green characteristics and the residues are suitable for feeding farm livestock (Saadan *et al*, 2000).

CHAPTER THREE

GENERAL MATERIALS AND METHODS

3.1 Study area

The study was conducted in Makueni County, in Kenya. Makueni County is located in the South Eastern Part of Kenya and covers an area of 8,034.7 Km^2. The county geographically borders Kajiado County to the West, Taita Taveta to the South, Kitui County to the East and Machakos County to the North. It lies between Latitude 1^0 35` and $3^0$ 00 South and Longitude $37^0$ 10` and 38^0 30` East. The county lies in the arid and semi-arid zones of the Eastern region of the country and is prone to frequent droughts (CIDP, 2013). The County experiences two rainy seasons, the long rains occurring from mid-March to April and the short rains which occur between October and December. The hilly parts of Mbooni and Kilungu receive 800-1200mm of rainfall per year with mean temperatures ranging from 20.2^0C to 24.6^0C. The low-lying areas receive from 150mm to 650mm of rainfall per annum and high temperatures of 35.8^0C typical of ASALs in Kenya (De Jalón*et al*, 2015). The area has an estimated poverty level of 64.1% (KIHBS, 2006). The main source of livelihood in this county is subsistence agriculture and most of the crops produced are consumed at the household level (Mwangangi *et al*, 2013). Other socio-economic activities in this area include; bee keeping, small-scale trade, sand harvesting and charcoal burning. The major crops grown are; maize, green grams, pigeon peas and sorghum (CIDP, 2013).

3.2. Soil sampling and farmyard manure analysis

Soil samples from the experimental site and farmyard manure were taken for physic-chemical analysis at the University of Nairobi soil science laboratory two weeks before the first planting season. The soil was sampled from the top soil at a depth of 0-30cm at 63 sampling points using a hand hoe. Soil sampling was done by first removing the surface litter and the vegetation around the sampling point. A 'V' shaped cut to a depth of 30 cm was made using a hand hoe. A thick slice of soil from top to bottom of exposed face of the 'V' shaped cut was removed and placed in a clean paper. From each sub plot three samples weighing 300gm were taken in a zigzag sampling method and placed in a clean plastic bag. Soil samples from all sub plots constituting one main plot were combined to make one composite sample. There were three main plots which were replicated three times making a total of nine composite samples. The nine samples were transported to the University of Nairobi soil science laboratory for analysis. The samples were air-dried for two weeks, ground, sieved in a 2mm sieve for analysis. The chemical soil properties analyzed were; the soil pH, electrical conductivity, macronutrients (nitrogen, phosphorus, potassium and Sulphur), exchangeable bases (Mg, Ca, K) and cation exchange capacity. The physical soil properties analyzed were the particle size and soil texture.

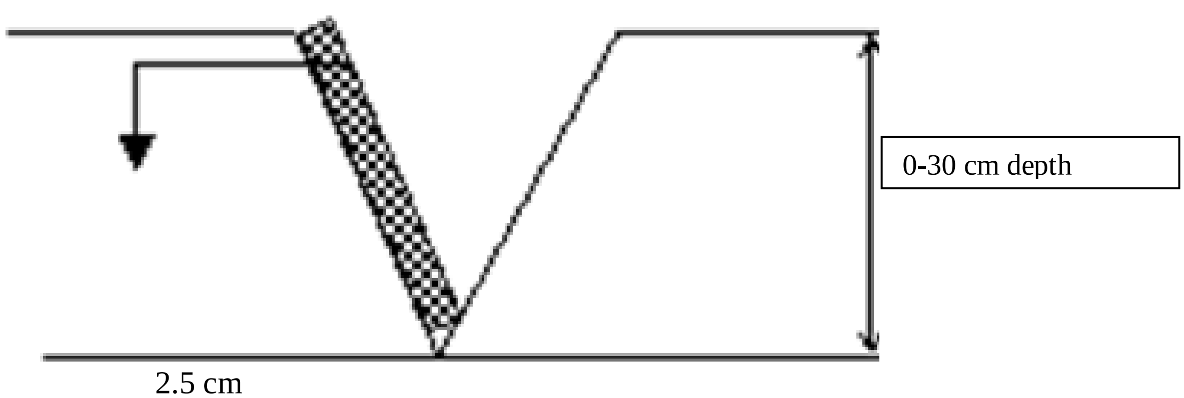

Figure 3.1 : An illustration of the soil sampling depth.

3.2.1. Soil pH

Soil pH was determined in 1:2.5 soil: water ratio and 0.01M $CaCl_2$ ratio suspensions by the potential metric method (Mclean, 1986). To each 10g soil sample, 25ml of distilled water was added and shaken on reciprocating mechanical shaker for 30 minutes. The pH of the soil sample was determined using a pH meter.

3.2.2. Organic carbon

Organic carbon was determined using the walkey-black method (Nelson & Sommers, 1982). To a 0.5 g of soil sample, 10ml of 1ml $K_2\ Cr_2\ O_7$ and 20ml of concentrated sulphuric acid was added and allowed to stand for 30 minutes to oxidize the soils organic matter. 200ml of water was added to cool the mixture followed by addition of 10ml of phosphoric acid (85% $H_3\ PO_4$) to sharpen the endpoint. The amount of dichromate reduced was used to estimate the organic carbon of the soil by titrating the excess dichromate against a ferrous sulphate solution using diphenylamine indicator.

3.2.3. Soil total nitrogen determination

This was determined by the micro Kjedahl digestion-distillation method according to the procedure described by Bremmer and Mulvaney (1982). 1g of soil sample was digested with concentrated H_2SO_4 in presence of catalyst ($K_2\ SO_4$ +$CuSO_4$ + selenium powder mixed in the ratio of 10:10:1 by weight). The digest wasdistilled in the presence of 40% NaOH. The NH_3 liberated was collected in 4% boric acid (mixed with indicator) and titrated against standard 0.05M H_2SO_4. The titre was used to calculate the total nitrogen content of the soil sample.

3.2.4. Soils extractable phosphorous

Extractable P of the soil sample was determined using the Bray 1 and Kurtz (1945). The Bray 1 method, used extracting solution containing 0.03M NH_4F and 0.025M HCl. A sample of 3.5 g of air-dried soil was placed in a plastic bottle and 20ml of extracting solution added and shaken by hand for 1 minute and filtered using whatman no. 2 filter paper into a dry plastic vial. Thereafter, 2-5 ml of filtrate aliquots were used for color development in a 50 ml volumetric flask using a molybdenum blue method (Murphy and Riley, 1962). The extractable P was determined by a spectrophotometer at the wavelength of 884nm.

3.2.5. Micronutrients

Extractable micronutrients in all soil samples were determined using the procedure by Lindsay and Norwell (1978). The extractant contained 0.005M DTPA (diethylenetriamine pentaacetic acid), 0.01M CaCl, $2H_2O$ and 0.1M TEA (triethanolamine) adjusted to pH 7.3. Soil sample weighing 20gwas placed in a 100ml plastic bottle, mixed with 40ml extracting solution. The contents were shaken using a mechanical shaker for two hours and filtered using Whatman no.2 filter paper into dry plastic vials. The micronutrients Zn, Cu, and Fe were determined by atomic absorption spectrophotometer (AAS) using appropriate wavelength of hollow cathode lamps specific to elements with standard of known concentration. Using appropriate standard curves of the known concentrations of the elements, the concentration of elements in the unknown concentrations was estimated.

3.2.6. Soil particle size and texture analysis

Particle size analysis was determined by the bouyoucos hydrometer method after soil dispersion in sodium hexametaphosphate as described by Day (1965) and NSS (1990). The textural class was determined using the USDA textural class triangle.

3.3 Crop husbandry

Land preparation was done by ploughing the field using a tractor drawn discplough where all the crop residues, crop volunteers and weeds were buried in the soil during ploughing. This process was advantageous to kill the weed seeds, hibernating insects, and disease organisms by exposing them to the sun heat. The field was ploughed twice to obtain a fine tilth. Harrowing of the soil was later done to reduce the clod size.

3.4 Experimental plot design

The field experiment was conducted in a randomized complete block design with split plot arrangement. Each main plot had seven $12m^2$ sub plots of (4mx3m) with the space between two sub-plots being 0.75m while the distance between two main plots was 1m. The total area under the experiment was $1300m^2$. Each experimental subplot had five planting rows with 21 planting hills to make a plant population of 105 plants per subplot (Figure 3.1). Three sorghum seeds were planted per hill and were later thinned to one plant per hill. The first weeding was done when the crop had 4-5 true leaves and the subsequent weeding procedures were carried out immediately the weeds were observed. The major pests of sorghum were; stalk borer, shoot fly, aphids, and birds.

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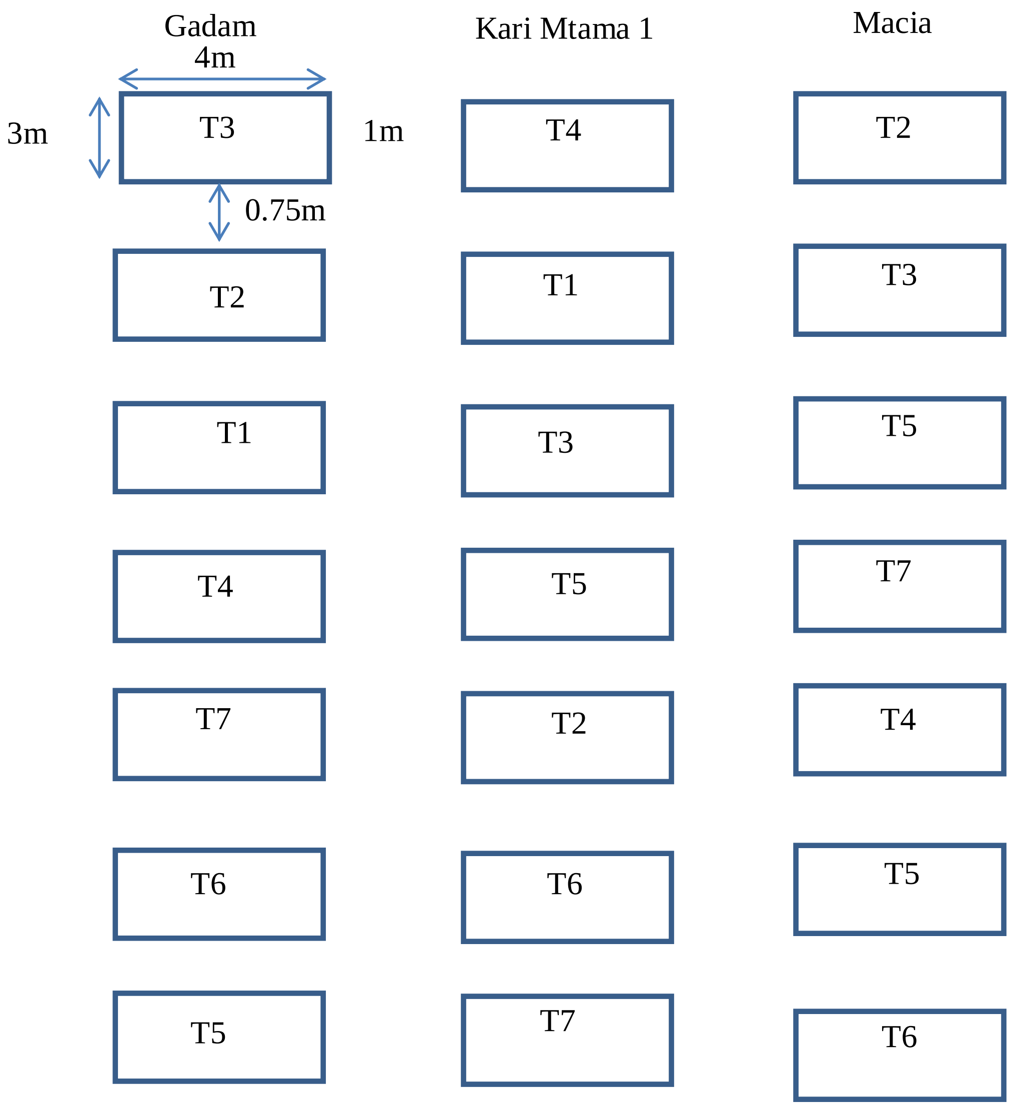

