IMPROVING SORGHUM GRAIN YIELD THROUGH USE OF MINERAL FERTILIZERS AND FARM YARD MANURE FOR SMALLHOLDER FARMERS IN MAKUENI AND MACHAKOS COUNTIES

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DECLARATION

I **Riziki Umazi Mwadalu** declare that this thesis is my original work and has not been presented for the award of a degree in any other University or any other award.

Signature___________________________ Date ___________________________

Riziki Umazi Mwadalu

We confirm that the work reported in this thesis was carried out by the candidate under our supervision and has been submitted with our approval as university supervisors.

Signature_________________________ Date___________________________

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DEDICATION

I dedicate this work to the Almighty God for His grace and protection throughout the research period and to my family and friends for their love, encouragement and support.

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ABBREVIATIONS AND ACRONYMS

ANOVA: Analysis of Variance

ASAL: Arid and Semi- Arid Land

C: Carbon

CAN: Calcium Ammonium Nitrate

CEC: Cation Exchange Capacity

CFI: Canadian Fertilizer Institute

Cm: Centimeters

CSTI: Centre for Science and Technology Innovation

EABL: East African Breweries Limited

FAO: Food and Agriculture Organization

FAOSTAT: Food and Agriculture Organization statistics

FYM: Farmyard manure

GDP: Gross domestic product

GLM: General Linear Model

Ha: hectare

ICRISAT: International Crop Research Institute for the Semi- Arid Tropics

ISFM: Integrated soil fertility management

K: Potassium

KARI: Kenya Agricultural Research Institute.

KASAL: Kenya Arid and Semi- Arid Lands

KAT: Katumani

KCl: Potassium chloride

Kg/ha: Kilograms per hectare

Km^2: Square kilometer

KYM: Kampi Ya Mawe

LH: Lower Highland zone

LSD: Least Significant Difference

me: milli equivalent

mm: Millimeters

NGO: Non-Governmental Organization

PPM: parts per million

RCBD: Randomized Complete Block Design

SL: Sandy Loam

SCL: Sandy Clay Loam

SSA: Sub-Saharan Africa

T/ha: Tons per hectare

TSP: Triple super phosphate

ABSTRACT

Reduced food productivity in smallholder farms is the principal cause of food insecurity in semi-arid parts of Kenya. This is mainly attributed to decline in soil fertility, low and unreliable rainfall, land degradation and adverse effects of climate change. The solution lies in the efficient use of nutrients and planting of drought tolerant crop varieties that can cope with the low rainfall in the ASALs. The aim of this study was to evaluate the effect of FYM, mineral fertilizers and their integration on the production of Gadam sorghum and change in soil properties in Makueni and Machakos counties. The experimental design was a factorial arranged in Randomized Complete Block Design. The study consisted of two experiments in each site. The first experiment was a pure mineral fertilizer experiment with two factors (nitrogen and phosphorus) each at four levels (0, 25, 50, 75 kg/ha). The second experiment tested a combination of FYM (0, 5 & 10 tons/ha) and NP fertilizer in form of CAN and TSP, respectively, at 0 and 50kg/ha each. The first experiment involved 16 treatments while the second experiment involved 6 treatments. The results of grain yields in the first experiment were significantly different in the various treatments ($p=0.02$) at Kampi ya Mawe and ($p=0.04$) at Katumani. Nitrogen increased sorghum yields more than phosphorus, but not significantly. However, combining N at 75 kg/ha and P at 50 kg/ha gave the highest yields of 4859.1 kg/ha at Kampi ya Mawe, which was an increase of 135% above the control. At Katumani, combining 50kg/ha N and 25 kg/ha P gave the highest grain yield of 2485.1 kg/ha which was 68.3% above the control. In the second experiment, combining FYM with NP fertilizer at 50kg/ha NP and 10 tons/ha FYM gave the highest yield of 5393kg/ha compared to the control treatment (4233.1 kg/ha) at Kampi ya Mawe, which was 13.7% more. At Katumani, however, combining FYM and NP fertilizer had less yields as compared to the control. FYM at 10ton/ha and NP 50 kg/ha gave 1566.4 kg/ha which was not significantly different compared to 1669.4 kg/ha for the control. The amount of available N in the soil increased proportionately with N application and declined gradually throughout the growing season. Nitrogen uptake by sorghum also increased with increased N application while soil microbial population was increased with the application of FYM. Nitrogen use efficiency (NUE) was optimal at 50 kg/ha N and declined with increased application of N while Phosphorus use efficiency (PUE) was highest at 50 kg/ha P. Sorghum was more efficient in utilizing nitrogen than phosphorus. Based on the results, a combination of FYM and NP fertilizer can be recommended for sorghum production both at Kampi ya Mawe and Katumani. The findings of this study will be valuable in extension efforts towards increasing sorghum productivity and awareness by farmers of best ISFM practises in semi-arid eastern Kenya.

CHAPTER ONE

1.0. INTRODUCTION

1.1. Background

Agriculture is the backbone of the Kenyan economy and is expected to remain the driver for the country's economic and social development for the foreseeable future. Agriculture directly contributes 26% of Gross Domestic Product (GDP) with an additional 27% through linkages to agro-based industries (Mwangi et al., 2010). About 80% of Kenya's population lives in rural areas with most of it being dependent on agriculture for a larger part of its livelihood. However, the emerging adverse effects of climate change have in the recent past led to massive crop failures especially in the Arid and Semi-Arid lands (ASALs). Between 20-25% of the Kenyan population lives in ASALs with the majority (estimated at 80%) living in areas where rain-fed agriculture is possible. Such areas include those with more than 600 mm of annual rainfall (Esipisu, 2011). Food insecurity is most severe in the ASALs, where in 2009, approximately 10 million Kenyans mainly in the ASAL areas needed food aid (KASAL, 2010). It is also reported that between the years 2000 and 2005, the Kenya government spent about £40-60 million annually on famine relief with Non-Governmental Organisations spending about the same amount. As climate change continues to unfold, the frequency of climate extremes such as severe droughts and floods are expected to increase. Good soil fertility and water management, and use of drought tolerant crop varieties are necessary to better cope with the effects of climatic vagaries for sustainable agricultural production in dry lands (Obia, 2011). The major constraint to productivity of crops in the semi-arid regions is inadequate, unreliable and poorly distributed rainfall (Nikus et al., 2004). Adaptation to climate change and mitigation is crucial for the achievement of sustainable development (CSTI, 2009).

Sorghum (*Sorghum bicolor* L. Moench), one of the drought tolerant crops, is the fifth most important cereal crop grown for human consumption in the world being surpassed only by maize, wheat, rice and barley (Akram et al., 2007). It is one of the main staple food crops for the world’s poorest and food insecure people (Timu et al., 2012). The Gadam sorghum variety was introduced by KARI to the semi-arid Eastern Kenya in 2009 as a way for farmers to improve their food security and earn some income for their livelihoods. This variety is not only a high yielding variety but also thrives well in harsh conditions, thus making it widely adopted by smallholder farmers in the region. It is high in starch and low in protein which makes it suitable for malting and offers a good alternative source of starch (Esipisu, 2011). In 2010, KARI estimated the annual demand for this variety of sorghum to be 60,000 metric tons due to the high demand from East African Breweries Limited (EABL), the region’s brewing giant. In contrast, the production during that period was estimated to be only 2,000 metric tons.

Providing nutrient inputs to sorghum through application of chemical fertilizers is needed to replace the nutrients which are exported and lost after crop harvests and to maintain positive nutrient balances in soils. However, because of the scarcity and high cost of fertilizers, most smallholder farmers in tropical Africa rarely use inorganic fertilizers on food crops including sorghum (Buah and Mwinkaara, 2009). Using inorganic fertilizer as a main source of nutrients can also lead to rapid decline in crop yields because of acidification and deterioration of soil structure (Iqbal et al., 2012). The use of all the possible resources available on the farms is increasingly gaining importance among small holder farmers. Such resources include crop residues, green manure and FYM (Achieng et al., 2010). Among the organic resources farm yard manure is the most commonly used because of its availability and the fact that it contains most of the nutrients needed for plant growth including trace elements though in low quantities. Use of FYM alone cannot, however, satisfy the crop requirements because of low nutrient concentration due to its slow decomposition rates (Tolessa and Friesen, 2001). Integrated nutrient management through combined use of mineral and organic fertilizer sources is of great importance for the sustainable improvement of soil productivity in intensive cropping systems (Alemu and Bayo, 2005). Nutrient depletion is a reversible constraint since high agricultural productivity can still be realized if appropriate soil nutrient management that integrates use of organic and inorganic sources of nutrients is practised (Mwangi et al., 2010).

1.2. Statement of the problem

Low soil fertility is one of the most severe constraints to smallholder crop production and to sustainable food security in dry lands (Alemu and Bayo, 2005). This is attributed to continuous cultivation of fragile land and low usage of fertilizer input use among smallholder farmers probably due to high cost and unavailability of fertilizers in rural areas. The dry lands are often characterized by cyclical and persistent droughts, sometimes going for two to three years at a stretch (Ongeko, 2011) which have contributed to low agricultural productivity and to the perennial food shortages in these areas. Despite the persistent droughts in the semi-arid eastern Kenya, farmers have for years clung to maize production which is highly vulnerable to the harsh agro-ecological conditions (Esipisu, 2011). This has led to high poverty indices in the ASALs (FAO Kenya, 2007) where nearly 80% of famine alarms in Kenya are raised (KARI, 2006). There is therefore need to promote drought tolerant crop varieties among other strategies which utilize resources that are easily available to increase yields. Farm yard manure is the most commonly used source of soil amendments in the ASALs, but FYM alone cannot satisfy the crop requirements due to its low nutrient concentration and slow decomposition. Of concern also is that information on sorghum response to N and P and FYM is inadequate. There is little data available on nutrient responses by sorghum due to limited research done in this area, especially in the semi-arid parts of Kenya. Moreover, there are no specific fertilizer recommendations that have been availed to sorghum farmers. This research therefore undertook a study on sorghum production as influenced by N and P mineral fertilizers and manure to establish crop-nutrient responses and their effect on sorghum grain yield.

1.3. Study Objective

The broad objective of the study was to improve sorghum grain yield through use of sustainable soil management practices that integrate use of organic and inorganic nutrient sources.

1.3.1. Specific objectives

1. To determine the effect of inorganic fertilizer (N and P) and farm yard manure on sorghum grain yield.
2. To determine the effect of inorganic fertilizer on sorghum nutrient uptake and nutrient use efficiency.
3. To evaluate the effect of inorganic fertilizer and farm yard manure on soil bio-chemical properties.
4. To evaluate the effect of farm yard manure on moisture storage in soils and its relation to sorghum grain yield.

1.4. Hypotheses

The study hypotheses were:

1. Application of different levels of inorganic fertilizers and farm yard manure significantly improve the grain yield of sorghum.
2. Nutrient uptake and nutrient use efficiency of sorghum are significantly influenced by varying levels of inorganic fertilizers.

3. The soil microbial biomass and available soil nutrients (N and P) are positively influenced by the application of inorganic fertilizers and farm yard manure.
4. FYM application has a significant influence on moisture storage in soils.

1.5. Justification and Significance of the study

Low soil fertility and low rainfall are the most severe constraints to smallholder crop production and sustainable food security in the ASALs (Alemu and Bayo, 2005). Maintenance and improvement of soil quality in a continuous cropping system is critical to sustaining agricultural productivity and environmental quality for future generations (Reeves, 1997). To realize higher yields and high quality produce, soil health is a critical factor. Therefore, integrating chemical fertilizers with organic manures such as FYM which are eco-friendly should be considered to achieve sustainable productivity with minimum deleterious effects on soil and crops (Iqbal et al., 2012). Alemu and Bayo (2005) reported an increase in maize grain yield after application of 120 Kg N/ha and 60 Kg P/ha which gave 3.77 tons/ha as compared to 0.54 tons/ha from the control without fertilizers. Application of organic materials such as FYM has also been reported to considerably improve the soil physical properties and nutrient uptake resulting into greater crop growth, yield and yield components (Satyanarayan et al., 2002). According to Ouedrago and Mando (2010), combining organic resources and mineral fertilizers proved better in increasing crop yield than applying FYM or mineral fertilizers alone. This was also emphasized by Gikonyo and Smithson (2004), who reported an increase of between 0.46 and 1.3 tons/ha of maize yield with the integration of FYM and mineral fertilizers.

Agriculture is the backbone of Kenya's economy and is expected to remain the driver for socio-economic development for many years. The sector directly contributes up to 26% of the GDP (Mwangi et al., 2010). However, with declining soil fertility coupled with the adverse effects of climate change, more massive crop failures are expected, especially in the semi-arid regions of the country. This, therefore, calls for more drought- tolerant crop varieties to be introduced into these marginal regions as per Kenya's vision 2030. Sorghum is one of the ideal crops for such agro-ecologies. In Kenya sorghum is a very important traditional crop in the dry land areas due to its tolerance to drought, diseases and destructive striga weed and from the fact that sorghum regularly out-yields maize in these areas. The acreage of sorghum has, however, decreased over the years due to competition with other food crops such as maize, wheat, beans and rice.

The sorghum variety "Gadam" has shown improved yields in ASALs and therefore could be important for improving food security in these areas. It is a short, early maturing variety which has been reported to survive and produce grain with as low as 200 mm rainfall. Apart from being a food security crop, demand for Gadam sorghum grain is high due to its suitability for malting. East African Breweries Limited has been promoting production of the variety since 2010 for brewing (Esipisu, 2011). The demand is estimated to be about 60,000 metric tons but its production is still very low (2,000 metric tons).

1.6. Conceptual framework

Low soil fertility under this study was manifested in the soil physical and bio-chemical properties which in turn lead to low crop productivity and hence food insecurity. Through addition of FYM coupled with inorganic fertilizer (N &P) it was expected that soil physical, chemical and biological properties would be improved, hence lead to increased sorghum yields.