T=Treatment

Where;

T1=Control

T2=5t FYM/ha

T3=15t FYM/ha

T4=25 kg N/ha NPK + 25kg N/ha urea

T5=50kg N/ha NPK + 50kg N/ urea

T6=5t FYM/ha +25 kg N/ha NPK + 25kg N/ urea

T7=15t FYM/ha + 50kg N/ha NPK +50kg N/haurea

Figure 3.1: Experimental design and layout

CHAPTER FOUR

SORGHUM PRODUCTION PRACTICES IN AN INTEGRATED CROP-LIVESTOCK PRODUCTION SYSTEM IN MAKUENI COUNTY, EASTERN KENYA

4.1 Abstract

Productivity of sorghum has been below potential in arid and semi-arid lands of Kenya, due to poor agronomic practices and soil nutrient deficiency. Sorghum crop is fairly drought tolerant, resistant to water logging, and yields are reasonably better under infertile soils compared to other crops. Proper agronomic practices would significantly increase the yields as well as the nutrient loads to the grains and the crop residues used for livestock feed. The objective of this study was to investigate the existing sorghum production practices and sorghum use as food and feed. A survey involving 90 farmers from sorghum producing areas in Makueni County was conducted. The survey focused on; farmer's sorghum production objectives, the size of land used for sorghum production, source of information on sorghum production, challenges and constraints in sorghum production, source of sorghum seeds used by farmers, varieties of sorghum produced and preferred, intercropping in sorghum production, cropping system and fertilizer use in sorghum production, sorghum yield, sorghum use and conservation as animal feed in Makueni County. Most farmers (84.43%) used uncertified seeds from own saved sources, and the commonly grown variety was Seredo (44.45%) due to resistance to bird damage. The majority (32.11%) of farmers recorded very low yield of sorghum grain, ranging from 0.151 to 0.250 tons ha^{-1}. Most farmers (68.9%) used farmyard manure in sorghum production, while 30.9 % of the farmers did not use any fertilizer. All the farmers indicated that their greatest challenge in sorghum production was inadequate rainfall. Bird damage to the crop was a chronic problem to most (73.33%) farmers. The majority (58.87%) of farmers conserved sorghum residue for feed in

the form of hay. The findings show that there is a need to provide technical information and guidance on the production practices such as choosing best-yielding seed varieties, proper methods of pest and disease control and proper use and conservation of sorghum residue as animal feed in Makueni County, Kenya.

Key Words: Dry land crops**;** multipurpose sorghum; Sorghum varieties; sorghum ratoon

4.2 Introduction

Generating a sustainable food and feed supply that can match expected increasing demand is, by far, the most formidable challenge facing sub-Saharan Africa (SSA) agriculture (Hounkonnou*et al*, 2012; Jayne and Shahidur, 2013). Enormous increases in human and livestock populations are projected to occur in the decades to come, coupled with massive increases in levels of urbanization. The anticipated population growth is also projected to generate heightened competition for land and increased scarcity of cropland (Strassburg *et al,* 2014; Mueller and Binder, 2015), especially in the rangelands, which may, in turn, induce agricultural intensification, in particular, integrated crop and livestock production (Baudron *et al*, 2014; Kindu *et al*, 2014; Castellanos-Navarrete *et al*, 2015). This is already happening in Kenyan arid and semi-arid rangelands. Thus, crop residues are the dominant feed resources for livestock in these eco zones as more rangelands are already being converted into cropland.

Sorghum is an under-utilized crop and one of the most important cereal crop in semi-arid tropics (Muui *et al*, 2013; Jacob *et al*, 2013). In Kenya, sorghum is grown in the often drought prone marginal agricultural areas of Eastern, Nyanza and coast provinces (Muui *et al*, 2013). Within these growing areas, people regard sorghum as a poor man’s crop and some still prefer to grow maize even in areas where it does not do well. As a result, there is increasing food insecurity (Dicko *et al*, 2006; Orr *et al*, 2016). A wide range of naturally occurring biotic and abiotic constraints including poor soils fertility, water scarcity, crop pests, diseases, weeds and unsuitable temperatures are well known to reduce the productivity of sorghum, leading to low efficiencies of input use, suppressed crop output and reduced food security (Strange and Scott, 2005; Gregory *et al*, 2005). In semi-arid Kenya, soil water evaporation can take up to 50% of total rainfall (Kinama *et al*, 2005).

Nitrogen losses through gaseous plant emissions, soil denitrification, surface runoff, volatilization and leaching are increasing with time especially in nutrient poor soils. This results to loss of nitrogen for cereal crops such as sorghum, which do not have ability for nitrogen fixation, resulting to low yields (William *et al*, 1999). Other constraints in sorghum production include; waterlogging, runoff and soil erosion which contributes to major yield constraints (Murty *et al*, 2007). Low temperatures, low soil Phosphorus (P) and Nitrogen (N), Iron (Fe) toxicity, acid soils, and wind damage (blown sand) also affect crop yields, while downy mildew, insect pests, and weeds such as Striga also cause severe losses in sorghum in the arid lands (Clay, 2013).

Although many producers view sorghum as a low maintenance crop, with its deep fibrous root system, sorghum responds well to nutrient application especially in soils that are not very fertile. Nitrogen is the most often limiting nutrient in sorghum production, hence if managed efficiently; it can result to significant increase in the yields (Vanlauwe, 2014; Potgieter *et al*, 2016). To address the many aforementioned challenges to sorghum production in the arid and semi-arid environments, the present study seeks to evaluate the farmers productivity practices and identify the areas of weakness resulting to the present low productivity of sorghum. These gaps will help in identifying intervention areas for increased sorghum productivity for both food and feed, and the areas of farmer training on the appropriate nutrient and agronomic practices. This aims to promote the efforts towards integrated crop-livestock production system in the semi-arid rangelands of Kenya.

4.3 Materials and methods

4.3.1 Study area

The survey was conducted in two sub counties of Makueni County, in Kenya, namely; Makueni and Kibwezi west. In Makueni sub county, the survey was conducted in Kathonzweni and Wote wards while in Kibwezi west, the survey was conducted in Makindu ward. The three wards lie in two Agro ecological zones (AEZ), Wote which is in lower mid land zone IV (LM4) while Kathonzweni and Makindu wards are both in Lower mid land zone V (LM5). Makueni County is located in the South Eastern Part of Kenya and covers an area of 8,034.7Km^2. The county geographically borders Kajiado County to the West, Taita Taveta to the South, Kitui County to the East and Machakos County to the North. It lies between Latitude 1^0 35` and 3$^0$ 00 South and Longitude 37$^0$ 10` and 38^0 30` East. The county lies in the arid and semi-arid zones of the Eastern region of the country and is prone to frequent droughts (CIDP, 2013). The County experiences two rainy seasons, the long rains occurring from mid-March to April and the short rains occur between November and December. The hilly parts of Mbooni and Kilungu receive 800-1200mm of rainfall per year with temperatures ranging from 20.2^{0}C to 24.6^{0}C. The low-lying areas receive 150mm to 650mm of rainfall per annum and high temperatures of 35.8^{0}C typical of ASALs in Kenya (De Jalón*et al*, 2015). The area has an estimated poverty level of

64.1% (KIHBS, 2006). The main source of livelihood in this county is subsistence agriculture at the household level (Mwangangi etal, 2013). Other socio-economic activities in this area include; bee keeping, small-scale trade, sand harvesting and charcoal burning. The major crops grown are; maize, green grams, pigeon peas and sorghum (CIDP, 2013).

4.4 Data collection Survey

A total of 90 farmers were interviewed using a semi structured questionnaire where purposive sampling method was used to target some of the sorghumgrowing farmers who had received seed from ICRISAT. The survey was conducted as a follow up on the farmers who had received seed from ICRISAT in subsequent years. A focus group discussion was conducted with some of the ICRISAT staff members, one extension officer and one of my supervisors. The purpose of the focus group was to identify the key areas where most farmers had received the seed. A total of 24 farmers were interviewed in Wote, 39 and 27 farmers were interviewed in Kathonzweni and Makindu wards respectively. The use of Key informants and agricultural extension officers in the region helped in identification of the sorghum farmers who had received seeds from those regions. The questionnaire tool used focused on; farmer's sorghum production objectives, the size of land used for sorghum production, source of information on sorghum production, challenges and constraints in sorghum production, source of sorghum seeds used by farmers, varieties of sorghum produced and preferred, intercropping in sorghum production, cropping system and fertilizer use in sorghum production, sorghum yield, sorghum use and conservation as animal feed in Makueni County. Three Key Informant Interviews (KIIs) and one Focus Group Discussion (FGD) containing six participants were carried out in order to conduct an exploratory analysis of the perceptions among the local farmers on sorghum production practices.

4.5Data analysis

The survey data was analyzed in a Statistical Package for the Social Sciences (SPSS) program version 20. Descriptive statistics was performed to derive the existing farmers' sorghum production practices and uses for both food and feed. The responses were reported in tables in the form of percentages, frequencies and averages.

4.6 Results

4.6.1 Farmer's sorghum production objectives

In the three sub counties, most (85.59%) farmers produced sorghum for their own consumption (Table 4.1). Notably, in Lower Mid zone V (Kathonzweni and Makindu) production for animal feed was higher than in Lower Mid Land zone IV (Wote).

Table 4.1: Percentage of farmers with different production objectives for sorghum

N = 90	Wote n = 24	Kathonzweni n = 39	Makindu n = 27	Weighted mean
Objective	LM4	LM5	LM5	
Own consumption	91.7	82.1	85.2	85.59
To feed animals	8.3	15.4	11.1	12.22
For sale	0.0	3.7	3.7	2.71

N = sample size, LM4 = Lower Mid Land zone IV, LM5 = Lower Mid Land zone V.

4.6.2 Land used for sorghum production

Although many farmers owned more than one hectare of land, most (48.87%) farmers had sorghum production in less than one hectare of land (0.6 to 1 hectare of land) (Table 4.2). Wote had more farmers (25%) using more than one hectare for sorghum production compared to Kathonzweni and Makindu (<19%).

Table 4.2: Percentage of farmers with various land sizes used for sorghum production

N = 90	Wote n = 24	Kathonzweni n = 39	Makindu n = 27	Weighted mean
Land size	LM4	LM5	LM5	
0-0.5 ha	37.5	28.2	33.3	32.21
0.6-1 ha	37.5	56.4	48.1	48.87
>1 ha	25	15.4	18.5	18.89

N = sample size, LM4 = Lower Mid Land zone IV, LM5 = Lower Mid Land zone V.

4.6.3 Source of information on sorghum production

The main source of information on sorghum production used by sorghum farmers was from the Ministry of Agriculture Extension staff (32.43%). The majority (44.64%) of the farmers did not have access to any information regarding sorghum production (Table 4.3). Other farmers (22.93%) of the respondents received information from farmer groups.

Table 4.3: Percentage of farmers obtaining information on sorghum production from various sources

N = 90	Wote n = 24	Kathonzweni n =39	Makindu n=27	Weighted mean
Source	LM4	LM5	LM5	
Ministryof Agriculture	50.0	37.5	9.5	32.43
Farmer groups	25.0	31.3	9.0	22.93
No information	25.0	31.2	81.5	44.64

n=sample size, LM4= Lower Mid Land zone IV, LM5= Lower Mid Land zone V.

4.6.4 Challenges and constraints in sorghum production in Makueni County

The major constraint to sorghum production across the three wards by all respondents was inadequate rainfall. Bird damage was the second most important challenge with 73.33% of farmers highlighting it a major problem(Table 4.4). The farmers also indicated that bird damage can be devastating in sorghum production, and it could lead to 100% loss of the crop during the focus group discussions. Farmers in Wote and Kathonzweni reported Head smut (*sphacelotheca reiliana*) disease, while stalk borer (*Busseola fusca*) was noted as a major challenge across all the three wards in Makueni.

Table 4.4: Percentage of farmers who reported various constraints in sorghum production

N = 90 Constraint	Wote n = 24 LM4	Kathonzweni n = 39 LM5	Makindu n = 27 LM5	Weighted mean
Bird damage	70.8	84.6	59.3	73.33
Stalk borers	8.3	5.1	40.7	16.63
Head smuts	20.8	10.3	0.0	10.01
Inadequate rainfall	100.0	100.0	100.0	100.0

N = sample size, LM4 = Lower Mid Land zone IV, LM5 = Lower Mid Land zone V.

4.6.5 Source of sorghum seeds used by farmers in Makueni County

The most farmers in Makueni County used their own saved seed (68.87%). (Table 4.5). The farmers reported to be using their previous harvest for next season planting. The second source of seeds was from certified seeds, though done by very few farmers (13.26%) and was reported to have been supplied by the Ministry of Agriculture at subsidized prices (Table 4.5). Very few farmers (<10%) reported to be getting seeds from the market or from other farmers. Other (7.97%) farmers from the three wards reported NGO as a source of sorghum seed, which was confirmed to be hybrid seed provided by an NGO under the climate smart adaptation program from key informant and FGD meetings.

Table 4.5: Percentage of farmers using various seed sources

N = 90 Sources	Wote n=24 LM4	Kathonzweni n=39 LM5	Makindu n=27 LM5	Weighted mean
Farm saved	70.8	61.5	77.8	68.87
Certified seeds	16.7	23.1	0.0	13.26
Market purchase	0.0	5.1	0.0	6.67
From other farmers	0.0	2.6	18.5	6.68
NGO (Anglican Development Services and ICRISAT)	12.5	7.7	3.7	7.97

N =sample size, LM4= Lower Mid Land zone IV, LM5= Lower Mid Land zone V.

4.6.6 Varieties of sorghum produced and preferred in Makueni County

The most common (44.45%) sorghum variety produced in Makueni, mostly by farmers in Makindu was Seredo. The reason for this was the variety is resistant to bird damage and mature early while still being drought tolerant (Table 4.6). Notably, Gadam was highly produced in Wote and Kathonzweni unlike in Makindu (Table 4.6). The farmers who grew Gadam reported high yielding variety and hence most preferred in the area. The varieties being promoted by extension officers were Gadam and Kari Mtama 1 with more farmers in Wote and Kathonzweni wards adopting these varieties than in Makindu. Serena variety was the least adopted across the three sub counties, reasons being low productivity and susceptible to birds damage.

Table 4.6: Percentage of farmers producing various sorghum varieties

N = 90	Wote n = 24	Kathonzweni n = 39	Makindu n = 27	Weighted mean
Sorghum varieties	LM4	LM5	LM5	
Gadam	45.8	53.8	11.1	38.86
Kari M 1	12.5	23.1	3.7	14.45
Serena	8.3	0.0	0.0	2.21
Seredo	33.3	23.1	85.2	44.45

N = sample size, LM4 = Lower Mid Land zone IV, LM5 = Lower Mid Land zone V.

4.6.7 Intercropping with sorghum in Makueni County

Cowpea is the most (25.56%) used intercrop in sorghum production in Wote ward while most of the farmers in Makindu ward reported mono-crop of sorghum (44.42%) (Table 4.7). The second intercrop in the county was maize followed by green grams. Most of the farmers who did intercrop reported the reasons of increasing yields and diversification of household diets. Most (74%) of the farmers in Makindu practiced mono-cropping due to moisture limitations and that most intercrop fields increased competition for water and reduced yields. Other farmers alsoreported thecrops used in intercrops were less tolerant to droughts than the sorghum crop. Bean was the least used as intercrop across the three wards.

Table 4.7: Percentage of farmers using various crops as intercrop

N = 90	Wote n = 24	Kathonzweni n = 39	Makindu n = 27	Weighted mean
Crop	LM4	LM5	LM5	
Cowpea	41.7	28.2	7.4	25.56
Pigeon pea	12.5	0.0	3.7	4.44
Beans	4.2	2.6	0.0	2.24
Maize	12.5	20.5	0.0	12.22
Green grams	4.2	12.8	14.8	11.11
No intercrop	25.0	35.9	74.0	44.42

N = sample size, LM4 = Lower Mid Land zone IV, LM5 = Lower Mid Land zone V.

4.6.8 Cropping system and fertilizer use in sorghum production in Makueni County

The most common cropping system was to have the plant “one season” in all the three wards (>90%). Very few farmers (5.55%) reported to harvest sorghum and allow for regrowth for the next season (ratoon). Farmers reported that the ratoon crop produced low yield and that is why many farmers were not practicing this cropping system. The common practice was “one season” with land cleared for the next crop (Table 4.8). Farmyard manure was the most commonly used (68.90%) fertilizer in Makueni County. A reasonable proportion of the farmers (27.77%) in the county did not use any fertilizer in sorghum production (Table 4.8).

Table 4.8: Percentage of farmers using various sorghum production systems and fertilizer use

N = 90	Wote n = 24	Kathonzweni n = 39	Makindu n = 27	Weighted mean
Production System	LM4	LM5	LM5	
Plant one season	91.7	92.3	100.0	94.45
Ratooning	8.3	7.7	0.0	5.55
Fertilizer use				
Urea	0.0	0.0	0.0	0.00
DAP	0.0	2.6	0.0	1.13
CAN	0.0	5.1	0.0	2.21
FYM	79.2	87.2	33.3	68.90
None	20.8	5.1	66.7	27.77

n=sample size, LM4= Lower Mid Land zone IV, LM5= Lower Mid Land zone V, DAP= Diammonium Phosphate, CAN=Calcium Ammonium Nitrate, FYM= Farmyard manure.

4.6.9 Sorghum yield in Makueni County

Sorghum grain yield was low with most (32.11%) of the farmers harvesting between 0.151-0.25tonsha^{-1}. A very low proportion of the farmers (18.89%) harvested more than 0.3tons ha^{-1} (Table 4.9). The reasons for the low productivity of sorghum in the county were low and unpredictable precipitation, bird damage and other farmers cited pest and diseases as reasons for the low yields.

Table 4.9: Percentage of farmers with various estimated sorghum yields/ha

N = 90	Wote n = 24	Kathonzweni n = 39	Makindu n = 27	Weighted mean
Yield/ha	LM4	LM5	LM5	
0 to 0.15tons	37.5	23.1	18.5	25.56
0.151 to 0.25tons	25.0	33.1	37.0	32.11
0.251 to 0.3tons	12.5	28.2	25.9	23.32
>0.3tons	25.0	15.4	18.5	18.89

N = sample size, LM4 = Lower Mid Land zone IV, LM5 = Lower Mid Land zone V.

4.6.10 Sorghum use and conservation as animal feed in Makueni County

The majority (44.42%) of the farmers use sorghum straw and grain to feed the animals while 25.55% do not use sorghum residue as animal feed (Table 4.10). The farmers using sorghum straw reported it to be a useful feed source during the dry seasons and could be easily stored after harvest. The most common form of sorghum conservation for feed purposes was as hay from straw (58.87%). Other farmers grazed the land after harvest and did not do any conservation (41.13%) (Table 4.10).

Table 4.10: Percentage of farmers using various sorghum parts as animal feed

N = 90	Wote n=24	Kathonzweni n=39	Makindu n=27	Weighted mean
Sorghum Part used as feed	LM4	LM5	LM5	
Straws	45.8	23.1	11.1	25.55
Grain	4.2	7.7	0.0	4.46
Straws and grain	37.5	48.7	44.4	44.42
Do not use as feed	12.5	23.1	44.4	26.66
Conservation strategy				
Hay	75.0	76.9	18.5	58.87
Do not conserve	25.0	23.1	81.5	41.13

N = sample size, LM4 = Lower Mid Land zone IV, LM5 = Lower Mid Land zone V

4.7 Discussion

The findings of this study on households producing sorghum for own consumption concurs with a study by Agrama *et al*, (2003), who showed that sorghum is a staple food for millions of people in Africa and in India while in the United States, livestock feeding accounts for most sorghum usage. In eastern Kenya, most farmers plant sorghum for their own consumption alongside other crops like cowpea, pigeon pea, green grams, maize, while only a few sell sorghum to generate income and this finding collaborates that by Muui *et al*, (2013). Most farmers produce sorghum for their own consumption because of the perceptions to be a less important crop and hence lowinvestment in its production. This view is traditional, and in most African societies in Kenya, sorghum has continued to be viewed as a poor man's crop (Dicko *et al*, 2006; Orr *et al*, 2016). The increasing crop failures of the preferred crops like maize and beans by farmers in the arid and semi-arid areas, has increased the need for farmers to shift crop choices to more drought tolerant varieties that are less prone to droughts and diseases (Khan *et al*, 2014; Hadebe *et al*, 2016). Already, early adopters of technologies have realized the importance of moving to dry land crops from conventional crops, especially after observing successive crop failures in the past (Chivenge *et al*, 2015; Vunyingah and Kaya, 2016).