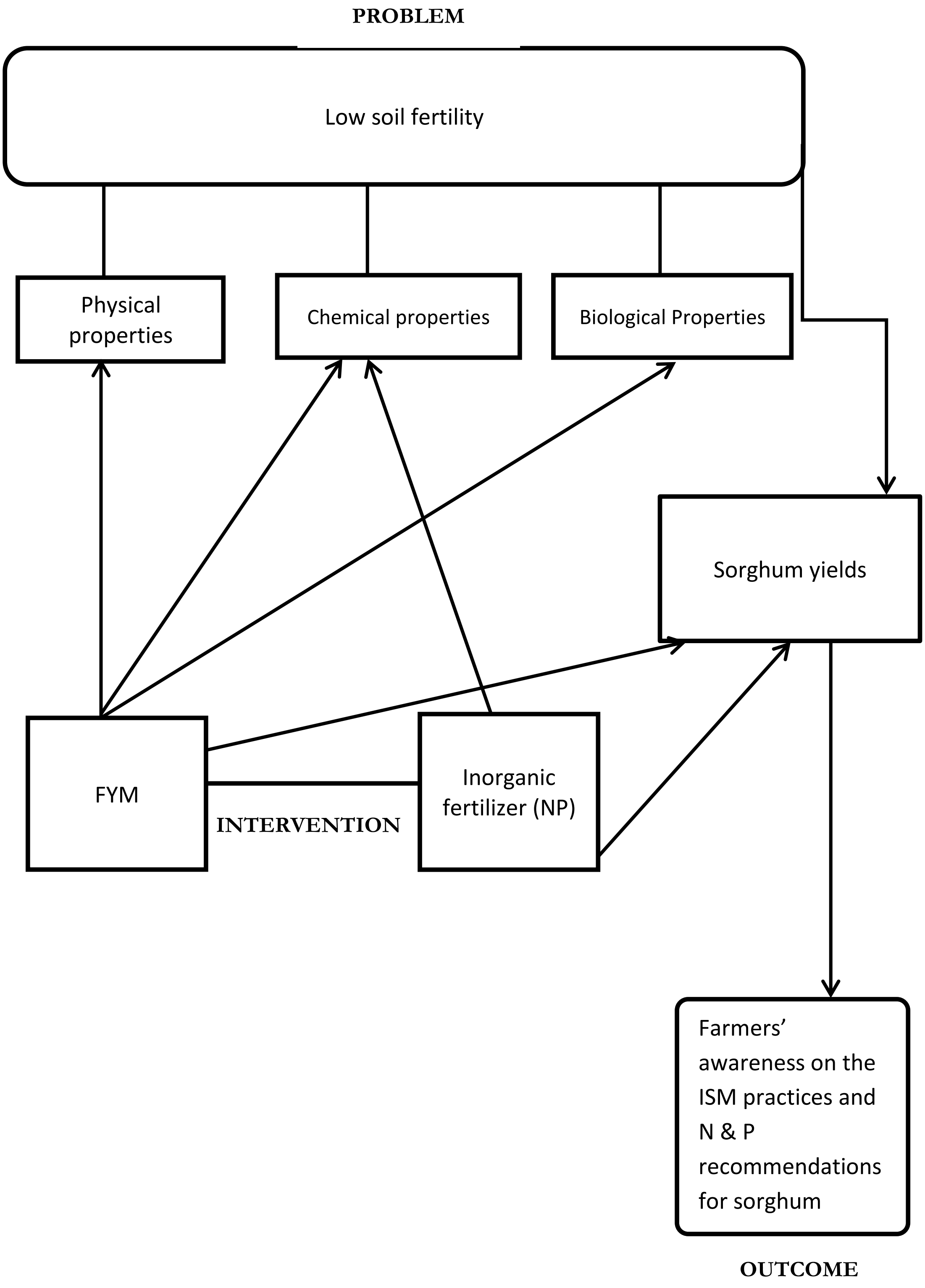

Figure 1: Conceptual framework

CHAPTER TWO

2.0. LITERATURE REVIEW

2.1. Overview of soil fertility management and rainfall patterns in dry lands

2.1.1. Overview of soil fertility management

Soil fertility refers to the inherent capacity of a soil to supply nutrients to a plant. On the other hand Integrated Soil Fertility Management (ISFM) refers to a set of agricultural practices adapted to local conditions to maximize the efficiency use of nutrient and water use to improve agricultural productivity (IFDC, 2013). The ISFM strategies centre on combined use of mineral fertilizers and locally available soil amendments such as lime, phosphate rock and organic matter (crop residues, farmyard manure, compost and green manure) to replenish lost soil nutrients. This improves both soil quality and use efficiency of fertilizers and other agro-inputs (IFDC, 2013).

Soil nutrient depletion is considered the most severe bio-physical root cause of declining per capita food production in Sub-Saharan Africa (Drechsel et al., 2001). Population growth and migration associated with drought, food shortages and land overuse have accelerated degradation of agricultural land. The main factors contributing to nutrient depletion are losses of nitrogen and phosphorus through soil erosion by wind, water, and leaching of N and K. Nutrient losses specifically due to erosion in African soils has been reported to range from 10 to 45 kg of NPK per hectare per year (Julio and Carlos, 2006).

Continuous cultivation of land in the absence of external nutrient inputs steadily reduces the nutrient stocks of land (macro and micro nutrients) through removed harvests, erosion, leaching and gaseous emissions resulting in poor crop yields. The two most depleted nutrients are N and P with annual losses estimated at 42 kg N/ha and 3-4 kg P/ha, respectively over 30 years of cropping (Smaling and Braun, 1996, Shisanya, 2003). About two thirds of Africa’s population depends on agriculture for their livelihood and all African countries except Mauritius, Reunion and Libya show negative nutrient balances every year (Julio and Carlos, 1999). The decline in soil fertility in Sub-Saharan Africa (SSA) is largely attributed to poor soil management practices (Omotayo and Chukwuka, 2009).

The effect of declining soil fertility shows on crop yields decline which is particularly visible in Africa where the most serious food security challenges exist. The low level of fertilizer use, decline in soil organic matter and insufficient attention to crop nutrient studies contribute the most to the loss of soil fertility in the region (Gruhn et al., 2000).

Declining soil fertility in Kenya has led to a decline in land productivity and for this reason land users are being encouraged to adopt soil improvement technologies. In Kenya, soil erosion, continuous cultivation, reduced land productivity, population pressure on land, low income, inappropriate and inadequate use of farm inputs such as fertilizers are some of the interrelated problems experienced by smallholder farmers (Muriu et al., 2005).

Demographic pressures and land availability constraints have partly contributed to the decline in yield growth and soil fertility. With increasing population, the traditional techniques for renewing soil fertility such as slash and burn and long-time fallowing are not as feasible as they once were. The need for subsistence is such that land can no longer be taken out of production for substantial periods to allow for nutrient replenishment (Gruhn et al., 2000).

Nutrient gains in Africa’s soils come about mainly through mineral fertilizer application, organic matter mineralisation, and nutrient deposition by precipitation and nitrogen fixation (BNF). Fertilizers tend to be used mostly on cash and plantation crops because of their high profitability and are usually meant for export to earn foreign currency. Food crops get less fertilizer because of unfavourable crop-fertilizer price ratios and financial constraints faced by farmers (Julio and Carlos, 1999). The use of organic resources for soil fertility improvement in SSA has also been in practice since earliest times and this include the application of farmyard manure, biomass transfer and also the use of legumes to replenish soil fertility (Omotayo and Chukwuka, 2009).

2.1.2. Rainfall patterns in dry lands

The definition of dry lands varies from country to country. For example in Uganda which has relatively high rainfall, if the maize crop fails once in five years, people regard the area as dry land (IIRR, 2002). There are, however, two aspects which are often used to define a dry land. They are: absolute amount of rainfall and length of wet season and the temperatures. In terms of the absolute amount of rainfall, the Convention to Combat Desertification (CCD) defines dry lands as areas with between 0 and 600 mm of rainfall per year, depending on altitude and latitude. In terms of length of wet season and the temperature, areas with less than three months of enough moisture to support plant growth and an average temperature of at least 27°C are categorized as dry lands (IIRR, 2002).

Dry lands are not homogeneous and different categories exist. Two distinct categories of dry lands can be distinguished: arid and semi-arid, and sub-dry humid wetter dry lands. The dividing line is often put at 600 mm of rain per year (Creswell and Martin, 1998; IIRR, 2002; Irungu et al., 2009). Sub-dry humid zones are categorized by low erratic and usually bi-modal rainfall of up to 1,000 mm while ASAL zones are categorized by as low as less than 200 mm per annum with periodic (every five years) droughts and different associations of vegetative cover and soils. Inter-annual rainfall can vary from 50-100% in arid zones and 20-30% in the semi-arid zones (Barrow and Mogaka, 2007).

The productivity of dry land is generally quite low compared to the high potential areas. In ASAL areas, rainfall is the limiting factor for the condition of vegetation (Barrow and Mogaka, 2007). The rainfall is low, erratic and scattered with a few heavy storms and rains may occur at times when they do not benefit crops in the fields (IIRR, 2002).

2.2. Sorghum varieties and factors affecting production

2.2.1. Sorghum varieties in Kenya

Drought events associated with climate change and climate variability have become more pronounced in Kenya in recent years adversely affecting the lives and livelihoods of smallholder farmers in ASALs (Miano et al., 2010). Although there is great potential for ASAL development, the current picture is rather grim. However, the future of ASALs need not be painted so bleak since these areas have enormous resources that can be harnessed not only to sustain themselves but also to contribute to national economic development. Focus on more drought tolerant crop varieties such as Sorghum has the potential to improve food security and contribute to economic growth.

Trials so far conducted in Kenya during the short rainy season show that sorghum has the capacity to produce higher yields than maize due to its ability to produce grain even with minimal rainfall (Taylor, 2003). Over the years, research institutions including KARI and ICRISAT have been working to produce suitable dry land crops. This has resulted in the development of genetically superior cereal and legume crops in terms of yields, early maturity and drought tolerance or drought escaping and higher water use efficiency. Among the cereals, several varieties of sorghum have been developed and released where the common ones include KARI Mtama 1, Gadam, Seredo and Serena (Table 1) (Miano et al., 2010). Table 1 shows the different sorghum varieties, their plant development (physiological) periods, potential grain yields and pests tolerance.

Table 1: Commonly grown sorghum varieties in Kenya.

Attribute	Serena	Seredo	Kari Mtama1	Gadam
Plant height	150-160 cm	150-160 cm	150-170 cm	100-130 cm
Flowering	69-78 days	65-77days	58-65 days	45-52 days
Maturity	110-120 days	110-120 days	95-100 days	85-95 days
Grain colour	Brown	Brown	White	Grey
Potential yield	1800-2300kg/ha	4000kg/ha	1800-4000 kg/ha	1700-4500kg/ha
Tolerance	Striga , drought	drought	Drought	Pests, drought
Pests	-	-	Quelea birds	Quelea birds

Source: KARI (2006)

2.2.2. Soil moisture and crop production in dry lands

Rainfall is the main source of water for raising crops in Africa despite the great variability in rainfall in semi-arid zones between years and seasons. Rain fed agriculture is the most common source of livelihood for the majority of the population in Sub-Saharan Africa (Alemau, 2012).

In agricultural water management, the most important criterion in decision making is to determine the level of soil moisture and its reliability to sustain crop growth without excessively depleting the available soil moisture. Water deficit is one of the most common environmental stresses that affects growth and development of plants. Seghatoleslami et al. (2008) reported that drought stress reduced seed yield and its components significantly. They highlighted that stress at ear emergence stage caused the greatest reduction in seed yield of millet because of pollination susceptibility to water stress. A study of pearl millet as reported by Seghatoleslami et al. (2008) indicated that seed yield in stressful and non-stress environments were 828-1136 and 3123-3942 Kg/ha, respectively.

Mahalakshmi and Bidnger (1985) as quoted by Seghatoleslami et al. (2008) reported that drought stress at seed filling stage reduced seed yield by up to 50%. Azevedo et al. (1999) concluded that available soil water and soil N are two factors of major importance in crop production.

Guang –hua et al. (2012) in a study to investigate drought induced changes of physio- biochemical parameters in maize reported that the overall effects of soil water content were found to be highly significant. Reductions in soil water content were found to lead to significant reduction of up to 25.2% grain yield.

2.3. Response of N, P and FYM on crop production

Mineral fertilizers are used to supplement the natural soil nutrient supply in order to satisfy the demand of crops with high yielding potential and produce economically viable yields. Nitrogen is a primary plant nutrient that plays a major role in achieving the maximum economic yields and is often one of the most limiting factors in soils for crop production (Blumenthal et al., 2008). This is as a result of the fact that plants absorb N in great amounts than any of the essential elements (Kotschi, 2013), though N must be balanced with other nutrients. Most plants absorb a majority of their nitrogen in the NO_3^- form and to a lesser extent in the ammonium (NH_4^+) form, however, plants growth seems to improve where a combination of ammonium and nitrate nitrogen is provided (Wopereis et al., 2006).

Plants also require adequate P from the very early stages of growth for optimum production. Phosphorus supply to the plants is, however, affected by soil P, P in fertilizer and by the soil and environmental conditions influencing P availability, and root growth such as soil acidity (Grant et al., 2005). Phosphorus is critical in biological energy transfer processes that are vital for life and growth of plants. Adequate P therefore results in higher grain production, improves crop quality, better stalk strength, increased root growth and encourages earlier maturity (Penn state extension, 2013).

Addition of inorganic fertilizer along with FYM has been reported to improve the soil structural index, infiltration rate and water retention characteristics when compared to the addition of inorganic fertilizer alone (Chandy, 2010). Mineral fertilizers on the other hand are known to increase the amount of nutrients available to plants since the nutrients are applied often in the forms available to plants. Integrating mineral fertilizers with organic manures thus improves soil health and soil productivity (Iqbal et al., 2012).

Mahmoud et al. (2009) reported that the application of organic wastes combined with or without mineral fertilizer to soil was considered a good management practice in any agricultural production system because it improves plant quality and soil fertility. They also reported that composted organic wastes could be used to substitute for around 25% of chemical nitrogen fertilizers. Mohsin et al. (2010) also stated that the integrated use of mineral and organic materials is a healthy approach for sustainable crop production and concluded that integrated use of chemical fertilizers and FYM is beneficial for improving crop yields. Mwangi et al. (2010) observed an increase in yields of maize as a result of integration of FYM and mineral fertilizer.

Achieng et al. (2010) reported that FYM had 108% grain yield advantage over mineral fertilizer in a study conducted in Western Kenya to assess the effects of FYM and inorganic fertilizer on maize production in Alfisols and Ultisols. They also revealed that FYM had 4% grain advantage over mineral fertilizer on Ultisols during the dry season because of its ability to improve the water holding capacity of a soil. This result concurred with that of Tasneem et al. (2004) who reported that different levels of organic and inorganic fertilizer significantly influenced the number of grains per cob in a study conducted to determine the effectiveness of FYM, poultry manure and N for corn productivity.

The growth and yields of maize were increased significantly with the application of enriched FYM by 40% compared to conventional FYM (Tolessa and Friesen, 2001).Wakene et al. (2001) also reported that NP fertilizers and FYM significantly increased grain yields in a study aimed at determining the optimum FYM and NP fertilizers on maize fields.

Gikonyo and Smithson (2004) reported a significant increase in yields by about 0.46 to 1.3t/ha in a study carried out to determine the effects of FYM and K and their combinations on maize yields in the high and medium rainfall areas of Kenya. Ouedrago and Mando (2010) also reported that combining organic resources and fertilizers was better in increasing crop yields than applying N fertilizer in the form of urea alone. The other factor limiting crop yield as highlighted by Gardner et al. (1994) is the low usage of phosphorus.

Alemu and Bayo (2005) reported that sorghum grain yield ranged from 0.54 tons in the control to maximum of 3.77tons grain /ha with the application of 120kg/ha N and 60 kg/ha P. This was an increase in yield of 3.23 tons/ha compared to the control treatment which was the farmers' practice (no fertilizer application). Significant differences in yield were also observed between grain yields of 0 kg/ha P and other two levels of P (30&60 kg/ha) at all levels of N except in the zero treatment of 0 kg/ha N.

Kogbe and Adediran (2003) reported that maize increased with rise in nitrogen rates. They also observed that yields declined at rates higher than 100kg/ha N applied and that maize responded well to P application. The control had the least yields that were significantly lower than the other application rates. Application of 40kg/ha P_2O_5 appeared to be the optimum since at higher rates, the yields were depressed.

Zentner et al. (1987) reported that combining N and P increased yield of wheat by up to 11% while Stewart (2003) reported a 19% reduction of sorghum yield with elimination of N fertilizer. Stewart (2003) further highlighted that average corn yield in the U.S was predicted to decline by 41% without fertilizer. Cakmak et al. (2010) and Solhi et al. (2012) concluded that nitrogen fertilization was the most influential in terms of increasing crop production and played an eminent role in plant nutrition.

2.4. Crop nutrient uptake and nutrient use efficiency

2.4.1. Crop nutrient uptake

The goal of balancing nutrient inputs with crop removals is twofold; it reduces the build-up of nutrients and addresses environmental concerns while keeping soil fertility management costs to a minimum. Actual uptake and removal of nutrients varies with crop yield, variety and soil fertility from year to year. Crop nutrient uptake is affected by soil and climatic conditions. Low soil moisture, poor aeration due to compaction or excessive moisture, low soil temperature and high lime in the root zone, nutrient imbalances and other factors may restrict uptake of plant nutrients (CFI, 1998).

Maximum nutrient uptake varies among crops and generally occurs prior to maximum growth rates but plants require a balanced supply of nutrients throughout their development (Jones et al., 2011). These authors also reported that low nutrient uptake in the early stages of plant growth lowers nutrient quantity for the seed affecting both yield and quality. Crop nutrient uptake rates are different at each growth stage and crop growth rates vary with crop, variety and growing conditions. Sanchez and Doerge (1999) and Jones et al. (2011) also reported that timing the application of nutrients so that they are available before peak crop nutrient demand is critical. Adequate nutrients early in the growing season are necessary to maximize yield and ensure that especially N and P are available for good grain and seed fill.

Nutrient uptake is dependent on both the ability of the roots to absorb nutrients and the concentration at the surface of the roots. Roots spread out both laterally and vertically as the plant grows to take advantage of areas within the soil that have more water and nutrients. Nutrient uptake varies with stage of plant growth (Jones and Jacobsen, 2001).

Plants have been reported to have difficulty in absorbing nutrients in dry soil because most nutrients are elemental and not in ionic forms. Therefore during the dry seasons, nutrient levels in plant tissues may be lower than normal (Sanchez and Doerge, 1999). Potassium and other nutrient deficiencies commonly occur in crops during dry years even though the soil test shows adequate amounts. Tillage practices are also reported to influence soil temperature, moisture and aeration which eventually affect nutrient uptake. Fertilizer placement may also influence nutrient availability and may depending upon conditions, either enhance or reduce nutrient uptake (Jones et al., 2011).

Mahamoud et al. (1980), as quoted by Malathesh (2005) reported that P uptake increased at different growth stages of maize with increasing rates of nitrogen and phosphorus. Nitroge N concentration of maize grain ranged between 1.36 and 1.75 and P concentration between 0.15 and 0.22 percent, with nitrogen rates of 5 to 200kg/ha. Under irrigated conditions the relative N uptake was related to fertilizer application and soil nitrate concentration. N concentration in maize stalk was increased by N fertilizer application up to 300kg/ha (Malathesh, 2005). Similarly the N amount in the grains of maize generally increased with increasing nitrogen application.

Sharma (1983) as quoted by Malathesh (2005) found out that addition of FYM at 12t/ha along with fertilizer levels of up to 60kg N, 30kg P_2O_5 and 30kg K_2O per hectare significantly improved the nitrogen uptake by the maize crop. Mahmoud et al. (2009) reported that the increase of N uptake appeared to be more obvious when compost was mixed with the mineral N fertilizer as compared to the 100% compost or 100% N mineral fertilizer alone on improving soil physical properties or to a higher mineralization of composts which is due to mineral N inputs.

Crop response to P depends on the availability of P in the soil solution and the ability of the crop to take it up. The ability of a plant to take up P depends on its root distribution relative to P location in the soil. This is because P is highly immobile in soil and does not move far in the soil to get to the roots. The diffusion rate to the roots is about 1/8 of an inch per year (Penn state extension, 2013).

2.4.2. Nutrient use efficiency

Efficient use of nutrients in agriculture may be defined differently when viewed from agronomic, economic or environmental perspectives (Mikkelsen, 2005). Nutrient use efficiency can be expressed in several ways: by partial factor productivity (PFP, Kg crop yield per kg nutrient applied); Agronomic Efficiency (AE, kg crop yield increase per kg nutrient applied); Apparent Recovery Efficiency (RE, kg nutrient taken up per kg nutrient applied) and Physiological Efficiency (PE, kg yield increase per kg nutrient taken up) (Roberts, 2008).

Estimates of fertilizer use efficiency usually differ depending upon the climate, crop and soil conditions and fertilizer parameters (fertilizer kind, rate, time and method of application) and management practices (Munir et al., 2006). Over or under application of fertilizer result in reduced nutrient use efficiency or losses in yield and crop quality. Soil testing is thus crucial for determining the nutrient supplying capacity of the soil and also for making appropriate fertilizer recommendations (Roberts, 2008). Roberts (2008) emphasized that great synchrony between crop demand and nutrient supply is necessary to improve nutrient use efficiency, especially for N.

Nitrogen Use Efficiency (NUE) is a term used to indicate the ratio between the amount of fertilizer N removed from the field by the crop and the amount of fertilizer N applied (Brentrup and Palliere, 2010). Crop removal efficiency that is removal of nutrient in harvested crop as a percentage of nutrients applied) is commonly used to explain further the nutrient use efficiency (Roberts, 2008). Berral et al. (2002) reported that at 50kg N/ha the improved genotype of sorghum had the highest NUE. Kayuki et al. (2012) reported that at very high N application rate the NUE declined despite the slight increase in grain yield and this had earlier been reported by Kogbe and Adideran (2003). Oikeh et al. (2007) reported that nitrogen utilization efficiency was lowest for sorghum with 12 to 19 kg grain per kg N applied. Maranville et al. (2002) added that nitrogen use efficiency (grain weight per unit of N supplied from soil and/or fertilizer) is reduced due to poor crop cultural practices, sub-optimal yields and N losses or deficiency of other nutrients.

The efficiency of fertilizer P use by crops ranges from 10 to 30% in the year that is applied. The remaining 70 to 90% becomes part of the P pool which is released to the crop over the following months and years (Malhi et al., 2002 and Johnston and Syres, 2009). Phosphorus use efficiency is sometimes measured by expressing total P uptake as a percentage of the P applied (Syres et al., 2008). Kogbe and Adediran (2003) reported that PUE increased until 40kg/ha but declined with increase in P application in the soil. Application of 40 kg P_2O_5 /ha appeared to be the optimum since at higher rates, the yields were depressed.

2.5. Effect of manure application on nutrient availability and soil moisture content

Farmyard manure consists of three main components namely, litter, like straw or other vegetable refuse, dung and urine of animals. Composition of FYM varies according to the composition of these components and the proportion in which they are present. The proportion of litter to manure material influences the decomposition of the mixture and the ultimate composition of the manure produced (Chandy, 2010).

The organic matter supplied to the soil through FYM accelerates the formation of granular or crumbly structure of the soil. The ability of manure to promote the formation of water stable aggregates has a profound effect on soil structure and soil physical characteristics. A high percentage of water stable aggregates increase infiltration, porosity, and water holding capacity. Water stable aggregates are also associated with decrease in compaction and erosion

(Bloom et al., 1999). In sandy soils organic matter helps the granulation of particles thereby enhancing water and nutrient retaining capacity of these soils. Humus on the other hand imparts grey colour or slightly black colour to the soil thereby helping the soil absorb greater amount of radiation which is necessary to maintain appropriate soil temperature of the soil. Humus also better withstands fluctuations in the soil temperature (Chandy, 2010).

Studies by Angers (1998) as quoted by Bloom et al. (1999) reported that even in silt clay soils with high organic matter contents, the addition of manure increases macro-aggregation which helps prevent structural degradation. Through improvement on soil physical properties, manure application also reduces the energy required for tillage and the impedance to seedling emergence and root penetration.

Nareed et al. (2010) also highlighted that the use of FYM significantly decreases the soil bulk density and improves aeration, water holding capacity and soil porosity. The density of organic matter itself is low and its mixture with the soil virtually reduces the density of the soil. This is also supported by Shirani et al. (2002), who observed that the total porosity of a soil increases with the use of FYM especially after the first harvest.

FYM also enhances infiltration and reduces soil crusting and compaction. It also reduces surface runoff during the initial stages of rainfall thus reducing the rate of soil erosion (Biamah et al., 2003). Application of FYM brings about rapid increase in chemical activities of the soil. During decomposition of FYM numerous organic acids are released and synthesized. The CO_2 liberated during decomposition dissolves in water to form hydro carbonic acid. The soil solution becomes acidic for a short period and helps in solubilisation of native nutrients attached to the soil minerals that become available to plants (Chandy, 2010).

According to Abasi et al. (2007) as quoted by Mubarak et al. (2010) variations of N mineralization among manures were strongly related to their initial contents of N, lignin, C/N ratio and lignin/ N ratios and concluded that soil is also an important parameter in determining N mineralization. Mubarak et al. (2010), reported that transformations of N in soil, including indigenous soil N and applied manure N are strongly controlled by the interaction of environmental and soil factors and by the composition or quality of the substrate.

C/N ratios are important. Plant and animal residues that have C: N ratios of 30:1 and above have little N to allow for rapid decomposition. Therefore the microorganisms will take NH_4^+ and NO_3^- out of the soil to fuel decomposition which depletes the soil of these elements. Plant and animal residues with low C/N ratios (20:1 and less) have sufficient N for the microorganisms to decompose the residues without taking from the soil (Goings, 1999).

Nahm (2004) reported that decreasing the C/N ratio increases N mineralization rate. At C/N ratios below 15:1 he observed an increase in net mineralization and also found that organic materials with C/N ratio of 15:1 or more was likely to cause net immobilization.

Ghoshal (2002) found out that application of FYM not only increased the rate of supply and pool size of available N in the dry land but it also sustained the enhanced N pool throughout the annual cycle. FYM conserves N during the initial phase of crop cycle thus reducing N loss and providing better synchronisation of N availability and crop demand during the latter part of the annual cycle.

Mohanty et al. (2010) found out that N mineralization from crop residues is influenced by the concentration of N, hemicellulose, lignin and C/N ratio. They also pointed out the fact that manures are different from crop residues as they vary greatly in composition being a complex of animal excreta and plant residues with varied mineralization kinetics ranging from relatively resistant lignin to readily available NH_4^+ and volatile fatty acids.

While the value of manure as a source of nutrient or soil amendment is recognized, the potential of manure to neutralize soil acidity is less well known (Bloom et al., 1999; Chandy, 2010). Long term field and greenhouse studies have demonstrated the liming effect of animal manure in acid and neutral soils (Bloom et al., 1999). Organic matter supplied by FYM develops buffering capacity in the soil thereby suppressing the effect of pH variation on plant growth. Saline and alkaline soils can also be amended by continuous application of FYM for years (Chandy, 2010; Keshavarz et al., 2012).

The main reason why manure raises soil pH is not only in buffering H^+ ions but also due to release of nutrients such as Calcium and Magnesium that are contained in the manure. For example, poultry manure contains 50 kg Ca and

Mg on a dry weight basis. Therefore applying manure to acid soils not only supplies nutrients needed for plant growth but also reduces soil acidity, thus improving P availability and reducing Al toxicity (Bloom et al., 1999). Applying FYM has also been reported to increase electrical conductivity of the soil, organic carbon and soil moisture content of cold tolerant sorghum in the dry highlands of Kenya (Ashiono et al., 2006).

2.6. Effect of manure application on soil microbial biomass

Research has shown that manure application has a significant effect on soil chemical, physical and biological properties. Most of these effects are due to an increase in organic matter with manure application (Bloom et al., 1999). Soil is a habitat for numerous organisms that feed on organic matter applied to the soil as source for their energy and body synthesis. Application of FYM is immediately followed by a marked increase in microbial population of the soil. Yagathjoth et al. (2008) reported that soil microbial population is enhanced with the addition of organic materials. Addition of FYM was also reported to increase the activities of soil microorganisms as compared to the addition of inorganic fertilizer alone (Yagathjoth et al., 2008).

A healthy microbial population is essential for the important bio-chemical changes taking place in the soil. The cycles that permit nutrients to flow from soil to plant are all interdependent and proceed only with the help of living organisms that contribute to the soil community. Their presence is therefore essential for a healthy ecosystem (Chandy, 2010).

CHAPTER THREE

3.0. MATERIALS AND METHODS

3.1. Description of the study sites

This study was conducted in two sites; one at Kampi ya Mawe in Makueni County and Katumani in Machakos county, Kenya.

3.1.1. Kampi ya Mawe, Makueni County

Makueni County is located in the South-eastern rangelands of Kenya and has a population of approximately 884,527 people with a growth rate of 2.8 % (GoK, 2011). The county occupies an area of 7965.8 km^2 and altitude ranges from 600 m in Tsavo at the Southern end of the county to 1900 m above sea level in Mbooni and Kilungu hills. Makueni County lies at latitude 1° 35´S and stretches from longitude 37°10´E to 38°30´E. The county is mainly semi-arid and is characterized by hot and dry climate for most of the year. Approximately 64% of the residents live below the poverty line and this is mostly attributed to low and unreliable rainfall.

There are thirteen agro-ecological zones in the county ranging from lower highland zone LH2 in Chyullu hills to lowland zone L6 or IL6 where the risk of maize crop failure is 25-75%. Kampi ya Mawe is located in transitional zone between agro ecological zones IV and V and is dominated by Chromic Luvisols (Siderious and Muchena, 1977). The county experiences two rainy seasons with long rains occurring in March/April while the short rains occur in November/December with marked spatial and temporal variation in amounts received. The hilly northern parts of the county receive annual rainfall of 800-

1200 mm while the drier southern parts receive low rainfall of up to 200 mm. About 22% of the county is considered arable. The temperature range is from 20 to 24°C.

The three main types of soil present in the county are: red clays found on the hills and part of the lowlands, sandy soils found mainly in the central parts including Kathonzweni, and black cotton soils that dominate the southern parts. The soils are of low to moderate fertility and are moderate to slightly acidic. According to FAO classification (1970), the soils are classified as Orthic Acrisols, Ferric Luvisols, Cambic Arenosols, Chromic Nitosols and Eutric Nitosols (Muchena, 1975). Makueni County is a food deficit region. Food production is low and has marked fluctuations due to unreliable rainfall. In 2005 Makueni produced only 9% of its estimated annual cereal demand of 127,720 metric tonnes (FAO Kenya, 2007).

3.1.2. Katumani, Machakos County

Machakos county has a population of 1,098,584 (GoK, 2011). The terrain is hilly and the altitude ranges from 1000 to 1600 metres above the sea level. It stretches from latitudes 0°45´S to 1°31´S and longitudes 36°45´ E to 37°45´E.

Machakos County covers an area of 6281.4 Km^2 most of which is semi-arid. High potential areas in the county where rain-fed agriculture is carried out consists of 1574 Km^2 or 26% of the total area. Approximately 59.6% of the population in the county live below the poverty line and the county is reported to account for 4.4% of national poverty (GoK, 2011). The soils of Machakos County reflect the largely metamorphic parent material and rainfall regimes which contribute to their formation. The dominant soil groups are Alfisols, Ultisols, Oxisols and lithic soils (FAO, 1970). The soils are generally of low fertility and many are highly erodible while less than 20% of the soils are well drained. The dominant vegetation is dry bush with trees and in the higher areas savannah with scattered trees. Katumani is located in agro ecological zone IV and is dominated by Chromic Luvisols soils (Siderious and Muchena, 1977).

Farming in the County is mainly subsistence-oriented with cultivation of crops such as maize, beans, pigeon peas and sorghum. The average farming household in the lowlands of Machakos has a freehold smallholding of about 2.5 ha and earns roughly 22% of its total income from agricultural activities. The risk of maize crop failure is high in the County. For example in 2006 maize productivity was estimated at 182.7 kg/ha from a total area of 152,000 hectares while for sorghum was 299.6 kg/ha with a total hectare of 6700 ha (FAO Kenya, 2007).