This study showed that farmers had large sizes of land but allocated very few acres for sorghum production, and as a result, the sorghum production was low. This is in line with study by Muui *et al*, (2013), that sorghum is grown by majority of farmers but on very small portions of land either in mixed crop or as few strips along the farm edges. A report by USAID, (2010) shows that sorghum is considered by communities as crop for small-scale resource-poor farmers in the ASALs, and this could be an explanation as to why most farmers do not allocate much land for sorghum production. The other reason for low land allocated to sorghum production could be the low commercialization of the crop and the lack of streamlined marketing channels that consider value addition (Rao *et al*, 2014; Kavoi *et al*, 2014). Chepng'etich *et al*, (2014) also reported low commercialization of sorghum in lower eastern Kenya, where this study was conducted. However, the recent efforts to strengthen climate smart production systems, has recognized sorghum as a potential crop with the increasing climate change effects. The farmers also reported increased adoption of sorghum production by many households during the FGDs due to increasing frequencies of droughts.

According to this study, the major source of sorghum production information to farmers was from the ministry of agriculture through the Agricultural Extension Officers. Past study by Rees *et al*, (2000) showed that government extension is a major source of production information. The other most important source of information reported in this study was the farmer groups, highlighting the importance of providing trainings to top groups for increased adoption of technologies. Past research has shown that there is a reduced effectiveness in extension services and as a result many farmers do not access important information on how to improve their crop productivity, leading to poor crop performance (Mwadalu and Mwangi, 2013). The recent devolved system of governance in Kenya into county governments has also been reported to have increased access to information at local level (Recha *et al*, 2016). Many counties are focusing on improving the livelihoods of the communities, and this has seen massive investments in agriculture, with other counties also working hard to mechanize agricultural activities (Yvonne *et al*, 2016; Berre *et al*, 2016). Makueni County is one of the counties that have worked hard to increase food production, and one of the efforts has been to adapt farmers to climate change effects through choice of appropriate crops and market linkages (Ontiri and Robinson, 2015). Other players including NGOs, development and research partnershave also come to support communities in the arid and semi-arid counties in Kenya. Most farmers reported to be benefiting from learning at research organizations, and some getting crop production support from NGOs.

Despite the potential of sorghum in areas that experience drought and with low fertile soils, sorghum sub sector is faced with many challenges (Mwadalu and Mwangi, 2013). In this study, all the farmers interviewed indicated that inadequate rainfall was the major challenge to sorghum production. The study also showed that invasion of the crop by Queleabirds were a major challenge that could result to 100% crop loss. This is in line with earlier study by Miano *et al*, (2010), which showed that Quelea birds make sorghum production more labor intensive causing majority of farmers to opt for maize production that has even more risks due to climatic requirements. The observed low productivity of the sorghum in the study area could be attributed topoor agronomic practices, where some farmers reported not to apply fertilizer at all. Karanja *et al*, (2014), reported agronomic practices like fertilizer application regimes highly determine sorghum yields. There exists opportunities for increased yields in sorghum in Makueni county if water harvesting technologies are adopted, in combination with access to drought tolerant seed varieties and resistant to birds damage. Rai *et al*, (1999) and Timu *et al*, (2014) reported access to good cultivars and varieties of sorghum can significantly increase sorghum yields in Africa.

Majority of farmers in this study use farm saved seeds and those who cannot save borrow from neighbors or buy from the market. Labeyrie *et al*, (2014) also reported farmers to be using their social organization in accessing seeds for sorghum, where farmer groups highly shaped the source of seeds used. This study also showed that very few farmers use certified seed in sorghum production. Other studies also showed that many farmers use farm saved seed, market seed or borrow from the neighbors (Muui *et al*, 2013). Other study showed more than 90% farmers in arid and semi-arid lands use informal seed (farm saved and market seed) (Omanga, 2001). A study by Ayieko and Tschirley, (2006) showed that many farmers use farm saved seed because the certified seeds are expensive and the smallholder farmers cannot afford. Other reasons could be marketing challenges especially due to poor transport and communication infrastructure, unavailability of clean seed in the market and cases of fake seed, which demoralize the farmers. The use of farm saved seeds could also explain the reported low yields by the farmers. The farm saved seeds have high chances of carrying pests and diseases to the next crop, and the germination and viability could be low if not well processed and stored as seeds (Mucioki *et al*, 2016). Surprisingly, the seeds used were also not harvested for seed purposes by farmers, but just picked from the total crop harvested for the purpose of consumption. The farmers also confirmed during the FGDs not to have been trained on seed production, multiplication and processing at a local level and hence the observed practices, which must have contributed to low yields. Muui *et al*, (2013) also working in eastern Kenya where Makueni falls, reported farmer own saved seeds for various crops as the major seed source. Hybrid or certified seeds have quality checks and hence ensure farmers get value for their money. The only challenge is the costs and access to the information by the farmers. There is increasing need to ensure farmers have a wide array of crop varieties that suite their locality if productivity is to be increased. Breeding programs that answer farmers' needs are needed if sorghum productivity is to be increased in East African region. The increasing climate uncertainties also demand responsive farming practices, and multi stakeholder need approach is needed to save the farmers from hunger and famine. McGuire and Sperling, (2016) also reported farmers' seed systems to be highly used in Makueni and Tharaka Nithi counties in Kenya, where quality control is not considered at the point of exchange.

The most commonly grown variety among the farmers interviewed in this study was Seredo. Farmers prefer this variety because it is very resistant to bird damage, which is a big challenge in sorghum production. Gadam on the other hand, though isearly maturing and has high yields, it is not highly preferred by farmers because of its susceptibility to birds damage. A study conducted by Muui *et al*, (2013) shows that farmers in Makueni prefer to grow landraces to hybrids because of some variable traits shown by the local varieties. These findings show that breeding programs that are geared to addressing the farmers' needs should increase adoption of preferred varieties that have traits of interest to the community, mainly drought tolerance, resistance to bird's damage and high yielding as identified by the respondents.

This study revealed that most farmers plant sorghum in mixed cropping systems. The commonly used intercrop is cowpea. Other crops such as pigeon pea, green grams, maize and beans are also used. Most farmers are known to practice intercropping in Africa in order to reduce food insecurity for improved livelihoods (Musa *et al*, 2011). Intercropping increases productivity per unit area and allows efficient use of space and time to optimize output while promoting diversification (Singh and Usha, 2003). In this study, majority of farmers do not practice the ratoon cropping system. Although studies show that the ratoon crop yields more than the first crop, very few farmers in Makueni practice ratoon system. In addition, many farmers interviewed do not use inorganic fertilizers in sorghum production, which has contributed to poor performance and yields of the crop. This is in line with study by Muui *et al*, (2013) that most farmers do not use fertilizers and still they do not control pests and diseases. This could be explained by the fact that sorghum is grown under marginal rainfall conditions and fertilizer prices are high in relation to grain price.

Sorghum grain yield in the study area was very low in t/ha compared to the potential yield of 10.5 t/ha when grown under ideal conditions (Jordan *et al*, 2012). The low yields could be attributed to constraints such as; lack of fertilizers use, failure to control pests and diseases, inadequate rainfall and unavailability of hybrid seed. Many of the farmers in the study area used own saved seeds, and this could be responsible to the reported high pest and disease and hence low productivity. The low adoption of certified seeds and hybrid seeds also explain why the yields are lower than the expected per unit of land.

This study showed that sorghum residue is widely used to feed livestock in Makueni County. Majority of farmers in this study conserved sorghum residues as hay because it is the cheapest and the easiest method of conservation. Other farmers grazed the animals in the sorghum field directly after grain harvesting. Sorghum being a dry land crop that can produce high biomass even with limited moisture supply makes it one of the potential strategic feed sources for livestock (Mwangi *et al*, 2017; Kashongwe *et al*, 2017; Oyier *et al*, 2017). There is need to provide information on the potential uses of sorghum residue as animal feed (Timu *et al*, 2014; Habyarimana *et al*, 2017). The existence of opportunities for value addition in sorghum residues to make quality feed is also a good reason to increase its production and conservation as animal feed in Makueni county. Sorghum provides adequate energy source to livestock and if well blended with other leguminous crop varieties that can be produced as intercrop; the farmers will realize increased productivity from crop-livestock integration. Breeding programs for high yielding dual-purpose sorghum varieties is also an opportunity that needs to be tapped by farmers in Makueni County (Hassan *et al*, 2015; Chikuta *et al*, 2015). This will increase production of grain for human food as well as solving the imminent challenge of low feed for livestock. The study findings did not show any farmer doing silage making from sorghum residues. This is another opportunity that is not tapped, more so, with the current breeding efforts by ICRISAT to develop high sugar straw sorghum that are high yielding and hence quality residues for animal feed making as silage. Notably also, the present conservation as hay is not well done by households, with the observed poor storage on rooftops, tree tops that exposes it to quality deterioration and reduced feed value when fed to animals. Most of the farmers reported no training received on crop residue use and conservation from sorghum and other intercrops.

4.8 Conclusion and recommendations

This study has shown that sorghum production has many challenges in Makueni County, ranging from poor agronomic practices, pest and diseases, poor soil fertility management as well as traditional production as a subsistence crop. There is need to increase adoption of hybrid and certified sorghum varieties, increase commercialization and mechanization of the production process. The opportunity to develop dual-purpose varieties that have the traits demanded by farmers of drought tolerance, high yielding and birds damage resistance will contribute to increased crop-livestock integration in Makueni County. We also recommend strengthening of the existing farmer groups and increase their capacity through training on better sorghum production practices, seed multiplication, processing and storage, feed processing and conservation from sorghum and other legume residues to increase productivity and support crop livestock integration for better livelihoods.

CHAPTER FIVE

EFFECT OF ORGANIC AND INORGANIC FERTILIZER REGIMES ON GROWTH AND YIELD OF GRAIN SORGHUM MAIN CROP AND RATOON

5.1 Abstract

Nitrogen is the element most frequently lacking for optimum sorghum production. Many sorghum farmers are traditionally known to produce sorghum without the use of fertilizers, which has contributed to very low yields. This study was conducted to determining the effect of organic and inorganic fertilizer regimes on growth and yield of grain sorghum. The experiment was laid out in a randomized complete block design with split plot arrangement. Two fertilizer sources, organic (farmyard manure- FYM) and inorganic (NPK and Urea) were evaluated against three sorghum varieties (Gadam, Kari Mtama1 and Macia). The treatment levels were; 5tFYM/ha, 15tFYM/ha, 25kgN/ha NPK + 25kgN/ha Urea, 50kgN/ha NPK + 50kgN/ha Urea, 5tFYM/ha +25kgN/ha NPK+ 25kg Urea, 15tFYM/ha + 50kgN/ha NPK + 50kgN/ha Urea. The parameters evaluated included number of productive tillers per plant, panicle length, days to 50% flowering, 1000 grain weight, stover yield and grain yield. The number of productive tillers increased with increase in fertilizer use where an average of two tillers per plant was recorded for both main and ratoon crop in the plots which had the highest (15tFYM/ha +100kgN/ha) fertilizer level. Gadam had the highest number of productive tillers per plant (1.762 in the main crop and 2.19 in the ratoon crop). The panicle length in both seasons increased with increase in the fertilizer levels where 26.34cm and 24.3cm in main and ratoon crop were recorded respectively. Macia had the highest panicle length (22.08cm) compared to the other varieties in both seasons. Gadam took fewer days (50days) to 50% flowering while Kari matama1 and Macia took 59 and 69 days respectively in the main crop. The highest (156.9) number of panicles were harvested in

Gadam. Different fertilization regimes had no significant effect ($p>0.05$) on 1000-grain weight in both seasons, but Kari Mtama 1 had the highest 1000-grain weight (36.05gm, 34.19gm) in both seasons among the varieties. There was a significant difference ($p<0.05$) in the stover yield and grain yield in t/ha among the treatments used. Gadam had the highest (5.548t/ha) grain yield whereas Macia had the highest (17.7t/ha) stover yield.

The study revealed that use of both organic and inorganic fertilizer can highly influence growth, yield and the yield attributes of grain sorghum. Most attributes of grain sorghum such as the number of tillers per plant, panicle length days to 50% flowering and grain yield increased with the increase in the fertilization level. Gadam variety proved to be better than Kari Mtama 1 and Macia in terms of grain yield while Macia does well as a dual purpose crop because it had a high residue yield. All varieties responded positively to application of fertilizer in different levels.

Key words: Sorghum; Dual purpose; Gadam; Macia; Grain weight; Panicle length; Stover yield

5.2 Introduction

Generating a sustainable food and feed supply that can match expected demand is, by far, the most formidable challenge facing sub-Saharan Africa (SSA) agriculture (Hounkonnou*et al*, 2012; Jayne and Shahidur, 2013

Sorghum is an under-utilized crop and one of the most important cereal crop in semi-arid tropics (Muui *et al*, 2013; Jacob *et al*, 2013). In Kenya, sorghum is grown in the often drought prone marginal agricultural areas of Eastern, Nyanza and coast provinces (Muui *et al*, 2013). People associate sorghum as a poor man’s crop and some still prefer to grow maize even in areas where it does not do well, and as a result, there is increasing food insecurity (Africa harvest, 2013). A wide range of naturally occurring biotic and abiotic constraints including poor soils, water scarcity, crop pests, diseases, weeds and unsuitable temperatures are well known to reduce the productivity of sorghum. This has often led to low efficiency in input use that has suppressed crop output and reduced food security (Strange and Scott, 2005; Gregory *et al*, 2005). Nitrogen losses through gaseous plant emissions, soil denitrification, surface runoff, volatilization and leaching are increasing with time especially in nutrient poor soils (William *et al*, 1999). This results to a minimal amount of nitrogen available for cereal crops such as sorghum, which cannot do nitrogen fixation leading to poor yields (William *et al*, 1999). Other constraints in sorghum production include; waterlogging, water runoff and soil erosion, which represent major yield constraints (Murty *et al*,2007). Low temperatures, low soil P and N, Fe toxicity, acid soils, and wind damage (blown sand) also hinder crop yields, while downy mildew, insect pests, and weeds such as Striga also cause severe losses (Clay, 2013).

Although many producers view sorghum as a low maintenance crop, with its deep fibrous root system, sorghum responds well to nutrient applications especially in soils that are not fertile. Nitrogen is the most often limiting in sorghum production, hence if managed efficiently; it can cause a significant increase in the yields (Vanlauwe, 2014; Potgieter *et al*, 2016). This study therefore, focused on the use of both organic and inorganic fertilizers in sorghum production to ensure increased yields for both human food and quality livestock feed. This is in quest to identify fertilization regimes and types for increased benefit from integrated crop livestock production, increase use of locally available farmyard manure, and reduce farmer's costs in input purchase while maintaining ecosystems health.

5.3 Materials and methods

5.3.1 Site description

The experiment was carried out at ICRISAT-Kiboko sub-Station for Crops Research, which occupies part of the KALRO-Kiboko Range Research Center land. The station is located in Kiboko, Kibwezi west sub-County, Makueni County. It is about 155km from Nairobi along the Nairobi-Mombasa highway, about 12 km before Makindu Town. ICRISAT-Kiboko site lies between latitude 2° 10' and 2° South and longitude 37° 40' and 37° 55' East and altitude of 975 m above sea level. The farm is surrounded by communities of agro-pastoral Kamba people to the North and East and the pastoral Maasai community to the West. Previously, Kiboko area was a hunting ground for licensed game hunters. The station receives bimodal rainfall of between 545 and 629 mm. The long rains season occurs between April and May while the short rains season occurs between October and January. This is a hot dry region with a mean annual temperature of 22.6°C, mean annual maximum of 28.6°C and mean annual minimum of 16.5^{o}C. The soils are eutric cambisols which are well-drained, sandy clay loam, deep and dark reddish brown (CIMMYT, 2013., Jaetzold *et al*, 2009)

5.3.2 Set up of the field experiment

The experiment was a Randomized Complete Block Design with split plot arrangement with three replications, where sorghum cultivars were the main plots and the fertilization treatments as sub-plots. Three fertilizer sources; urea, NPK and farmyard manure were evaluated against three sorghum varieties (Gadam, Kari Mtama 1 and Macia). These are the identified adapted species and currently grown by farmers in the area. Each main plot had seven12m^2 sub plots. The total area under the experiment was 1300m^2. The space between two sub-plots was 0.75m while the distance between two main plots was 1m. Each experimental subplot measured 4mx3m had 5 planting rows each having 21 planting hills, making a plant population of 105 plants per subplot. Three sorghum seeds were planted per hill and were later thinned to one plant per hill. The fertilizer treatments were; Control (no nitrogen fertilizer and no farmyard manure), 5t FYM/ha applied two weeks before planting, 15t FYM/ha applied two weeks before planting, 25 kg N/ha applied as NPK at planting + 25kg N/ha applied as urea 30 days after planting, 50kg N/ha applied as NPK at planting+ 50kg N/ha applied as urea 30 days after planting, 5t FYM/ha two weeks before planting+25 kg N/ha applied as NPK at planting + 25kg N/ha applied as urea 30 days after planting, 15t FYM/ha two weeks before planting + 50kg N/ha applied as NPK at planting +50kg N/ha applied as urea 30 days after planting. Supplemental irrigation was done throughout the two planting season since the rain was inadequate (Figure 5.1).The frequency of irrigation was determined by the amount of rainfall experienced, the field capacity, the stage of the crop and whether the crop was showing any symptoms of water stress such as drooping of leaves.

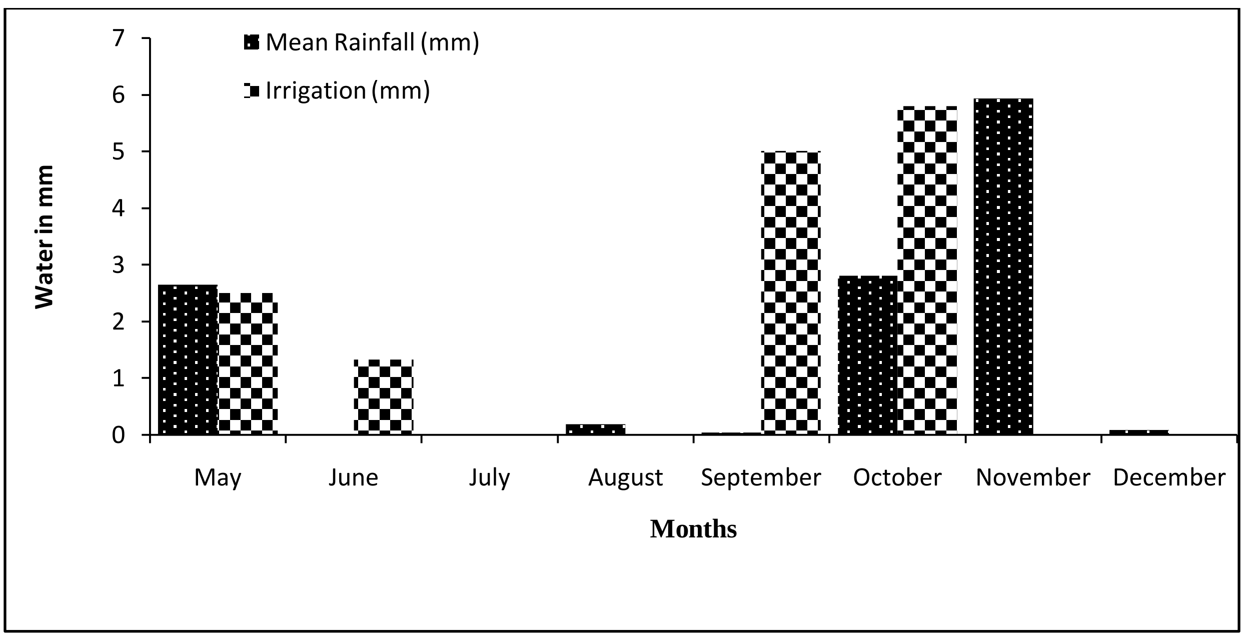

Figure 5. 1: Rainfall experienced over the two planting seasons and supplemental irrigation (May 2017 to December 2017)

5.3.3 Collection of soil samples and determination of soil nutrients

Soil samples from the experimental site and farmyard manure were taken for physico-chemical analysis at the University of Nairobi, College of Agriculture soil science laboratory two weeks before the first planting. Sampling was done at a depth of 0-30cm using an auger, which was the critical rooting zone for sorghum. From each sub plot three samples weighing 300gm each were taken in a zigzag sampling method and placed in a clean plastic bag. Soil samples from all sub plots constituting one main plot were combined to make one composite sample. There were three main plots which were replicated three times making a total of nine composite samples. The nine samples were transported to the University of Nairobi soil science laboratory for analysis. The soil samples were air dried for 3 days, ground, sieved in a 2mm and 0.5mm sieve and analyzed. The soil samples were analyzed for soil pH, electrical conductivity, macronutrients (nitrogen, phosphorus, potassium), exchangeable bases (Mg, Ca, K, Na) micronutrients (Mn, Zn, Cu, Fe) and cation exchange capacity. The physical soil properties analyzed were the particle size and soil texture (Detailed analytical procedures are described in the general materials and method).

5.3.4 Data collection

Data collection was done by picking four tagged plants from the outer two rows in each plot after every two weeks starting one month after planting to flowering.

- **Number of tillers per plant**

All tillers of the four sampled plants were counted and the mean number of tillers was determined for each plot.

- **Days to 50% flowering**

The number of days from sowing until 50% of plants in each plot flowered was determined.

- **Plant stand at harvest**

Before harvesting, all the plants in all the plots that had not fallen were counted and recorded.

- **Panicle length and number of grains per panicle**

Four panicles were taken randomly from the middle rows of each plot, and the panicle length was measured in cm. The panicles were threshed separately and the mean number of grains per panicle was determined.