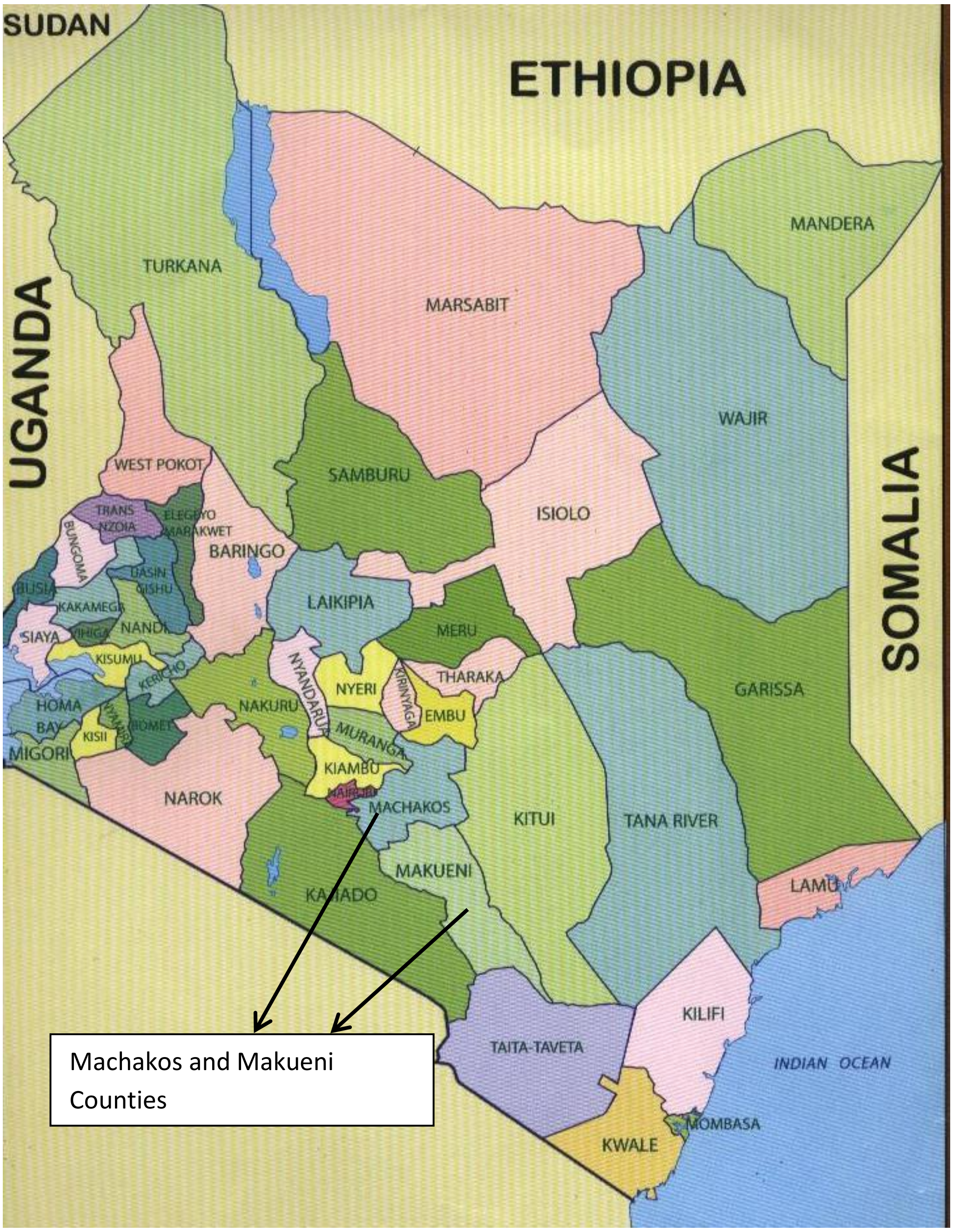

Figure 2: Map showing the study area (source: internet)

3.2. Initial soil fertility status

The initial soil fertility status of the two sites was as shown in Table 3. The soils in both sites were moderately acidic. Before the beginning of the experiment, soil samples were taken from the experimental sites for initial bio-chemical-physical soil property analysis. Composite samples of top soil (0-20 cm) and sub-soil (20-40 cm) and (40-60 cm) were taken using a soil auger, based on the Y-sampling frame. Samples were put in labelled polythene bags (site, time, trial number, plot number and depth). The composite soil samples were analysed for Total C, Total N, available P, available N (NO_3^- and NH_4^+), Cations (Ca, K, and Na), soil pH and microbial population (bacteria and fungi).

3.3. Rainfall status during the season

Rainfall data during the experimental period (Fig.3) was obtained from the respective meteorological stations and the data was used to relate to sorghum yields in both sites. Total rainfall amounts were higher in Kampi ya Mawe (543.3 mm) than in Katumani (152.3 mm) throughout the experimental period.

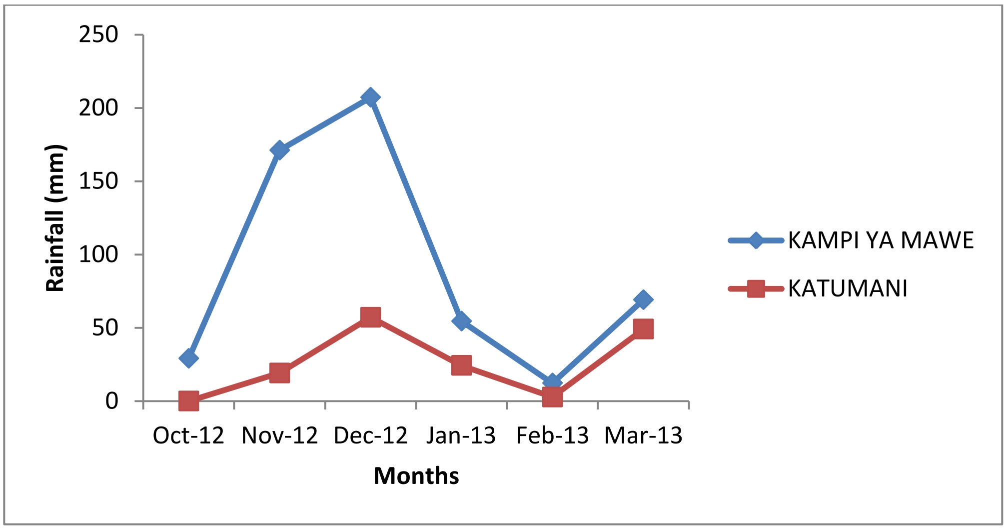

Figure 3: Rainfall pattern for Kampi ya Mawe and Katumani during the 2012/13 short rain growing season.

3.4. Experimental field design and treatments layout

Treatments were in a factorial design arranged in a Randomized Complete Block Design (RCBD). Sorghum, Gadam variety, was planted as the test crop and was grown as a sole crop. The study consisted of two experiments. The first experiment had two factors namely: Nitrogen and Phosphorus each at four levels (0, 25, 50 and 75 Kg/ha) and the second experiment had also two factors that is NP fertilizer at two levels (0 and 50 Kg/ha each) and FYM at three levels (0, 5 and 10 ton/ha). The treatments were replicated three times for each experiment. The details of the treatments are as shown in Table 3.

Table 2: Inorganic N and P fertilizer treatments in experiment 1 and FYM and NP in experiment 2.

TREATMENT	**Fertilizer levels (Kg/Ha)**	
	N	**P**
T1	0	0
T2	0	25
T3	0	50
T4	0	75
T5	25	0
T6	25	25
T7	25	50
T8	25	75
T9	50	0
T10	50	25
T11	50	50
T12	50	75
T13	75	0
T14	75	25
T15	75	50
T16	75	75

FYM and NP Fertilizers Treatments in Experiment Two

	NP kg/ha	FYM ton/ha
T1	0	0
T2	0	5
T3	0	10
T4	50	0
T5	50	5
T6	50	10

3.5. Land preparation and experimental set-up

The trials were established at both sites during the short rain season (October 2012 to March 2013). Land was prepared using ox-plough to approximately a depth of 20 cm. The size of each plot was 4.5 x 4.5 m with spacing of 75cm between the rows and 20 cm within the rows. Gadam sorghum seeds obtained from KARI Katumani Seed Unit were used. Five seeds were planted per hole and thinned to two 10 days after emergence. Triple Super Phosphate (TSP) was applied at planting and was placed in the planting holes while Calcium Ammonium Nitrate (CAN) was top-dressed four weeks after emergence. Farm yard manure was applied at planting and was placed in the prepared holes where it was mixed thoroughly with soil. Fertilizers were pre-weighed for each plot before going to the field and applied using dollop cups to ensure uniform distribution within the plot. Weeding was done two times during the growth period and insect pest control was carried out to eradicate stem borers using Bulldock (R).

3.6. Soil sampling and management

To monitor the dynamic changes of available N and P, and soil moisture content, soil sampling was done three times during crop growth period. That was at four weeks after emergence, at heading and at maturity stages of sorghum. Initially, soil sampling had been done at the beginning of the experiment before planting for initial soil properties status and another sampling was done at the end of the experiment for comparison purposes to evaluate soil property changes due to treatments. The soil properties analysed included soil pH, soil total carbon, total nitrogen, available nitrogen (NH_4^++NO_3^-), available P, calcium, magnesium, sodium and potassium. Microbial population (bacteria and fungi biomass) was also determined at the beginning of the experiment and at the end of the experiment in manure fertilized plots only. Bulk density and soil texture were determined at the beginning of the experiment.

3.7. Lab analysis

3.7.1. Soil pH analysis

Ten grams of soil sample was weighed in a 50 ml beaker then 25 ml of distilled water (for pH water) was added using a pipette. The mixture was stirred and allowed to stand for one hour. The pH value was then measured using a pH meter (Okalebo et al., 2002). The electrode was rinsed with distilled water between samples. A similar procedure was followed using 1M KCl instead of distilled water for pH KCl (potential pH). (To obtain 1M KCl, 74.56 g KCl was dissolved in 1litre volumetric flask with distilled water and filled up to the one litre mark).

3.7.2. Soil texture analysis

Hydrometer method was used for soil particle size analysis (Okalebo et al., 2002). A sample of 50g of air dried soil was weighed out into a 400 ml beaker and was saturated with distilled water before adding 10 ml of 10% calgon solution. The suspension was transferred to the dispersing cup and added about 300 ml of tap water. The suspension was mixed for 2 min with an electric high speed stirrer then transferred into a graduated cylinder. The cylinder was covered with a tight-fitting rubber band and the suspension was mixed by inverting the cylinder carefully ten times. The time was noted and 2-3 drops of amyl alcohol were quickly added in order to remove froth and after 20 seconds the hydrometer was gently placed into the column. The hydrometer readings and thermometer measurements at 40 seconds were recorded. The cylinder was covered again with a tight-rubber bung and the suspension was mixed by inverting the cylinder ten times and allowed to stand undisturbed for 2 hours after which both hydrometer and temperature readings were taken. The percentage sand, silt and clay were then calculated using the formulas in the Appendix V.

3.7.3. Total Nitrogen and total Carbon in soil

Total nitrogen and total carbon in the soil were determined at the beginning and at the end of the experiment. Both total N and total C in the soil were determined using the flash combustion method using the CN Elemental

Analyzer (Krotz et al., 2013). Fifty milligrams of soil was weighed in a tin capsule. This was done twice: once after filling the tin capsule and again after folding the tin capsule. The weight of each sample was recorded in the sample table which is contained in the Eager Experience Software which calculates and records the data as obtained from the CN analyzer. The flash elemental analyzer system completely oxidizes the sample with a catalyst through combustion. It is then further reduced to CO_2, N_2 and H_2O under high temperature reactor chambers. The solid sample was wrapped inside a tin capsule and placed into a steel column through an auto sampler. The tin capsule containing the sample was burned in a pure oxygen environment. The carbon in the sample was converted into carbon dioxide, nitrogen into free air or oxides and hydrogen to water.

A stream of helium gas carried those gases into a quartz column (which carries the reduction processes) filled with copper that reduced the nitrogen oxides to nitrogen and removes excess oxygen.

The gas stream then flowed through a magnesium perchlorate trap (adsorption filter) which removed water before CO_2 and N_2 went into a gas chromatograph (GC) column at room temperature. N_2 then flowed through the gas chromatograph column first (retention time -110 seconds) then CO_2 (retention time- 190s) and the thermal detector (TD) was used to give the quantative data (in percentages). Helium is used as a carrier gas because it is chemically inert.

3.7.4. Soil available nitrogen (NH_4^+ and NO_3^-)

Soil mineral nitrogen (NH_4^+ and NO_3^-) was determined using the flow injection method using the Flow Injection Analyzer (FIA). The method uses cadmium reductor for nitrates and gas diffusion method for ammonium (FOSS Analytical, 2010). Nitrates in the soil sample were extracted by 2 M KCl. Five grams of air-dried soil was weighed into a 50 ml polythene bottle and 25 ml of 2 M KCl was added and mechanically shaken for one hour. The suspension was centrifuged and filtered through Whatman No.1 filter paper and the filtrate was then introduced into the flow injection system. The procedure for determination of nitrates is reduction to nitrite in a cadmium reductor. (Nitrates are reduced into nitrites because nitrates cannot react with sulphanilamide). The nitrites reacted with sulphanilamide to form a diazo-compound which further reacted with NED to form an Azo dye (pink in colour) whose absorbance was read at 540 nm. The intensity of the colour corresponds to the amount of nitrates in the soil extract. The results obtained were in ppm units. Hence to obtain ppm in the soil, the following formula was used:

$$w = (C x V)/W$$

Where:

w= mg NO_3^--N/kg soil

C= concentration nitrate as mg/l NO_3^--N

V= volume of the extract in ml

W= weight of the sample in g

For ammonium, the soil was extracted by 2 M KCl. Five grams of air-dried soil was weighed in 50 ml polythene bottle and 25 ml of 2 M KCl was added and shaken mechanically for one hour. The suspension was then transferred into centrifuge tubes and centrifuged for 5 minutes then filtered through Whatman No. 1 filter paper to obtain a clear filtrate. The filtrate was then introduced into the flow injection system. The soil sample extract was injected into a carrier stream which is merged with sodium hydroxide stream. In the resulting alkaline stream gaseous ammonia is formed which diffused through a gas permeable membrane into an indicator stream. The indicator stream which comprises of a mixture of acid-base indicators reacted with ammonia gas. A colour shift resulted which was measured photometrically at 590 nm. The results were expressed in mg NH_4^+-N mg/kg (ppm) sample using the following formula:

$$w = (c x v)/W$$

Where:

w= mg NH_4-N/kg soil (ppm)

c= concentration ammonium as mg/l NH_4-N

W= weight of soil sample in g

3.7.5. Available P in soil

The Mehlich1 double acid extraction method was used for the determination of available P (Moore, 1992; Kissel and Sonon, 2008 and Savoy, 2009). The dried soil was extracted in 1:5 ratios (w/v) with a mixture of 0.1 N HCl and

0.025 N H_2SO_4 solutions. The hydrochloric acid serves to replace the bulk exchangeable metal cations. (The sulphate ions in the acid medium fulfil the replacement of the soluble P available to plants which is held in exchangeable form).

Five grams of dried soil was weighed in 50 ml polythene bottle and 25 ml of extracting solution was added. The suspension was shaken mechanically for one hour and then transferred into centrifuge tubes and centrifuged for 5 minutes which was then filtered through Whatman No.1 filter paper to obtain a clear filtrate. Five milli litres of working standard series, soil extract and blank were pipetted in test tubes. One milli litre of ammonium vanadate-molybdate mixture was added and mixed well and its optical density read on the UV-Visible spectrophotometer after one hour at 430 nm. To obtain the concentration of P in the soil (ppm), the ppm in solution obtained from the UV-Visible spectrophotometer was multiplied by the dilution factor, which is the ratio of soil sample in grams to the extracting solution which in this case was the ratio 1:5 obtained from 5 g of soil sample in 25 ml extracting solution.

3.7.6. Magnesium in the soil

Measurement of the level of magnesium in the soil was done at the beginning and at the end of the experiment. The concentration of magnesium in the soil was determined using the Mehlich1 double acid extraction method (Kissel and Sonon, 2008 and Savoy, 2009). Five grams of dried soil was weighed in 50 ml polythene bottles and 25 ml of extracting solution (0.1N HCl and 0.025 N H_2SO_4) was added. The suspension was then shaken mechanically for one hour and transferred to centrifuge tubes where it was centrifuged for 5 minutes and then filtered through Whatman No.1 filter paper to obtain a clear filtrate. One milli litre of the extract was then pipetted into test tubes. Five milli litres of magnesium compensating solution was added, followed by 2 ml titan yellow and 2 ml sodium hydroxide mixing after each addition. The optical density was then read on the UV-Visible spectrophotometer after one hour at 540 nm.

3.7.7. Ca, K and Na in soil

To assess the fertility of the soil, Ca, Na and K were determined at the beginning and at the end of the experiment. The method used was the Mehlich1 double acid extraction method (Kissel and Sonon, 2008 and Savoy, 2009). Five grams of soil sample was weighed into 50ml polythene bottle and 25ml extracting solution was added (0.1 N HCl and 0.025 N H_2SO_4). The suspension was mechanically shaken for one hour and then transferred to centrifuge tubes where it was centrifuged for 5 minutes and then filtered through Whatman No.1 filter paper to obtain a clear filtrate. The concentrations of the cations in the soil extract were then measured using the flame photometer. A calibration graph was obtained from the working standard series against elements (Ca, K and Na) concentrations (in me/100g soil) from which the concentrations of cations were read.

3.7.8. Exchangeable acidity in soil

The determination of exchangeable acidity (H^+ and Al^{3+}) was done by weighing 5 g of soil sample which was leached using potassium chloride (K^+ ions replace exchangeable H^+ and Al^{3+} held against permanent negative charges of the exchange complex). The total exchangeable acidity (H^+ and Al^{3+}) was determined by titrating with NaOH. The amount in milli litres of NaOH needed to bring the potassium chloride back to its original pH is equivalent to the amount in milligram-equivalent (me) of hydrogen and Aluminium exchanged. Seventy five milli litres of 1 M KCl solution was used for leaching. To the filtrate, 2-3 drops of phenolphthalein indicator were added and filtrate was titrated with 0.05 N NaOH until the colour changed from colourless to pink. The burette readings were recorded (ml) of NaOH used. The amount of NaOH used for reaction, that is bringing back to original pH was equivalent to amount of H^+ and Al^{3+} exchanged and was calculated. Each ml of NaOH used is equivalent to milli equivalent per 100 g of soil.

3.7.9. Population in soil (bacteria and fungi)

The measurement of microbial population was done at the beginning and at the end of the experiment in the manure fertilized plots. Both bacteria and fungi in the soil samples were determined using the dilution plate counting method (Ogunmwoyi et al., 2008). For the determination of bacteria in the soil, 39 g of Nutrient Agar (NA) was dissolved in 1000 ml conical flask of deionized water to prepare a bacteria growth medium. The mixture was then autoclaved for about one hour and dispensed into petri dishes and 0.1 ml of the diluted soil sample was then spread on the plates containing nutrient agar (three replicates per sample). To serial dilute the soil sample, 9 ml of distilled water was measured using a measuring cylinder into test tubes and covered with cotton wool and Aluminium foil to prevent contamination. This was also autoclaved for about one hour for sterilization. One gram of the soil sample was then dissolved into the 9 ml sterilized deionized water and shaken thoroughly. Serial dilution was then done until the fifth dilution. The first dilution was spread on the nutrient agar dispensed on petri dishes which were incubated for 12 hours in an oven at 37°C for bacteria to grow. A colon counter was then used to count the number of colonies in each petri dish and the mean was determined for each sample.

The determination of fungi population in the soil also followed the same procedure as that of determining bacteria population in the soil except that the growth medium for fungi was Potato Dextrose Agar (PDA) instead of nutrient agar (NA). Twenty eight grams of PDA was dissolved in 1000 ml deionized water in a conical flask. After spreading the diluted soil sample on the petri dishes containing dispensed PDA, it was incubated for 120 hours after which the colonies were counted using a colony counter. The number of colonies in the soil solution was then converted to the number of colonies per gram of soil.

3.7.10. Soil moisture content

The determination of soil moisture content was done gravimetrically. A known weight of soil sample was put in a beaker of a known weight and was oven dried at 105°C for 24 hours until the soil sample in the beaker reached a constant weight which was then weighed. The mass of water was determined by subtracting the final weight from the initial weight and then expressed as a percentage of the dry weight.

3.8. Plant tissue sampling and analysis

3.8.1. Plant tissue sampling

The plant tissue sampling was done three times according to crop growth stages, namely: seedling stage (four weeks after emergence), at heading and at the maturity stage (grains). The samples were dried at 70°C for 48 hours. The dried plant materials and sorghum grains were milled using 0.5mm sieve and were analyzed for total nitrogen. Consistent labelling of sorghum plant tissues with site, plot, and date and sample type was used throughout the sampling process.

3.8.2. Analysis of total N in plants

The method used for the determination of total N in plant tissues was the flash combustion method using CN Elemental Analyzer. Five milli grams of dried and milled plant tissue sample was weighed into a tin capsule which was then folded and its weight recorded using tweezers to avoid contamination using hands. The samples were then placed into a steel column using an auto sampler. The tin capsule containing the plant sample was then burned in a pure oxygen environment. (The flash elemental analyser completely oxidizes the sample with a catalyst through combustion and further reduced to produce CO_2, N_2 and H_2O under high temperature reactor chambers). The rest of the procedures are as described in section 3.7.3.

3.9. Determination of Nutrient Use Efficiency

Agronomic nutrient use efficiency was determined to assess the efficiency of sorghum in utilizing nutrients. The formula used to determine Agronomic Efficiency (AE) was as described by Rajendra (2009).

$$\boldsymbol{AE = (yf - yc)/Na}$$

$\boldsymbol{AE}$= kg grain/ kg nutrient applied

Where:

$\boldsymbol{yf}$= yields in fertilized plots (kg/ha)

$\boldsymbol{yc}$= yields in control plots (kg/ha)

$\boldsymbol{Na}$= amount of nutrient applied (kg/ha)

$\boldsymbol{AE}$= is the same as crop response ratio or Agronomic Efficiency

3.10. Statistical Analysis

Data was subjected to analysis of variance (ANOVA) using SAS for windows software (version 9.0) at 5% confidence interval (p=0.05). The different means were separated using the Least Significant Difference (LSD) test (Mugenda and Mugenda, 2003; Kothari, 2004 and Abunyewa, 2008). The data was also subjected to correlation and regression analyses to draw existing relationships between variables and to determine the extent of the existing relationships between variables.

CHAPTER FOUR

4.0. RESULTS AND DISCUSSION

4.1. Overview of results presentation

The results of this study are presented as follows: section 4.2 Initial soil status and rainfall pattern, 4.3 Effect of treatments on sorghum grain yield, 4.4 Effect of treatments on sorghum nutrient uptake, 4.5 Effect of treatments on nutrient use efficiency, 4.6 Effect of treatments on bio-chemical soil properties, 4.7 Effect of FYM on soil moisture content and section 4.8 Effect of FYM on nutrient concentrations in the soil at different stages of sorghum growth.

4.2. Initial soil fertility status and rainfall pattern of Kampi ya Mawe and Katumani

4.2.1. Soil physical and bio-chemical properties

The initial soil fertility status analysis results of the two sites, Kampi ya Mawe and Katumani are shown in Table 3.The soils were poor in N and P. The pH was slight to moderately acidic (6.2- 4.9) while exchangeable acidity ranged between 1.9 and 1.1 me for Katumani soils and between 2.3 and 1.7 me/100g of soil for Kampi ya Mawe soils with both decreasing with depth. Organic carbon in both soils was extremely low and ranged between 0.3 and 0.89%. The soil at Katumani was classified as Sandy Clay Loam (SCL) while that at Kampi ya Mawe were classified as Sandy Loam (SL). The bacteria population was higher in the soil at both sites than fungi population and the microbial population generally decreased with depth.

Table 3: Initial soil fertility status.

PROPERTY	KATUMANI			KAMPI YA MAWE		
	0-20CM	**20-40CM**	**40-60CM**	**0-20CM**	**20-40CM**	**40-60CM**
pH water	5.90	6.00	6.17	4.88	4.88	4.80
pH KCl	5.79	5.89	6.02	4.58	4.57	4.37
N-NO3- mg/kg	12.64	10.38	6.50	11.40	12.57	4.17
N-NH4- mg/kg	4.73	4.17	3.98	3.91	3.95	3.967
Available P-mg/kg	12	6	6	24.57	10.60	12.26
Na(mg/kg)	7.35	9.15	8.55	9.82	8.17	9.36
Mg(mg/kg)	17.6	25.6	30.6	1.45	1.62	1.55
Ca(mg/kg)	48	32	36	35	34	48
K(mg/kg)	39.8	22.6	14.8	66.22	52.20	43.28
Total N (%)	0.09	0.05	0.06	0.04	0.05	0.054
Total C (%)	0.59	0.30	0.38	0.67	0.89	0.84
Exchangeable acidity(me)	1.9	1.5	1.1	2.3	1.7	1.7
Fungi colonies	67	45	30	43	116	26
Bacteria colonies	204	117	89	109	51	50
Bulk density (g/cm^3)	1.37	1.32	1.22	1.34	1.34	1.32
Texture						
Sand%	59	42	44	80	74	74
Silt%	9	6	6	7	6	5
Clay%	32	52	52	13	20	21
Texture grade	SCL	Clay	Clay	SL	SL	SL

4.2.2. Rainfall pattern during 2012/13 short rains at Kampi ya Mawe and Katumani

Table 4 shows the amount and distribution of rainfall received during the growing season at both sites. Kampi ya Mawe received higher rainfall (543.3 mm) than Katumani (152.3 mm) during the 2012/13 short rains. In terms of rainfall pattern, rainfall at Kampi ya Mawe was well distributed throughout the season, recording a total of 44 rainy days as compared to 14 rainy days at Katumani during the same period.

Table 4: Rainfall data at Kampi ya Mawe and Katumani during the growing season.

	Kampi ya Mawe		Katumani	
Month	**Rainfall (mm)**	**No. of days**	**Rainfall (mm)**	**No. of days**
October	29.1	5	0	0
November	171.1	16	19.1	2
December	207.2	16	57.1	3
January	54.5	4	24.3	2
February	12.3	1	2.7	2
March	69.1	2	49.1	5
Total	543.3	44	152.3	14

4.3. Effect of inorganic fertilizer on sorghum grain yield at Kampi ya Mawe and Katumani

4.3.1. Kampi ya Mawe

The grain yields of Gadam sorghum variety at Kampi ya Mawe differed significantly in the various treatments applied (p=0.02) (Table 5).The combined application of nitrogen and phosphorus at 75 kg N/ha and 50 kg P/ha gave the highest grain yield of 4859.1kg/ha followed by treatment of nitrogen at 75 kg/ha and phosphorus at 25 kg/ha 3821.1kg/ha. The control without fertilizer gave the lowest sorghum grain yield of 2059.6kg/ha, a difference of 135% from the highest yields. The findings show that the grain yields increased with increase in the amount of fertilizer applied except for the application of N at 75 kg/ha and P at 75 kg/ha which gave lower yields of 3279.1 kg/ha but higher than the control by 59.2%.

Whereas sole application of N and P also increased grain yield above the control, it is only through application of N that significant (p=0.001) increments were observed (Table 5). This is made clearer in Fig. 4 which shows the response of N and P fertilizers to sorghum grain yield. The Gadam sorghum variety responded more to the increasing dose of nitrogen applied than to P application (Mahmoud et al., 2009 and Tayebeh et al., 2010).

Table 5: Effect of N and P on sorghum grain yield at Kampi ya Mawe and Katumani during the 2012/13 short rains

Attribute	**Yield (Kg/Ha)**	
TREATMENT/RATES (KG/HA)	**KYM**	**KAT**
N0 - P0	2059.62^{e}	1476.97^{e}
N0 - P25	2273.71^{de}	1552.85^{de}
N0 - P50	2628.73^{bcde}	2129.51^{cde}
N0 - P75	2886.18^{bcde}	2032.52^{abcd}
N25 -P0	2276.42^{de}	1799.46^{bcde}
N25-P25	2569.11^{cde}	1997.29^{abcde}
N25-P50	2601.63^{cde}	2040.65^{abcd}
N25-P75	3710.03^{abc}	2186.99^{abc}
N50-P0	2913.28^{bcde}	2149.05^{abc}
N50-P25	3514.91^{bc}	2485.10^{a}
N50-P50	3804.89^{ab}	2460.70^{a}
N50-P75	3685.64^{abc}	2214.18^{abc}
N75-P0	3542.01^{bc}	2257.45^{ab}
N75-P25	3821.14^{a}	2121.95^{abc}
N75-P50	4859.08^{a}	2257.45^{ab}
N75-P75	3279.13^{bcd}	2102.98^{abc}
P (P=0.05)	0.02	0.04
N	0.001	0.0006
P	0.12	0.43
N*P	0.51	0.70
LSD	1198.6	549.5

Note: means denoted by the same letter along the column are not significantly different at p=0.05 according to F-protected LSD test

The sole application of nitrogen and phosphorus gradually increased sorghum yields with increasing rates. Grain yields responded better to N application than P by a difference of between 100 and 700 Kg Grain/ha (Fig. 4).

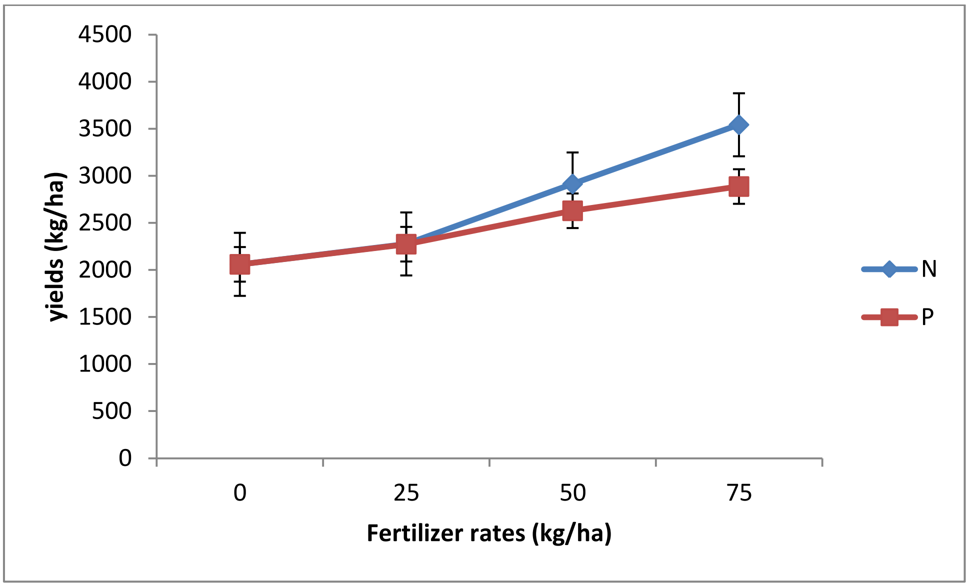

Figure 4: Response of sorghum grain yield to N and P fertilizer at Kampi ya Mawe during 2012/13 short rain.

4.3.2. Katumani

The effect of various treatments on Gadam sorghum grain yield at Katumani is shown in Table 5. The grain yields due to various treatments applied were significantly different (p=0.04) between treatments (Table 5). At Katumani, the highest grain yields (2485.1 kg grain/ha) were recorded with combined treatment of 50 kg N and 25 kg P, which was 68.3% higher than the control (1477.0 kg/ha grain). This was followed closely by treatment 50 Kg N and 50 Kg P which yielded 2460.7 Kg grain/ha.

Figure 5 shows the response of sorghum grain to N and P fertilizer application. Sorghum grain responded better to Nitrogen (p=0.0006) than P inputs. Yield grain increase due to N input rose steadily from 1500 Kg to around 2300Kg grain/ha at 75 Kg N dose while for P, the increase was only up to 2130 Kg

Grain/ha obtained at 50 Kg P but decreased to 2100 Kg Grain /ha at higher dose of 75 Kg P/ha.