- **Number of panicles**

All harvested panicles in all the plots were counted and recorded as the number of panicles per plot.

- **Threshing percentage**

The threshing percentage calculated as the ratio of grain biomass to total panicle biomass was determined.

- **Stover yield per hectare**

Stover yield under different fertilization regimes was determined from the three sorghum varieties. Total stover harvested at one node (approximately 3cm) above ground immediately after grain harvest was weighted and recorded.

- **1000-Grain weight (g)**

A sample of 1000 grains were taken from yield of each plot then weighed to determine 1000-grain weight for each treatment.

- **Grain yield per hectare (t/ha)**

This was determined by harvesting the heads of the sorghum plants in the two middle rows in each plot. The heads were left to dry then threshed and weighed. Then grain yield per hectare was calculated.

5.4 Data analysis

The data on number of tillers per plant, panicle length, days to 50% flowering, 1000 grain weight, stover yield and grain yield was subjected to analysis of variance using GENSTAT© statistical package. Mean separation was done using Fisher's protected Least Significant Difference at 5% level of significance.

5.5 Results

5.5.1 Soil analysis

The soil at the experimental site was deficient of nitrogen (Table5.1). Most of the micronutrients (Mn, Zn, Cu, Fe) were adequately present in the soil and in manure and in soil hence application of fertilizers containing these nutrients would not significantly change the yields. According to the soil scale of Landon (1991), phosphorous was high in both the soil and the farmyard manure. The levels of potassium and calcium were low in soil but high in farmyard manure while as magnesium levels were low in soil and farmyard manure. The total organic carbon was low in soil but high in farmyard manure. The soil pH for soil was neutral (7.31) while that for the farmyard manure was slightly alkaline (8.97).The textural class for the soil at the experimental site was sandy clay loam with 60% sand, 34% clay and 6% silt.

Table 5. 1: Soil chemical and physical characteristics before planting

Properties	Soil sample	Farmyard manure
A: Physical Properties		
Sand (%)	60	-
Silt (%)	6	-
Clay (%)	34	-
Textural class	Sandy clay loam	-
B: Chemical composition		
pH	7.31	8.97
Total Organic Carbon (%)	0.939L	7.69
Total N (%)	0.111 VL	0.52
Phosphorus (ppm)	176.2H	812.5
K^{+}(cmol/kg)	0.892ML	1.736
Ca^{2+}(cmol/kg)	0.915L	3.438
Mg^{2+}(cmol/kg)	0.455L	0.886
Na^{+}(cmol/kg)	0.926NT	1.863
Mn^{2+}(ppm)	11.9 A	42.02
Zn^{2+}(ppm)	14.09A	27.15
Cu^{2+}(ppm)	3.31H	3.53
Fe^{2+}(ppm)	8.97A	53.41

H = high, L = low, VL = very low, ML = moderately low, NT = not toxic, A = adequate (Landon, 1991)

5.5.2 Effect of organic and inorganic fertilizer regimes on the number of tillers

High number of productive tillers was observed in the plots where the highest level of fertilizer and manure were used in both main and ratoon crop seasons(Table5.2). Application of 50kgN, 100kgN, 5t FYM +50kgN, and 15t FYM+100kgN per hectare showed no significant difference in the number of productive tillers in both seasons. On the other hand, fewer (1tiller per plant) productive tillers were observed in the plots where no fertilizer was used. Application of farmyard manure at 5t/ha and 15t/ha resulted in no significant difference at $P \leq 0.05$ in the number of tillers. The number of both aerial and basal tillers was not affected by fertilization regimes in the main crop season, however, in the ratoon crop, the number of basal and aerial tillers increased with increase in the rate of fertilizer application. Significant differences in the number of tillers in the three varieties were observed with Gadam having the highest number of tillers followed by Kari Mtama 1 and Macia had the least number of tillers in both seasons (Table 5.2). The number of aerial and basal tillers was not significantly different between Gadam and Kari Mtama 1 varieties in the first season. In the ratoon crop, the number of basal tillers was significantly different with Gadam recording the highest (3.286 tillers) number of basal tillers among the three varieties.

Table 5. 2: Effect of organic and inorganic fertilizer regimes on the number of basal, aerial and productive tillers per plant

	Main crop			**Ratoon crop**		
Fertilizer	Aerial	Basal	Productive	Aerial	Basal	Productive
0kg/ha fertilizer	0.889a	1.222a	1.000b	1.444b	1.667c	1.333b
5tFYM/ha	0.667a	1.222a	1.000b	1.667b	2.222bc	1.333b
15tFYM/ha	0.778a	1.333a	1.000b	1.778ab	2.333bc	1.444b
50kgN/ha	0.667a	1.333a	1.222ab	1.778ab	2.333bc	1.556ab
100kgN/ha	0.445a	1.333a	1.333ab	1.778ab	2.556ab	1.556ab
5tFYM/ha+50kgN/ha	0.667a	1.556a	1.333ab	2.000ab	2.778ab	1.667ab
15tFYM/ha+100kgN/h	0.889a	1.556a	2.000a	2.333b	3.111a	2.000a
LSD(P≤0.05)	NS	NS	0.957	0.626	0.723	0.467
Variety						
Gadam	1.000a	2.476a	1.762a	2.571a	3.286a	2.19a
Kari Mtama 1	1.000a	1.286b	1.762a	2.476a	2.619b	1.81a
Macia	0.143b	0.286c	0.381b	0.429b	1.381c	0.667b
Mean	0.714	1.35	1.3	1.825	2.429	1.556
LSD (P≤0.05)	0.374	0.671	0.604	0.643	0.223	0.911
CV (%)	82.7	78.7	73.4	35.9	30.2	35

For each parameter means in the same column followed by the same letter(s) are not significantly different at P≤0.05 probability level, LSD = Least Significant Difference, CV (%) = Coefficient of Variation

5.5.3: Effect of organic and inorganic fertilizer regimes on the panicle length (cm), days to 50% flowering and plant stand at harvest per plot

There was a significant difference among the sorghum varieties on the panicle length in both seasons although the length of the panicles in the second season was lower. Application of 0kg fertilizer, 5t FYM, 15t FYM, 50kgN and 100kgN per hectare resulted in no significant difference in panicle length for specific varieties in both seasons. The use of organic and inorganic fertilizer at the highest levels recorded panicles with more length (26.34cm, main crop and 24.3cm ratoon crop).

The length of panicles was significantly different among the three varieties with Macia having panicles with more length (28.5cm, main crop and 26.76cm in ratoon crop) in both seasons (Table5.3). In the main crop, all the varieties took more (Gadam 50 days, Kari Mtama 1 59 days and Macia 69 days) to flowering across all the fertilizer levels however in the ratoon crop the days to flowering were fewer (Gadam36 days, Kari Mtama 1 42 days and Macia 43 days). Flowering occurred first on the plots where 50kgN, 100kgN, 5tFYM+50kgN and 15tFYM+100kgN per hectare were applied. There was a significant difference in the days to anthesis among the three varieties with Gadam taking lesser days to flowering followed by Kari Mtama 1 and Macia (50 days, 59 days and 69 days respectively) in the main crop. The same trend was observed in the ratoon crop where Gadam took fewer days to flowering compared to Kari Mtama 1 and Macia (36 days, 42 days and 43 days respectively). There was no significant difference in the stand at harvest among all the treatments in both seasons but the plant stand reduced in the ratoon crop season. However, stand at harvest was highest in Macia variety with Gadam having the least stand at harvest in the first season.

Table 5. 3: Effect of organic and inorganic fertilizer regimes on the panicle length, days to 50% flowering and stand at harvest

	Main crop			Ratoon crop		
Treatment	Panicle length (cm)	50% flowering	Stand at harvest	Panicle length (cm)	50% flowering	Stand at harvest
0kg/ha fertilizer	23.64b	61.56a	77.00a	21.52a	41.78a	74.00a
5tFYM/ha	24.72ab	59.56b	85.56a	22.96ab	41.67a	83.56a
15tFYM/ha	24.61ab	59.78b	83.89a	23.33ab	40.89b	81.33a
50kgN/ha	25.31ab	59.33bc	79.56a	22.83ab	40.33c	71.00a
100kgN/ha	25.23ab	59.00c	79.33a	23.38ab	40.33c	77.44a
5tFYM/ha+50 kgN/ha	25.83a	59.00c	81.78a	23.77a	40.00d	79.44a
15tFYM/ha+100kgN/ha	26.34a	59.00c	79.44a	24.30a	40.00d	75.89a
LSD (P≤0.05)	2.024	0.554	8.89	NS	0.726	NS
Variety						
Gadam	22.08c	50.05c	68.19c	20.01c	36.38c	66.48b
Kari Mtama 1	24.73b	59.19b	93.71a	22.70b	42.10b	90.38a
Macia	28.50a	69.57a	80.90b	26.76a	43.67a	78.29ab
Mean	25.1	59.603	80.9	23.16	40.71	78.4
LSD (P≤0.05)	1.202	0.497	7.9	1.207	0.4649	18.9
CV (%)	7.6	1.3	15.4	8.6	0.7	13.7

For each parameter means in the same column followed by the same letter(s) are not significantly different at P≤0.05 probability level, LSD = Least Significant Difference, CV (%) = Coefficient of Variation, NS = Not significant

5.5.4: Effect of organic and inorganic fertilizer regimes on the number of panicles harvested, number of grains per panicle and threshing percentage

There was a significant difference in the number of panicles harvested among the varieties at different fertilization levels across the seasons (Table 5.4). The average number of panicles harvested in the ratoon crop were fewer than those harvested in the first crop (114.7 and 104.3 panicles respectively). Application of 15tFYM+100kgN per hectare resulted in more panicles (122 in main crop and 109 panicles in ratoon crop). The control (no fertilizer plots) had the least panicle numbers with105.6panicles in main crop and 94.2 panicles in ratoon crop. There was no significant difference in the number of panicles harvested in plots where 5tFYM, 15tFYM, 50kgN, 100kgN and 5tFYM+50kgN per hectare were applied in both seasons. The number of panicles harvested was significantly different among the three varieties used with Gadam recording the highest (156.9, main crop and 136.5 panicles, ratoon crop) (Table5.4).The number of grains per panicle was significantly different in regards to the fertilizer treatments. The plots where both organic and inorganic fertilizer was applied at the rate of 15tFYM/ha+100kgN/ha resulted in the panicles having the highest number of grains (3592, main crop and 3298 grains, ratoon crop) per panicle. The threshing percentage was significantly different among the various fertilizer treatment levels. The plots where 15tFYM/ha+100kgN/ha was used had the highest (87.8%) threshing percentage while the plots where 0kg/ha fertilizer was used had the least (78.89%) threshing percentage. There was no significant difference in the threshing percentage among all the three varieties evaluated in both the first and the ratoon crop.