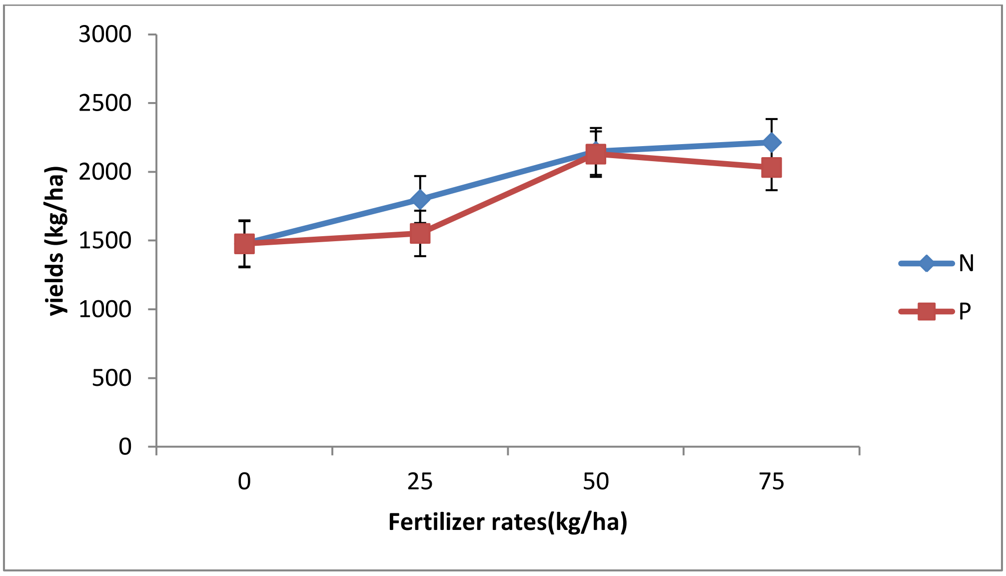

Figure 5: Response of sorghum grain to N, and P at Katumani during 2012/2013 short rains.

Similar findings have been reported by various researchers (Zentner et al., 1987; Stewart, 2003; Kogbe and Adediran, 2003 and Tayebeh et al., 2010). Kogbe and Adediran (2003) reported yield increase of maize while Stewart (2003) reported that of sorghum with rise in nitrogen rates. They also reported decline of yields at higher N and P doses especially above 75 Kg/ha.

The results of this study, therefore indicate that 50kg/ha P_2O_5 was the optimum rate for P application. These findings concur with Kogbe and Adediran (2003) who concluded that the application of P_2O_5 at 40kg/ha appeared to be the optimum since at higher rates, the yields were depressed.

4.4. Effects of FYM and mineral fertilizer on sorghum grain yield at Kampi ya Mawe and Katumani sites

4.4.1. Kampi ya Mawe

In the second experiment at Kampi ya Mawe where manure and NP fertilizer were used (Table 6a), the combination of NP at 50 kg/ha and manure at 10 tons/ha gave the highest grain yield of 5393.0 kg/ha followed by NP at 50 kg/ha and manure at 5tons/ha (5187.0kg/ha). The control (NP0-M0) gave the lowest yield of 4233.1 kg/ha (Table 6a) a difference of 1160 kg/ha or 21.5% from the highest yield (5393.0 kg/ha). Grain yield slightly increased with increasing rates of fertilizer applied. The effect of NP fertilizer application in increasing sorghum grain yield was statistically significant (p=0.006) while the effect of sole FYM application was not significant and did not differ much from the control. Application of FYM alone at 10tons/ha had the lowest yield increase of 5.4%, followed by that of FYM at 5 tons/ha with 11.4% grain yield increase above the control.

In general, therefore, the yields realised with manure alone were lower than those obtained under sole mineral fertilizer and even with the combination of both manure and mineral fertilizer. The potential yield of Gadam sorghum as reported by KARI is approximately 4800 kg/ha with the application of 50 kg/ha NP (KARI, 2006), however the integration of manure with NP fertilizer greatly improved Gadam sorghum yields above the documented potential.

Table 6: Effect of FYM and NP fertilizer on sorghum at Kampi ya Mawe and Katumani during the 2012/13 short rains.

Attribute	**Yield (Kg/ha)**	
TREATMENT	**(a) KYM**	**(b) KAT**
NP0 - M0	4233.062^{c}	1669.38^{a}
NP0 - M5	4715.447^{abc}	1970.19^{a}
NP0 - M10	4463.414^{abc}	1886.18^{a}
NP50 - M0	4813.008^{abc}	1994.58^{a}
NP50 - M5	5186.992^{ab}	1864.50^{a}
NP50 - M10	5392.954^{a}	1566.40^{a}
p=0.05	0.04	0.69
NP	0.006	0.85
FYM	0.18	0.69
NP*FYM	0.62	0.35
LSD	817.9	553.4

Note: means followed by the same letter along the column are not significantly different at p=0.05 according to F-protected LSD test.

It is therefore, evident from these findings that application of both FYM and mineral fertilizer gave higher grain yields than application of mineral fertilizer or manure alone. This could be attributed to the ability of FYM to improve soil moisture storage, especially in areas where rainfall is low and erratic. Similar findings have been reported by Alemu and Bayo (2005), Achieng et al. (2010) and Ouedrago and Mando (2010). Alemu and Bayo (2005) reported significant sorghum grain yield increase of up to 3.23tons/ha over the control as a result of N and P fertilizer application. Similar conclusions were reached by other researchers dealing with maize (Wakene et al., 2001; Gikonyo and Smithson, 2004; Mohsin et al., 2010 and Mwangi et al., 2010).

4.4.2. Katumani

At Katumani as shown in Table 6b, the effect of manure appeared to depress grain yields significantly. In this experiment 2, the application of NP fertilizer at 50 kg/ha alone recorded the highest grain yield of 1994.8 kg/ha which was 19.5% increase above the control treatment (1669.5 Kg Grain/ha). This was followed by FYM at 5tons/ha with grain yield of 1970.2 Kg.

Interestingly, the combination of FYM and NP fertilizer at 10tons/ha and 50kg/ha, respectively, recorded the lowest grain yield of the experiment (1566.4 Kg Grain/ha) which was 6.2% below the control treatment. This was not expected especially in a combination application of manure and mineral fertilizers because manure has been reported by many researchers as enhancing crop yields in semi-arid zones (Mochoge et al., 1997; Achieng et al., 2010; Mohsin et al., 2010; Mwangi et al., 2010 and Ouedrago and Mando, 2010). In a fertilizer use experiment carried out in semi-arid parts of Kenya, Mochoge et al. (1997) recorded maize yield of between 370 and 940 Kg/ha from unfertilized plots, between 900 and 2010 Kg/ha from NP fertilized plots, 700-1720 Kg/ha from manure applied plots and even higher in plots where NP fertilizers combined with manure were applied (1000-2280 Kg/ha).

4.4.3. Comparison of yields performance at KYM and Katumani (KAT)

The comparisons (Fig. 6 and7) clearly shows that the grain yield of sorghum was lower in Katumani than Kampi ya Mawe in both experiments. This could be attributed to low, erratic and poorly distributed rainfall received at Katumani during the growing season (Fig. 8 and Table 4) as compared to that of Kampi ya Mawe which was fairly distributed in the season.

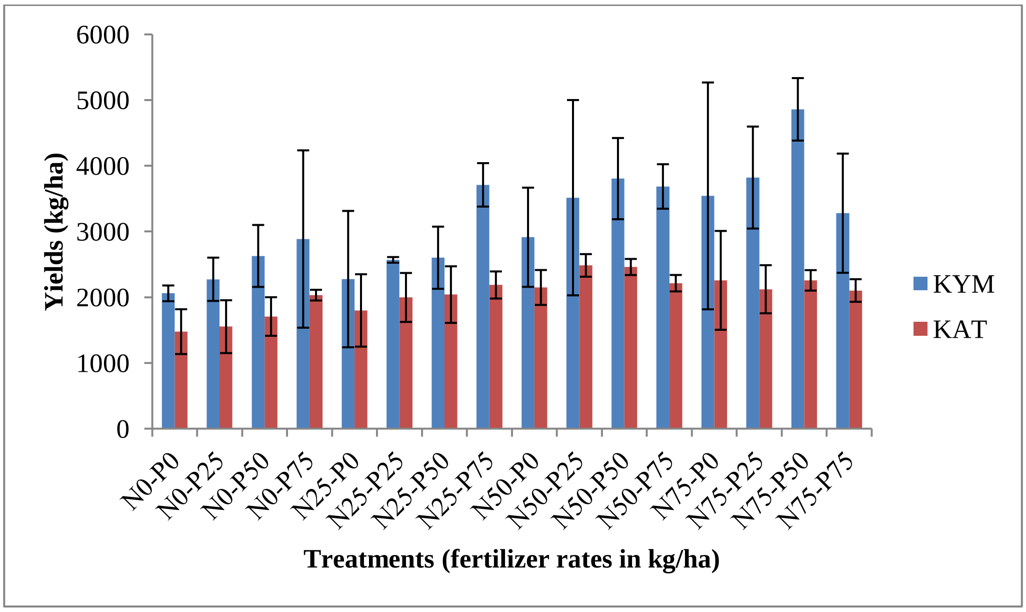

Figure 6: Comparison of yields in Kampi ya Mawe (KYM) and Katumani (KAT) (Experiment 1) in relation to fertilizer treatment.

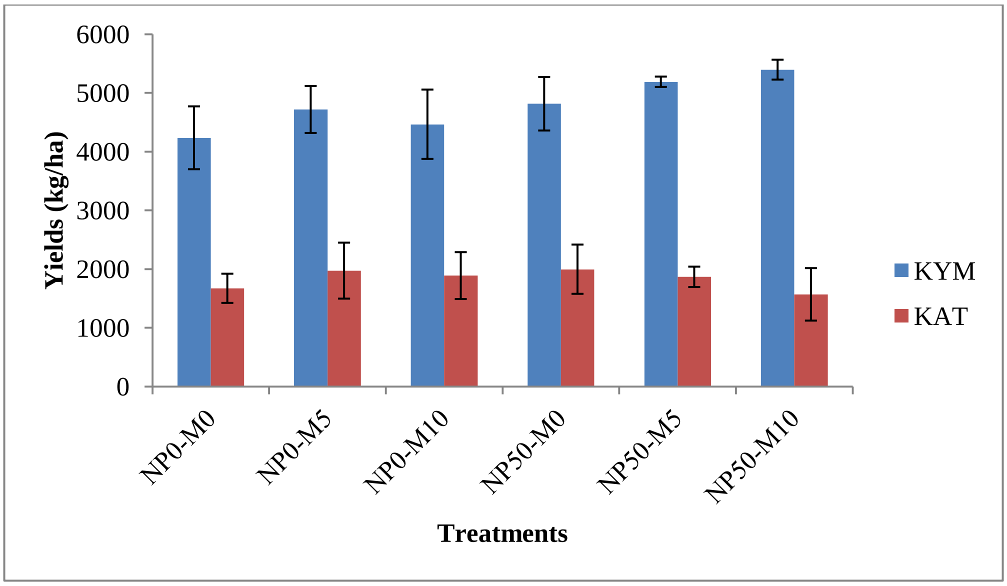

Figure 7: Yield comparison at Kampi ya Mawe (KYM) and Katumani (KAT) (Experiment 2) in relation to treatment with combined fertilizer and manure.

The variability and differences in rainfall patterns during the growing season at the two sites as shown in Fig. 3 might have led to the differences in sorghum yields at Kampi ya Mawe and Katumani (Fig. 6&7). Moisture stress which was experienced at Katumani during the grain milk filling stage (see Photo 1) might have greatly contributed to low grain yield.

Photo 1(b) shows the effect of dry spells in crop development especially at Katumani during the seed milk filling stage which is an important stage in sorghum crop development. Leaf drooping at Katumani due to water stress adversely affected the grain yields during this season.

Photo 1. Sorghum at the seed filling stage at Kampi ya Mawe (left) and Katumani (right) during the 2012/13 short rains.

4.5. Effect of FYM and inorganic fertilizer on nitrogen uptake by sorghum

Nitroge N concentration in sorghum tissues was significantly higher at seedling stage than in the other stages with respect to various treatments both in Kampi ya Mawe (p=0.003) and Katumani (p=0.01) as shown in Tables 7 and 8, respectively. Whereas N concentration in the grains (maturity stage) at Kampi ya Mawe (Table 7) was slightly elevated above that at heading stage, at

Katumani there was no such elevation and the changes in N concentration in tissues were generally minimal (Table 8). The N concentration in tissues was significantly (p=0.001) higher after N application than the control and after P fertilizer application at Kampi ya Mawe. This, however, was not the case at Katumani where the interaction of N and P gave highest N concentration in the tissues than other treatments (Table 8). The application of P as a treatment tended to depress N concentration in tissues especially at Kampi ya Mawe than even the control treatment.

The higher N concentration observed in seedling stage than at heading stage could be due to plant biomass sizes. At seedling stage the plant biomass materials are less massive than at heading stage and hence dilution effect of nutrient concentrations at the heading stage. The slight elevation of N concentration in the grains could be due to accumulation of nutrient as the storage organ of the plant. Similar trends have been reported by other researchers (Pal et al., 1982 and Malathesh, 2005). Pal et al. (1982) observed a continuous decline in N concentration in whole plant tissues until 75 days after planting followed by increased N concentration up to maturity. Pal et al. (1982) explain that N concentration of vegetative parts of sorghum plants generally decreases with advance in age while it increases in the grains.

The absence of N concentration elevation in grains at Katumani could be explained by unfavourable climatic conditions especially low moisture content in soil to enable appropriate nutrient uptake.

Table 7: N concentration (%) in sorghum tissues for selected treatments at Kampi ya Mawe during 2012/13 short rain.

TREATMENT FERTILIZER RATES (KG/HA)	Seedling stage^{x}	Heading stage^{y}	Maturity stage^{z} (grain)
N0 - P0	3.27^{b}	2.49^{ab}	2.60^{ab}
N0-P 75	3.30^{b}	2.24^{b}	2.36^{b}
N75 - P0	4.06^{a}	2.77^{a}	2.79^{a}
N75-P 75	3.59^{b}	2.56^{ab}	2.77^{a}
P(0.05)	0.003	0.17	0.02
N	0.001	0.08	0.008
P	0.07	0.17	0.17
N*P	0.05	0.89	0.24
LSD	0.43	0.41	0.25

^{x} whole plant tissues were analysed at seedling stage; ^{y} flag leaf tissues analysed at heading stage

^{z} sorghum grains were analysed at sorghum maturity

Note: means followed by the same letter along the column are not significantly different at p=0.05 according F-protected LSD test

Table 8: N concentration (%) in sorghum tissues for selected treatments at Katumani during 2012/13 short rains.

TREATMENT FERTILIZER RATES (KG/HA)	Seedling stage^{x}	Heading stage^{y}	Maturity stage^{z} (grain)
N0 - P0	3.90^{a}	2.97^{ab}	2.97^{a}
N0 - P75	3.44^{b}	3.67^{b}	3.32^{a}
N75 - P0	3.88^{a}	3.74^{ab}	3.46^{a}
N75 - P75	3.92^{a}	3.74^{a}	3.72^{a}
P=0.05	0.01	0.05	0.44
N	0.03	0.03	0.94
P	0.04	0.46	0.90
N*P	0.02	0.06	0.12
LSD	0.18	0.32	0.35

^{x} whole plant tissues were analysed at seedling stage

^{y} flag leaf tissues were analysed at heading stage

^{z} sorghum grain were analysed at sorghum maturity

Note: means followed by the same letter along the column are not significantly different at p=0.05 according F-protected LSD test

The harsh weather conditions of 2012/2013 short rains season during the seed fill stage of sorghum grain might have contributed to low nitroge N concentration in the grains. The rainfall was low and erratic during the growth period thus influencing the soil solution and nutrients available concentrations for plant uptake. The results at Katumani showed that the amount of N in plant tissues declined progressively during the growing season.

Studies have shown that crop uptake is often affected by both soil and climatic conditions. Low soil moisture, poor aeration due to compaction or excessive moisture, low soil temperature and high lime in the root zone, nutrient imbalances and other factors may restrict uptake of plant nutrients (CF1, 1998; Jones et al., 2011). Jones et al. (2011) reported that nutrient uptake varied among crops and generally occurred prior to maximum growth. They further reported that crop nutrient uptake rates were different at each growth stage. Jones and Jacobsen (2001) had earlier highlighted that nutrient uptake by roots was dependent on both the ability of the roots to adsorb nutrient and the concentration at the surface of the roots. This explains the increased N uptake with increased N application in this study (Table 7 &8).

Plants have been reported to have difficulty in absorbing nutrients in dry soil. Therefore this could lead to lower tissue concentrations than normal (Jones et al., 2011). This may have been the case in Katumani which recorded low N accumulation in the sorghum plant tissues which may have been due to low moisture availability in the soil as a result of low rainfall during the growing period (Table 8). The findings of this study are also concurring with the findings by Malathesh (2005) who reported increased concentration of N in the grains of maize with nitrogen fertilization rates.

4.6. Effect of mineral fertilizer on agronomic nutrient use efficiency

Agronomic fertilizer use efficiency was determined to assess the efficiency of sorghum in utilizing nitrogen and phosphorus for grain production (Roberts, 2008). Nitrogen use efficiency (NUE) was 8.7, 17.1 and 19.8 kg of grain for each kilogram of N applied with respect to the application of 25, 50 and 75 kg/ha, respectively, at Kampi ya Mawe while at Katumani, nitrogen use efficiency was 12.9, 13.4 and 10.4 kg of sorghum grain for every kilogram of nitrogen applied at 25, 50 and 75 kg/ha N, respectively (Table 9).

Phosphorus use efficiency (PUE) was lower than that of nitrogen at Kampi ya Mawe averaging 8.6, 11.4 and 11 kilogram of sorghum grain for every kilogram of P applied at 25, 50 and 75 kg/ha P_2O_5 respectively. At Katumani, the values of PUE were even lower than Kampi ya Mawe with its PUE averaging 3, 13.1 and 7.4 kilogram of sorghum grain for each kilogram of P_2O_5 applied at 25, 50 and 75 kg/ha P_2O_5, respectively (Table 9).

Table 9: Agronomic Nutrient Use Efficiency of sorghum at Kampi ya Mawe and Katumani (kg grain/ kg of fertilizer applied) during 2012/13 short rains.

Attribute	**NUE**		**PUE**	
Fertilizer Rates(Kg/Ha)	**KYM**	**KAT**	**KYM**	**KAT**
25	8.67	12.9	8.56	3.04
50	17.07	13.44	11.38	13.05
75	19.77	10.41	11.02	7.41

The results of this study concur with the research done by other researchers. Berral et al. (2002) reported that at 50 kg N/ha the improved genotype of sorghum had the highest NUE. Kayuki et al. (2012) reported that at very high N application rate the NUE declined despite the slight increase in grain yield and this had earlier been reported by Kogbe et al. (2003). Oikeh et al. (2007) reported that nitrogen utilization efficiency was lowest for sorghum with 12 to 19 kg grain per kg N applied. Maranville et al. (2002) added that nitrogen use efficiency (grain weight per unit of N supplied from soil and/or fertilizer) is reduced due to poor crop cultural practices, sub-optimal yields and N losses or deficiency of other nutrients.

Kogbe and Adediran (2003) reported that PUE increased until 40kg/ha but declined with increase in P application in the soil. Application of 40kg P_2O_5 /ha appeared to be the optimum since at higher rates, the yields were depressed.

4.7. Effect of FYM and mineral fertilizer on bio-chemical soil properties

4.7.1. Soil pH

Tables 10 and 11 present the active soil pH as influenced by various treatments of this study. The results show that there was a slight change in pH in plots treated with manure and those with sole nitrogen fertilizer as compared to the control treatment (4.9) at Kampi ya Mawe and 5.57 at Katumani. The soils in Kampi ya Mawe were very acidic with pH range of 4.55-5.27 while soils at Katumani were moderately acidic with pH levels of 5.46-6.09. Generally there was no significant effect of treatments on soil pH at both sites.

Table 10: Effect of treatments on pH (0-20cm depth) at Kampi ya Mawe during 2012/13 short rains.

Soil pH (water 1:2.5)				
TREATMENT FERTILIZER RATES (Kg/ha)	Initial	End of experiment	Difference	t-(p value)
N0-P0	4.88	4.90^{a}	0.02	0.83
N0-P75	4.88	4.52^{a}	-0.36	0.11
N75-P0	4.88	4.54^{a}	-0.34	0.18
N75-P75	4.88	4.55^{a}	-0.33	0.27
CV (%)		5.75		
R^2		0.34		
LSD		0.44		
P Value		0.32		
2ND TRIAL				
NP0-M10	4.88	5.27^{a}	0.39	0.006
NP50-M0	4.88	4.94^{a}	0.06	0.81
NP50-M10	4.88	5.22^{a}	0.34	0.38
P value		0.653		
R^2		0.226		
LSD		1.02		
CV (%)		8.79		

Note: means with the same letter along the column are not significantly different at p=0.05 according to the F-protected LSD test.*pH at the beginning of the experiment was 4.88

Table 11: Effect of treatments on soil pH (0-20cm depth) at Katumani during 2012/13 short rains.

Soil pH (water 1:2.5)				
TREATMENT FERTILIZER RATES (Kg/ha)	Initial	End of experiment	Difference	t-(p value)
N0-P0	5.90	5.57^{a}	-0.33	0.22
N0-P75	5.90	5.56^{a}	-0.34	0.09
N75-P0	5.90	5.63^{a}	-0.27	0.04
N75-P75	5.90	5.46^{a}	-0.44	0.22
CV (%)		7.70		
R^2		0.46		
LSD		0.84		
P Value		0.485		
EXPERIMENT 2				
NP0-M10	5.90	6.09^{a}	0.19	0.88
NP50-M0	5.90	5.55^{a}	-0.35	0.05
NP50-M10	5.90	5.82^{a}	-0.08	0.41
P value		0.426		
R^2		0.52		
LSD		0.63		
CV (%)		4.86		

Note: means followed by the same letter along the column are not significantly different at p=0.05 according to F-protected LSD test.*pH at the beginning of the experiment was 5.90

Treatments which had manure recorded slightly higher pH levels compared to other treatments at both sites. This could be attributed to the ability of FYM as a buffer against excess H^+ production and improvement of Cation exchange capacity (CEC) of the soil (Bloom et al., 1999).

Bloom et al. (1999) reported the liming effect of animal manure in acid soils after long term field and greenhouse experiments. It was also reported that saline and alkaline soils can be amended by continuous application of FYM over several years (Chandy, 2010).

The main reason why manure raised soil pH was reported to be due to fairly high Calcium and Magnesium contents contained in the farmyard manures. Therefore, applying manures to acid soils not only supply needed nutrients and organic matter for plant growth but also reduce soil acidity, thus improving P availability and reducing Al toxicity (Bloom et al., 1999). Nitrogen fertilizer plots recorded the lowest pH as compared to other treatments (Cholick, 1991). This could be as a result of nitrification of ammonium –N which in the process produces hydrogen protons. These findings concur with Whitney et al. (1991) who reported that treatments receiving nitrogen had a significantly lower pH values than the no-nitrogen treatments.

4.7.2. Effect of treatments on available soil N (NO_3^- & NH_4^+)

Tables 12 and 13 show the concentration of available nitrogen (NO_3-N and NH_4-N) in soil during the growing period of sorghum as influenced by the various treatments applied. In the case of nitrates, concentrations initially in the soil increased in relation to nitrogen application rates but declined progressively throughout the growth period with the lowest concentrations at harvest. Concentration of nitrates was significantly different in the various treatments at the seedling stage (WK4) at both sites with P values of 0.04.

There was however no significant effect of P application and its interaction with N on soil nitrates throughout the growing period.

Table 12: Concentration of available N in soils at Kampi ya Mawe during 2012/13 short rain.

NO_3^- and NH_4^+CONCENTRATION AT KAMPI YA MAWE (mg/kg)						
Treatment FERTILIZER RATE (KG/HA)	NO_3^-			NH_4^+		
	Week 4	**Week 8**	**Week 12**	**Week 4**	**Week 8**	**Week 12**
N0-P0	6.368^{c}	3.153^{ab}	1.386^{a}	2.7^{c}	1.748^{a}	3.127^{a}
N0-P75	7.382^{bc}	2.28^{b}	0.739^{a}	4.932^{bc}	4.032^{a}	2.95^{a}
N75-P0	9.8^{ab}	5.493^{a}	2.51^{a}	10.333^{a}	3.808^{a}	3.746^{a}
N75-P75	10.853^{a}	4.39^{ab}	1.38^{a}	8.538^{ab}	4.275^{a}	3.675^{a}
p(0.05)	0.04	0.05	0.23	0.03	0.19	0.63
N	0.009	0.01	0.15	0.007	0.2	0.23
P	0.33	0.21	0.15	0.89	0.13	0.81
N*P	0.98	0.89	0.68	0.23	0.3	0.92
Mean	8.6	3.83	1.5	6.63	3.47	3.37
LSD	3.15	2.51	2.16	4.68	3.25	2.00

Note: Means followed by the same letter along the column are not significantly different at p=0.05 according to F-protected LSD test.*at week 0 nitrate-nitrogen was 11.4mg/kg and ammonium-nitrogen was 3.91mg/kg

Table 13: **Concentration of available N in soil at Katumani during 2012/13 short rains.**

NO_3^- and NH_4^+CONCENTRATION AT KATUMANI (mg/kg)						
Treatment	**NO_3^-**			**NH_4^+**		
Fertilizer rates (Kg/Ha)	**Week 4**	**Week 8**	**Week 12**	**Week 4**	**Week 8**	**Week 12**
N0-P0	10.57^b	12.55^a	7.11^b	3.60^a	3.75^a	2.65^b
N0-P75	7.68^b	10.44^a	5.62^b	4.05^a	2.75^a	2.60^b
N75-P0	22.95^{ab}	29.1^a	15.01^a	3.79^a	10.3^a	17.52^a
N75-P75	27.99^a	15.56^a	12.37^a	15.67^a	9.29^a	8.59^b
p(0.05)	0.04	0.12	0.008	0.25	0.19	0.0008
N	0.007	0.04	0.002	0.23	0.04	0.0003
P	0.82	0.25	0.22	0.21	0.72	0.03
N*P	0.41	0.45	0.72	0.24	0.99	0.03
Mean	17.3	17.66	10.03	6.78	6.52	7.84
LSD	15.52	19.86	4.34	16.53	8.91	6.67

Note: means followed by the same letter along the column are not significantly different at p=0.05 according to F-protected LSD test.* At week 0, nitrate-nitrogen was 12.3mg/kg and ammonium-nitrogen was 4.75mg/kg

In the case of ammonium concentration in the soils as shown in Table 12 and 13were slightly lower than those of nitrates but show similar trends as that of nitrates with high initial concentrations which however declined rather obscurely with time. Concentration of ammonium at the end of the experiment was higher than that of nitrates and this could be due to the fact that ammonium is taken by plants in very small quantities as compared to the nitrates (Cakmak et al., 2010). The observed higher concentrations of available N in soils after nitrogen dose has also been emphasized by Dubey et al. (2012) who reported that continuous use of nitrogenous fertilizers generally increased the available N status of the soil.

4.7.3. Effect of treatments on available P in soils

Tables 14 and 15 show available P levels in the soil during the growing season of sorghum as influenced by the various treatments applied. P concentration in the soil increased with increased P application. The plots which were not fertilized with P recorded the lowest P levels. P concentration in soil was not significantly different for the various treatments applied at Kampi ya Mawe except for the concentration at harvest (WK12). In Katumani, however, P concentration was significantly different between the various treatments applied in all the growth stages of sorghum (Table 15). The concentration of available P remained relatively high throughout the growing period and this can be attributed to the fact that P is immobile and cannot be lost through leaching (Penn State Extension, 2013).

Table 14: P concentration in soil at Kampi ya Mawe during 2012/13 short rain.

Treatment	**STAGE OF GROWTH**		
Fertilizer Rates (Kg/Ha)	**Week 4**	**Week 8**	**Week 12**
N0-P0	21.00^{a}	19.37^{b}	22.79^{b}
N0-P75	41.14^{a}	37.76^{a}	28.50^{b}
N75-P0	28.46^{a}	25.5^{ab}	27.28^{b}
N75-P75	110.04^{a}	37.6^{a}	36.07^{a}
p(0.05)	0.17	0.09	0.009
N	0.21	0.59	0.02
P	0.11	0.02	0.007
N*P	0.3	0.57	0.46
Mean	50.16	30.06	28.67
LSD	91.43	15.08	6.92

Note: means denoted by the same letter along the column are not significantly different at p=0.05 according F-protected LSD test.* P concentration at the beginning of the experiment was 24.6mg/kg

Table 15: P concentration in soil at Katumani during 2012/13 short rains.

Treatment	**STAGE OF GROWTH**		
Fertilizer rates (Kg/Ha)	**Week 4**	**Week 8**	**Week 12**
N0-P0	30.58^{b}	28.36^{b}	44.75^{ab}
N0-P75	40.17b^{ab}	43.59^{a}	57.15^{a}
N75-P0	29.37^{b}	28.25^{b}	32.55^{b}
N75-P75	45.24^{a}	48.28^{a}	47.10^{ab}
p(0.05)	0.03	0.02	0.05
N	0.58	0.61	0.06
P	0.005	0.003	0.03
N*P	0.37	0.59	0.83
Mean	36.34	37.12	45.39
LSD	11.99	15.17	15.14

Note: means followed by the same letter along the column are not significantly different at p=0.05 according to F-protected LSD test.* P concentration at the beginning of the experiment was 12.0 mg/kg

4.7.4. Effect of some selected treatments on some soil chemical properties at the end of the experiment

Tables 16 and 17 show the chemical status of the soil at the end of the experiments at both sites where the study was conducted as compared to the beginning of the experiment. At the end of the experiment, the conditions of most soil properties were improved significantly. In case of total carbon, increases were up to 298 and 200% were realized after 10 tons of manure application at Kampi ya Mawe and Katumani, respectively. However, in the case of total nitrogen, the various treatments appeared to reduce its concentration at Kampi ya Mawe even after 10 tons of manure application (by 34% reduction) but showed slight improvement at Katumani of up to 22% after 10 tons manure application.

Table 16: Soil chemical properties at Kampi ya Mawe at harvest (12 weeks after emergence).

Attribute	End of experiment					
	Control	75kg/ha N	75kg/ha P	75kg/ha NP	10tons FYM	50g/ha NP+10t FYM
N-NO3- mg/kg	1.39	0.74	2.51	1.38	2.57	2.62
N-NH4- mg/kg	3.13	2.95	4.01	3.68	5.86	3.72
Available P- mg/kg	22.79	28.50	27.28	36.07	27.28	32.45
Na(ppm)	9.87	9.75	10.78	10.56	9.23	9.39
Mg(me/100g soil)	3.35	3.17	2.94	2.70	4.25	4.90
Ca(ppm)	18.33	17.00	21.67	13.33	30.00	29.67
K(ppm)	49.87	51.86	61.13	46.56	77.69	77.06
Total N (%)	0.08	0.09	0.08	0.07	0.12	0.11
Total C (%)	0.39	0.89	0.88	0.81	1.99	1.10

Table 17: Soil chemical properties at Katumani at harvest (12 weeks after emergence).

Attribute	End of experiment					
	Control	75 kg/ha N	75 kg/ha P	75 kg/ha NP	10 tons FYM	50 kg/ha NP+10 t FYM
N-NO3- mg/kg	7.11	5.62	15.01	12.37	8.85	17.55
N-NH4- mg/kg	2.65	2.60	17.52	8.58	3.87	12.14
Available P- mg/kg	44.75	57.15	32.55	47.10	47.05	49.72
Na(ppm)	10.14	8.43	10.11	10.20	9.98	8.75
Mg(me/100g soil)	4.93	4.44	4.15	4.57	4.97	4.91
Ca(ppm)	55.67	35.67	44.00	57.00	47.00	34.33
K(ppm)	79.01	73.71	57.81	70.40	75.70	72.06
Total N (%)	0.11	0.11	0.09	0.1	0.11	0.11
Total C (%)	1.17	1.11	0.96	0.90	1.14	1.79

4.7.5. Effect of treatments on soil microbial population

Tables 18 and 19 show the microbial population at Kampi ya Mawe and Katumani at the beginning and at harvest (12 weeks after emergence) as influenced by FYM. The bacteria colonies were not significantly different between the treatments, however plots fertilized with manure recorded the higher bacteria population than non-manure plots. There were 11.1% and 17.3% bacteria increase above the control in plots fertilized with 10 tons manure at Kampi ya Mawe and Katumani, respectively. Plots fertilized with NP at 50kg/ha and manure at 10 tons/ha recorded the highest microbial population increase of up to 43.3% at Kampi ya Mawe and 20.3% at Katumani.