Table 5. 4: Effect of organic and inorganic fertilizer regimes on the number of panicles, grains/panicle, threshing percentage

	Main crop			Ratoon crop		
Treatment	No.of Panicles	Grains/ panicle	Threshing (%)	No.of panicles	Grains/ panicle	Threshing (%)
0kg/ha fertilizer	105.6b	2462d	78.89c	94.2b	2323c	67.40c
5tFYM/ha	114.3ab	2543d	84.60ab	99.1ab	2416c	74.04bc
15tFYM/ha	115.8ab	2656cd	84.16ab	104.9ab	2369c	78.3abc
50kgN/ha	116.7ab	2816bcd	81.84bc	104.9ab	2671bc	83.94abc
100kgN/ha	109.7ab	3266abc	82.71abc	108.2a	2856abc	80.60abc
5tFYM/ha+50kgN/ha	119.2ab	3404ab	84.90ab	109.8a	3010ab	91.15ab
15tFYM/ha+100kgN/ha	122.0a	3592a	87.80a	109.0a	3298a	98.1a
LSD (P ≤ 0.05)	11.91	581.1	5.418	11.3	541.2	22.21
Variety						
Gadam	156.9a	2171b	84.95a	136.5a	2048b	81.4a
Kari Mtama 1	102.0b	2703b	82.76a	96.0b	2452b	79.28a
Macia	85.3c	4014a	82.96a	80.4c	3619a	85.38a
Mean	114.7	2963	83.56	104.3	2706	82
LSD (P ≤ 0.05)	14.56	644	NS	11.06	994.1	NS
CV (%)	13.3	22.7	6.8	12.7	20.7	26.5

For each parameter means in the same column followed by the same letter(s) are not significantly different at P≤0.05 probability level, LSD=Least Significant Difference, CV (%) = Coefficient of Variation, NS = Not significant.

5.5.5 Effect of organic and inorganic fertilizer regimes on the 1000 grain weight (g), stover yield (t/ha) and grain yield (t/ha) of grain sorghum

There was no significant difference in the 1000-grain weight in all the treatments in both main crop and ratoon seasons, However, there was a significant difference in the 1000-grain weight among the three varieties with Kari Mtama 1 having the highest (36.05gmain crop and 34.19g ratoon crop) 1000-grain weight (Table5.5). There was a significant difference in the yield of the sorghum stovers after harvest within the different fertilization regimes. The plots where 15tFYM/ha+100kgN/ha was applied, more (15.19t/ha main crop and 16.74t/ha ratoon crop) stover yield was recorded. Notably, the plots where no fertilizer was applied recorded the least (11.99t/ha main crop and 12.96t/ha main crop) Stover yield. Interestingly, the stover yield was higher in the second season across all the fertilizer treatments. There was no significant difference in the weight of the stovers between Gadam and Kari Mtama 1 while Macia recorded the highest (16.47t/ha main crop and17.7t/ha ratoon crop) stover yield in both seasons. The grain yield was significantly different among the fertilizers treatment levels with 5tFYM/ha+50kgN/ha and 15tFYM/ha+100kgN/ha treatments recording more grain yield (6.25t/ha and 6.44t/ha respectively) for the first season. Grain yield was lower in the ratoon crop season, which decreased with fertilizer level decrease (Table 5.5). The plots where no fertilizer was applied recorded the least (3.55t/ha main crop and 2.92t/ha ratoon crop) grain yield. In both seasons, Gadam (4.54t/ha main crop and 4.5t/ha ratoon crop) variety recorded the highest grain yield followed by Kari Mtama 1(4.81t/ha main crop and 3.96t/ha main crop) and lastly Macia (4.79t/ha main crop and 3.76t/ha ratoon crop).

Table 5. 5: Effect of organic and inorganic fertilizer regimes on the 1000 grain weight, Stover yield and grain yield t/ha

	Main crop			**Ratoon crop**		
Treatment	1000grain weight (g)	Stover yield (t/ha)	Grain yield (t/ha)	1000 grain weight (g)	Stover yield (t/ha)	Grain yield (t/ha)
0kg/ha fertilizer	32.00a	11.99c	3.556e	30.78a	12.96e	2.926e
5tFYM/ha	32.00a	12.31c	4.139d	30.89a	13.8cde	3.537de
15tFYM/ha	31.78a	12.78bc	4.574cd	31.89a	13.24de	3.491de
50kgN/ha	31.78a	14.44ab	5.009bc	31.44a	14.64bcd	3.898cd
100kgN/ha	32.11a	14.86a	5.389b	31.22a	15.23bc	4.38bc
5tFYM/ha+50 kgN/ha	32.00a	14.91a	6.25a	32.00a	15.51ab	4.991ab
15tFYM/ha+100kgN/ha	34.22b	15.19a	6.444a	32.89a	16.74a	5.315a
LSD (P≤0.05)	1.739	2.303	0.68	NS	2.18	0.845
Variety						
Gadam	31.43b	12.16b	5.548a	30.9b	12.92b	4.508a
KariMtama 1	36.05a	12.72b	4.810b	34.19a	13.15b	3.96ab
Macia	29.43b	16.47a	4.798b	26.67b	17.7a	3.762b
Mean	32.3	13.8	5.1	31.59	14.6	4.1
LSD (P≤0.05)	2.39	1.487	0.617	4.551	2.62	0.62
CV (%)	9.8	13.9	11.7	8.7	10.8	18.3

Means in the same column followed by different letter(s) are significantly different at P≤0.05 probability level, LSD = Least Significant Difference, CV (%) = Coefficient of Variation, NS = Not significant.

5.6 Discussion

The results showed that fertilizer levels are the key drivers of tillering where more productive tillers per plant were observed in plots which received the highest combination level of organic and inorganic fertilizers. These results are in agreement with the findings of Belete *et al*, (2015) who reported that the highest number of productive tillers per plant (7.22 tillers) was recorded in plots with the highest (92 kg N/ha) level of nitrogen fertilizer application. Fertilizer treatment did not have an impact on the number of aerial and basal tillers for the three sorghum varieties. Grain filling process requires a lot of nutrient supply (Alley *et al*, 1997) such as phosphorus and nitrogen and this explains why more productive tillers per plant were observed in plots which had the highest amount of this elements supply. A study conducted by Lafarge *et al*, (2002) showed that tiller fertility is determined by the amount of assimilates or nutrients supply to the crop at the time of tiller emergence, resulting to more productive tillers in plots with the highest nutrient supply level. More basal, aerial and productive tillers were observed in the ratoon crops for all the varieties with Gadam having the highest ratooning potential compared to Kari Mtama 1 and Macia. An interaction between the number of aerial and basal tillers and productive tillers was observed, where the more the basal and aerial tillers per plant the more the productive tillers were observed. The findings also showed that many productive tillers per plant resulted from the basal tillers which sprouted earlier than the aerial tillers. This is possibly because the basal tillers were able to draw nutrients directly from the soil compared to aerial tillers which depend on the main plant for nutrients and hence low performance. The plants that were not fertilized had few tillers, and delayed tillering. This points out to the important role plant nutrients play in the health and productivity of the crop. This explains the reported low yields by farmers who did sorghum cultivation without the use of fertilizer as reported in the study survey presented in chapter 3. Among the three varieties evaluated, Gadam and Kari Mtama 1 recorded the highest number of productive tillers per plant compared to Macia, a local dual-purpose variety. On the contrary, Opole *et al*, (2007), indicates that high yielding improved varieties have poor ratoonability compared to the local varieties.The higher productive tillers in Gadam is in agreement with studies carried out by Thuranira *et al*, (2015) and KARI, (2006) which showed that Gadam is a high yielding variety attributed to its ability to produce many fertile tillers per plant. Macia had the least number of productive tillers per plant possibly because it is a local and unimproved variety. This is supported by results from a study by Yoseph *et al*,(2014) which reported low number of tillers per plant for local grainsorghum varieties.

The observed increase in panicle length with increasing levels of fertilizer application in the planted crop is in line with results reported by Arun *et al*, (2007) and Gowda, (2012), where the length of the sorghum panicles increased with increase in the fertilizer levels. A study conducted by Asgharipour, (2011), showed that the panicle length of grain sorghum increased with increase in potassium fertilizer application. Melaku *et al*, (2017)also showed that the panicle length increased with increase in the level of fertilizer. However, in this study the panicle length in the ratoon crop was lesser thanin main crop which could be attributed to nutrient competition due to the observed increase in the number of tillers per plant for the ratoon crops. Panicle length is one of the attributes that affect sorghum grain yield hence the smaller the panicle the lower the grain yield. Among the three varieties, Gadam had the least average panicle length of 22.08 cm but had more yields because of more productive tillers than Macia and Kari Mtama 1. Similar results observed by Kimani *et al*, (2013) showed that Gadam had an average panicle length of 21.01cm. Macia, a local dual-purpose variety had the highest panicle length of 28.5cm. This is also in agreement with findings of Kimani *et al*, (2013), who reported that Makueni local, which is also a local variety had an average panicle length of 29.62cm.A study by Manyathi, (2014) also showed that Macia had the largest panicles. AlthoughMacia had panicles with more length than the Gadam and Kari Mtama 1, the yields were still low because it had very few productive tillers than the other varieties. In chapter four of this study, farmers reported low yields because most of them preferred to produce local varieties such as Macia which produce very low yields.

The days to 50% flowering reduced as the fertilizer levels increased in both main crop and ratoon crop. This may have resulted from rapid growth of plant parts hence early development of the floral parts due to sufficient nutrients. It took fewer days for the ratoon crop to flower compared to the planted crop. This is so because a ratoon crop has an established root system, which utilizes the available nutrients much earlier in the season, hence the crop takes a shorter time to flower. Delayed flowering observed in unfertilized sorghum plants suggests that crop development and harvest is delayed in sorghum planted in soils with low nutrient levels. A study by Buah *et al*., (2012) showed similar results. Findings by Hussain *et al*, (2011); Yoseph *et al*,(2014); Mapfumo *et al*,(2007) agree with results in this study in that days to flowering were affected by the variety, where by Gadam took fewer days to flowering compared to other varieties. Gadam is an early maturing variety (KALRO, 2016), flowering in 45-52 days in the main crop and 36 days in the ratoon crop as shown in this study. On the other hand, Macia is a late maturing variety compared to the three varieties evaluated taking up to 67 days to flower (Saadan *et al*, 2000) in the main crop and 43 days in the ratoon crop according. The different fertilization regimes in the present study had no effect on the plant stand at harvest in the first and the ratoon crop. This suggests that all the varieties were resistant to lodging which is a great challenge in sorghum production. Among the three varieties, Kari Mtama 1 had the highest plant stand. Although Macia had stems with more diameter, the plant stand at harvest was lower than that of Kari Mtama 1. Pests control was done throughout the season for all varieties but Macia was highly susceptible to insect pests such as the sorghum stem borers that led to complete destruction of the infested plant hence reduced plant stand at harvest and this contributed to low yields. Farmers can still adopt Macia variety as a dual-purpose variety because of its ability of the harvested stovers to stay green longer than other varieties.

Study by Buah *et al*, (2012) and Dagash *et al*, (2015) showing increase in the number of panicles harvested from increase in the amount of fertilizer applied supports the present study where the number of panicles harvested and the number of grains per panicle increased with increase in fertilizer in both themain crop and the ratoon crop. However, the number of panicles harvested in the ratoon crop was lesser than those harvested in the main crop in all the treatments. This is because of the fewer productive tillers recorded in the ratoon crop. Gadam had the highest number of panicles because of its high ratooning potential. The variety also had the highest number of productive tillers per plant and hence contributing to its high number of panicles and consequently high grain yield. Macia had the least number of panicles, unlike Gadam, this variety had a low ratooning ability hence very few productive tillers hence low grain yield compared to Gadam and Kari Mtama 1. On the other hand, Macia had the highest number of grains per panicle because its panicle length was higher than that of Gadam and Kari Mtama 1.

The observed increase in stover and grain yield with increase in the fertilizer levels for both the planted crop and the ratoon crop in all the varieties supports the findings of Erickson *et al*, (2011) and Vermerris *et al*, (2011) who showed that the yield for the ratoon crop was half as much as that of the primary crop. The observed lower grain yield in ratoon crop that was significantly lower than that of the main crop explains the fact that many tillers in the ratoon crop must have resulted to insufficient nutrients for the tillers, which lead to very few productive tillers and hence reduced grain yield. Sorghum crop should be provided with enough nutrients in order to obtain high yields, furthermore, inadequate supply of nutrients to the crop could significantly reduce the number of panicles harvested and this would consequently reduce the yields. On the contrary, the stover yield from the ratoon crop was more than that from the primary crop because of many tillers per plant produced, which could be attributed to well developed roots, and the removal of apical dominance after harvest, triggering the tillering characteristics.

The threshing percentage increased with increase in the amount of fertilizer applied. This is possibly because increased fertilizer application led to faster growth hence earlier maturity which gave the sorghum kernels more time to dry hence making threshing easier. This is in agreement with a study carried out by (Hartmond *et al*, 1996) who found that the threshing percentage improved with application of Ca. In pearl millet, the threshing percentage is one of the selection criterion used to identify the lines with improved ability to fill and set grains (Yadav, 1994). Previous studies show that there was a significant difference in the threshing percentage among the varieties evaluated (onyango, 2000; Amal *et al*, 2010). However, this study shows that the threshing percentage for the three varieties was not significantly different. This could be due to the fact that threshing percentage is genetically controlled (Adeyanju *et al*., 2015)which makes it vary between varieties but in this particular study, Gadam, Kari Mtama 1 and Macia seem to have the same threshability.

The observed no difference of fertilizer levels on 1000-grain weight supports the findings of Buah *et al*.,(2012) who showed that the N, P and K interaction was not significant in affecting the 1000-grain weight in sorghum. On the contrary, findings by Kaushal *et al*, (2017)., Mukhtiar, (2018)showed that 1000-grain weight increased with increase in the fertilizer levels. 1000-grain weight can be used to estimate the seeding rate and harvest losses in cereal crops such as wheat and sorghum (Miller *et al*, 2001).

5.7 Conclusion

It is evident that grain sorghum, regardless of the variety responds positively to use of organic and inorganic fertilizers hence the use of these fertilizers should be encouraged in order to increase the yield. From the findings, farmers should be encouraged to use organic manures if they cannot afford the commercial fertilizers to increase grain sorghum yields. There is need to understand the basic growth patterns and tillering behavior of a particular sorghum variety to facilitate management of ratoon crops for maximum production.

CHAPTER SIX

GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

6.1 Discussion

According to this study, 85.59% of farmers grew sorghum for their own consumption and very few farmers produced sorghum for sale while 12.22% of farmers grew sorghum as animal feed. Most of grain sorghum produced in African and Asian countries is for human consumption (Ratnavathi and Patil 2013). This could be attributed to poor sorghum markets and the fact that sorghum production is viewed as a labor intensive crop by small holder farmers due to the reported challenge of birds damage that can lead to up to 100% crop loss (Omoro, 2013 ; Miano *et al*, 2010). Sorghum production by households was practiced on small pieces of land even though the farmers owned large pieces of land but used them for other crops. This is as a result of farmers having not embraced the value of sorghum as food and cash crop and many farmers still prefer to produce other crops such as maize.

Many farmers in Makueni County rely on agricultural information from the ministry of agriculture through the extension officers. However, majority of farmers in this study did not acquire any information on sorghum production and this could explain the poor production practices carried out in the region. These results are in agreement with those of Rees *et al*, 2000, who reported that the government extension was a crucial source of information although the farmers were not satisfied with the quality and the number of times the extension officers interacted with the farmers. Farmers therefore, ended up relying on information from their neighbors and some went to an extent of copying what their neighbors were practicing. Inadequate rainfall and bird damage were the two most important challenges that were reported by farmers in Makueni County. A study by Miano *et al*, (2010) shows that bird damage can lead up to 100% crop loss. Many farmers in this study reported that they did not allocate a lot of land to sorghum production because bird scaring is labor intensive and so they preferred planting other crops that are not prone to bird damage.

The most common seed source used by farmers in Makueni County was farmer own saved seeds where farmers preserved a portion of grain harvested in one season to be used as seed in the next season. A study by Muui *et al*, 2013 show that most farmers used informal seed systems in that seeds are locally bought from the market or literally borrowed from the neighbors. This could explain the low yields obtained by farmers from this region. Very few farmers obtained certified seeds, which were supplied by the government through the extension officers. Other farmers especially from Kathonzweni Sub County obtained seeds from NGOs such ADS (Anglican Development Services) and ICRISAT where they could be given seeds at no cost but not all farmers could access these centers. A research conducted by ICRISAT in Busia County indicated that farmers were provided with quality seeds of three drought tolerant crops (sorghum finger millet and groundnuts) of improved varieties to promote production and utilization of these crops (ICRISAT, 2017).

Most sorghum farmers in this region preferred to grow local landraces because they possessed characteristics that are embraced in that region. The finding of Muui *et al*,(2013) is in agreement with that of this study in that most farmers used local and unimproved varieties. The farmers reported that they preferred varieties such as Seredo because they were resistant to bird damage and drought tolerant. However, these local varieties produced very low yields. Gadam and Kari Mtama 1 were the varieties that were mostly promoted by the Agricultural extension officers in the study area. These two varieties were high yielding and early maturing (especially Gadam that takes less than three months to mature) but they are very prone to bird damage, making farmers hesitant in adopting these varieties.

According to this study, most farmers practiced intercropping in order to maximize on land use and increase food availability throughout the season. The most common crop used as an intercrop by farmers in Makueni County was cowpea followed by maize, green grams and lastly beans. A study by Musa *et al*,(2011), reveals that most farmers in Africa practice intercropping in order to optimize on space and time (Singh and Usha,2003) hence reducing food insecurity due to diversity of output throughout the season.

Most farmers in this study practiced the plant 'one season' cropping system and very few farmers practiced ratoon-cropping system. The farmers noted that the ratoon crop yield was lower than that of the planted crop, which is supported by the results from the experimental study in chapter five. However, ratoon cropping is advantageous in that a farmer can get more yield in both seasons without the initial cost of land preparation and inputs. For farmers to obtain better yields in the ratoon crop, fertilizer application is required which should be done one week after cutting back the crop.

According to the results of this study, most farmers recorded grain yield of 151 to 250 kg/ha which is very low compared to the potential grain yield of 10.5t/ha (Jordan *et al*, 2012). This could be attributed to factors such as; poor production practices, inadequate rainfall, bird damage and failure to use fertilizers in sorghum production. Most farmers also used uncertified seeds that have not been improved, this contributes to the reported low yields. Hay was the most commonly used method of conserving sorghum residues as animal feed. Conservation of sorghum residue as hay was cheaper than other methods of conservation. Other farmers in the region preferred to graze the animals directly to the field immediately after harvesting as this minimized the cost of land clearing.

There was a positive interaction between the amount of fertilizer used and the number of productive tillers recorded in this study in that, more productive tillers were recorded in the plots with the highest level of fertilizer and manure application. This is in line with the results of a study conducted by Belete *et al*, (2015), who reported that the number of productive tillers increased with increase in the amount of fertilizer applied. More aerial and basal tillers were recorded in the ratoon crop than in the main crop among the three varieties. Macia had the least productive tillers than Gadam and Kari mtama 1 and this explains the low grain yield obtained in Macia variety. Local and unimproved sorghum varieties have been reported to have low number of tillers per plant (Yoseph *et al*, 2014).

The panicle length, number of panicles and grains per panicle increased with the increase with the level of fertilizer and manure application. Similar results were reported by Arun *et al,* 2007; Gowda, 2012; Melako *et al*, 2017 and Buah *et al*, 2012. More panicle length was recorded in Macia variety while Gadam had the least average panicle length. In his study, Kimani *et al*,(2013) shows that Gadam had the least panicle length of 21.01cm. Due to its ability to produce more productive tillers per plant, Gadam recorded more panicles in both main and ratoon crop and this explains why more grain yield was recorded in Gadam than Macia even though Macia had panicles with more length.

Increase in stover and grain yield in both the plant and the ratoon crop increased with increase in the level of manure and fertilizer. Ahmed *et al*, (2007) indicated that the use of different N fertilizer sources significantly increased the grain and stover yield of grain sorghum. It is clear from this study that fertilizer, whether organic or inorganic plays a major role in growth and yield of grain sorghum. In chapter four of this study, most farmers did not use any fertilizer in sorghum production and this contributed to low yields reported in the study area.

6.2 Conclusion

In conclusion, the major challenges facing sorghum farmers in this study are inadequate rainfall and bird damage that was reported to cause up to 100% crop loss. Farmers also have a limited access to certified seeds and they end up using their own farm saved seeds that are not genetically improved and are susceptible to damage by pests and diseases hence low yields. Most farmers in this region also have not embraced sorghum production despite being a drought tolerant crop that does well under infertile soils compared to other crops like maize. This has significantly contributed to low grain yield reported in the area.

Fertilizer application at the rate of 15tFYM/ha applied two weeks before planting and 100kgN/ha in split application gave the highest grain and stover yields across all the varieties in both the plant and ratoon crop. Among the three varieties evaluated, Gadam performed well in terms of grain yield in both plant and ratoon crop compared to Kari Mtama 1 and Macia. However, Macia was the best in terms of stover yield compared to Kari Mtama 1 and Gadam in both seasons.

6.3 Recommendations

1. Extension officers should create more awareness on the importance of sorghum production regarding the upcoming market opportunities especially in the beer brewing industry
2. Certified sorghum seeds should be made more available to farmers either through the agricultural extension officers or the NGOs
3. Farmers should use fertilizers (organic or inorganic) in sorghum production as this will greatly influence the growth and the yield of grain sorghum both for human consumption and as fodder
4. With the use of 15tFYM/ha +100kgN/ha in combination, farmers can obtain up to5t/ha grain and 13t/ha stover yield when proper production practices are observed
5. Farmer demonstration plots also seem a promising extension avenue, especially with the lead farmers where peer farmer leaning was reported
6. Further studies should be conducted to establish the best production practices regarding the management of ratoon crop for better yields

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