The same trend was observed with fungi biomass in soil, where Kampi ya Mawe recording 6.9% and 13.5% increase with the application of manure alone at 10tons, and the combination of NP at 50kg/ha and 10tons manure ,respectively. At Katumani plots fertilized with 10 tons manure had 13.3% fungi increase and the combination of NP at 50kg/ha and 10 tons manure recorded a 29.0% fungi population increase above the control. At the beginning of the experiment, the mean microbial population was $9.9*10^2$ and $4.3*10^2$ colonies per gram of soil for bacteria and fungi at Kampi ya Mawe and $1.1*10^3$ and $6.7*10^2$ at Katumani, respectively.

Table 18: Soil microbial population at Kampi ya Mawe as influenced by FYM during 2012/13 short rain.

Attribute	**BACTERIA CFUs(10^2)/g soil**		**FUNGI CFUs(10^2)/g soil**	
Fertilizer rates (Kg/Ha)	**Week 0**	**Week 12**	**Week 0**	**Week 12**
N0-M0	9.9	7.7^b	4.30	4.7^a
N0-M10	9.9	8.5^b	4.3	5.1^a
N50-M0	9.9	6.2^c	4.3	4.6^a
N50-M10	9.9	11.0^a	4.3	5.4^a
P Value		0.01		0.13
R^2		0.97		0.77
MEAN		8.3		4.9
LSD		0.99		0.93

Note: Means followed by the same letter along the column are not significantly different at p=0.05 according to F-protected LSD test.

Table 19: Microbial population at Katumani as influenced by FYM during 2012/13 short rains.

Attribute	**BACTERIA CFUs (10^3)/g soil**		**FUNGI CFUs (10^2)/g soil**	
Fertilizer rates (Kg/Ha)	**Week 0**	**Week 12**	**Week 0**	**Week 12**
N0-M0	1.09	1.49^{a}	6.7	6.8^{b}
N0-M10	1.09	1.75^{a}	6.7	7.7^{ab}
N50-M0	1.09	1.59^{a}	6.7	6.4^{b}
N50-M10	1.09	1.79^{a}	67	8.8^{a}
P Value		0.54		0.12
CV (%)		8.35		10.45
R^2		0.47		0.78
MEAN		1.66		7.4
LSD		0.32		1.8

Note: Means followed by the same letter along the column are not significantly different at p=0.05 according to F-protected LSD test

Research has shown that manure application has a significant effect on soil chemical, physical and biological properties (Chandy, 2010). Most of these effects are due to an increase in organic matter with manure application (Bloom et al., 1999). Chandy (2010) reported that application of FYM was immediately followed by a marked increase in microbial population in the soil. Yagathjoth et al. (2008) also reported that soil microbial population was enhanced with the addition of organic materials. In comparison with plots fertilized with mineral fertilizer alone, Luu and Takeshi (2004) reported that the microbial population were less. This was also emphasized by Peacock et al. (2001).Organic carbon is the source of energy and carbon for body building for microbes in soil.

4.8. Influence of FYM on moisture storage in soils in relation to rainfall pattern in the season

4.8.1. Available soil moisture content in soil as influenced by FYM and rainfall pattern

Farm Yard Manure (FYM) increased available moisture content in the soil at both sites (Table 20). There were up to 20.6% moisture increase in manure fertilized plots at Kampi ya Mawe while at Katumani the manure fertilized plots recorded up to 38.9% moisture increment above the no-manure plots. However, the mean water content was not significantly different between the various treatments applied. Application of FYM was found better in increasing soil moisture content than no-FYM plots which recorded low moisture content.

Table 20: Volumetric water content at Kampi ya Mawe and Katumani during the growing season of sorghum.

	KAMPI YA MAWE				**KATUMANI**			
TREATMENT	**Week 4**		**Week 8**		**Week 4**		**Week 8**	
	0-20CM	**20-40CM**	**0-20CM**	**20-40CM**	**0-20CM**	**20-40CM**	**0-20CM**	**20-40CM**
NP0-M10	0.32^{a}	0.22^{a}	0.21^{a}	0.2^{a}	0.28^{a}	0.23^{a}	0.18^{a}	0.19^{a}
NP50-M0	0.29^{a}	0.28^{a}	0.24^{a}	0.22^{a}	0.26^{a}	0.28^{a}	0.23^{ab}	0.18^{a}
NP50-M10	0.35^{a}	0.29^{a}	0.17^{a}	0.19^{a}	0.31^{a}	0.25^{a}	0.25^{b}	0.23^{a}
P=0.05	0.66	0.32	0.73	0.65	0.66	0.89	0.19	0.4
R^2	0.39	0.62	0.34	0.4	0.39	0.2	0.72	0.57
MEAN	0.32	0.26	0.21	0.21	0.3	0.26	0.24	0.21
LSD	0.12	0.1	0.14	0.1	0.11	0.15	0.07	0.07

The results of this study indicate that FYM has the capability of retaining soil moisture as reported by other researchers. Magagula et al. (2010) reported that there was no significant difference in the soil moisture content among treatments in a study conducted to determine the effect of chicken manure on soil properties under sweet potato in Swaziland. They also reported that plots fertilized with manure resulted into not-significant higher soil moisture content than the non-manure plots. They explained the high moisture content in manure plots to be as a result of manure capability to absorb and retain moisture for use by the crop.

The findings of this study however differed with the results of Tadesse et al. (2013) which recorded a significant difference in soil moisture content among treatments in a study aimed at assessing the effect of FYM and inorganic fertilizer on soil physico-chemical properties and nutrient balance in rain fed lowland rice. They reported that application of FYM significantly increased water holding capacity of the soil. Compared to no FYM application, 7.5-15 tons/ha FYM resulted in 3.6-10.3 % increase in available water holding capacity of soil.

The observation of improved water holding capacity with FYM application is also supported by Dejene and Lemlem (2012). They reported that soil water content was significantly improved with FYM application and plots that received 10 and 15 tons/ha had 1.3 to 3.5 % greater water content than the control. Despite the differences in findings as reported by various researchers on the effect of FYM in increasing water holding capacity of a soil, it is evident that whether the results were significantly different among the different treatments or not, FYM increased available soil moisture content as compared to the control and the other non- FYM plots in this study.

4.8.2. Relationship between moisture content and sorghum grain yields

Figures 12 and 13 show correlation between sorghum grain yield and available soil water at Kampi ya Mawe and Katumani during 2012/13 short rains. The relationship between soil moisture and sorghum yields was positive but weak at both sites (R^2 of 0.39 and 0.04 at Kampi ya Mawe and Katumani, respectively). Soil moisture is known to have an effect on grain yield as it supports the growth of crops (Tadesse et al., 2013)

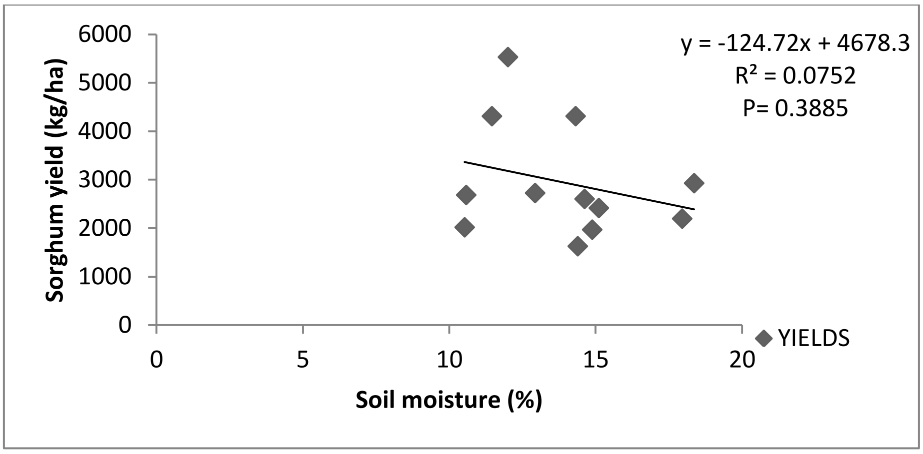

Figure 8: Relationship between sorghum yields and available soil water at Kampi ya Mawe.

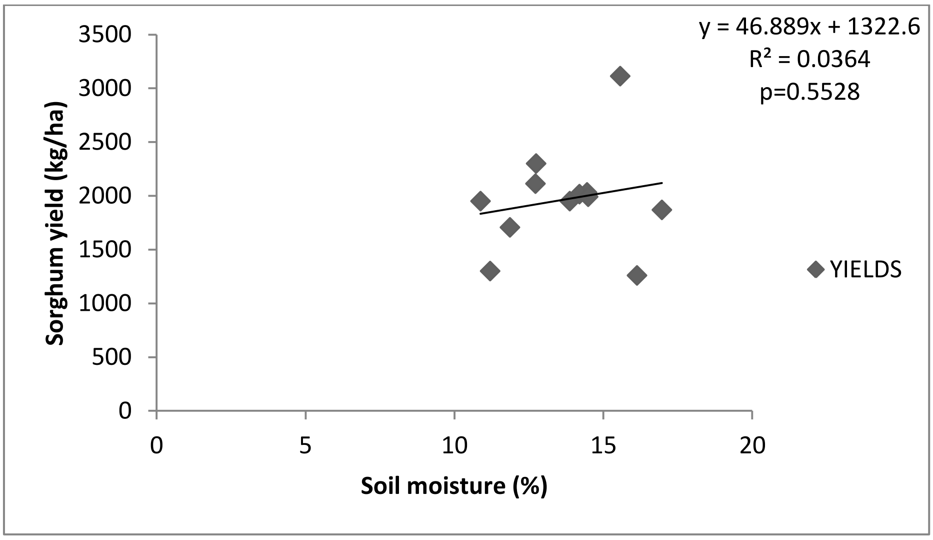

Figure 9: Relationship between sorghum yields and available soil water at Katumani.

4.8.3. Comparison of initial and end of experiment soil moisture contents as influenced by FYM treatment and soil depth

Figure 11 and 12 show volumetric soil moisture content in relation to depth and time at Kampi ya Mawe and Katumani. It is evident from the Figures 11 and 12 that plots fertilized with manure generally had slightly improved moisture storage in the soil, specifically in the first four weeks of the experiment reflecting the intensity of rainfall during the period (Table 4). While the moisture content decreased with depth, it remained more or less constant with time (WK8). However, at Katumani, the soil moisture retention kept increasing with time, and especially where manure was applied (Tadesse et al., 2013).

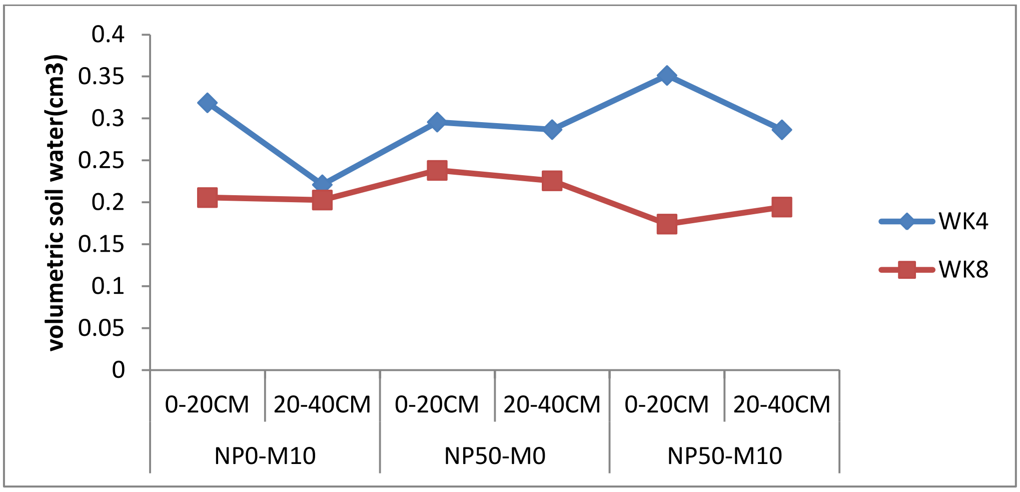

Figure 10: Volumetric water content at Kampi ya Mawe in relation to soil depth and time.

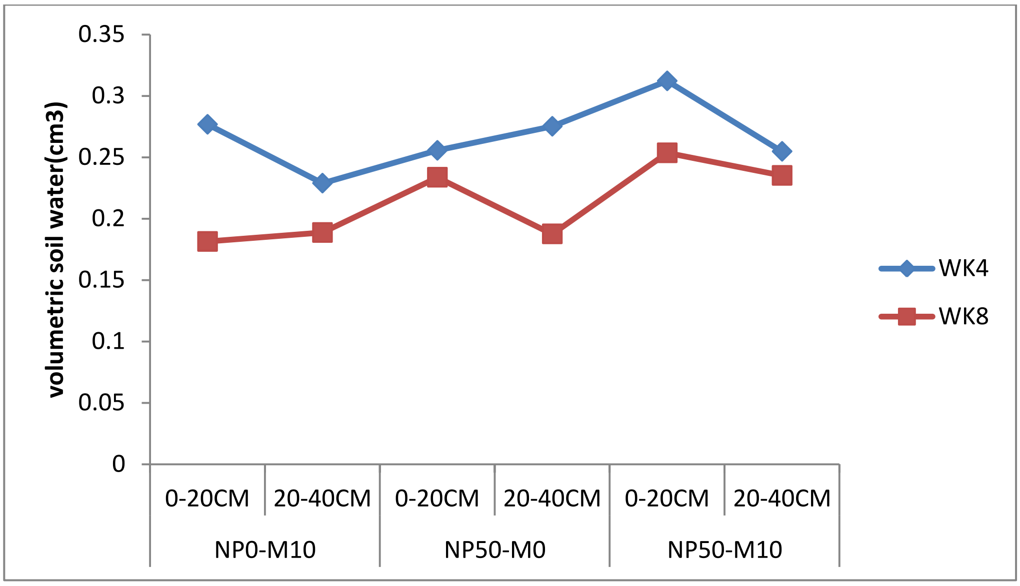

Figure 11: Volumetric water content at Katumani in relation to depth and time.

CHAPTER FIVE

5.0. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The main aim of this study was to evaluate the effect of farm yard manure and inorganic fertilizer on sorghum grain yields and soil properties in semi-arid eastern Kenya. From the results the following conclusions can be drawn:

1. Sorghum yields were significantly affected by the various treatments as per the results obtained in this study. In regard to response, sorghum grain yield appeared to respond more to nitrogen than Phosphorus at both sites.
2. In the experiment with FYM, the combination of NP at 50 kg/ha and farm yard manure at 10tons/ha gave the highest yields at Kampi ya Mawe while at Katumani, the same combination gave the lowest yields. The ability of manure to supply nutrients to the soil is dependent on C/N ratio of the manure which might have led to the decline in yield at Katumani due to immobilization caused by high C/N ratios
3. Highest nitrogen N concentration in plant tissues (4.06%) was recorded in plots fertilized with high rates of nitrogen (sole nitrogen plots at 75 kg/ha) at Kampi ya Mawe and 3.88%N at Katumani. The concentrations of nitrogen in plant tissues were higher in the seedling stage and declined progressively untill sorghum maturity (grain) stages than where sorghum grains had higher N concentration than at the heading stage

4. Most soil properties were not much affected by the treatments in this one season crop. However, soil pH, organic carbon, soil moisture content and microbial populations (bacteria and fungi) significantly increased due to FYM application. In soils fertilized with nitrogen, Soil pH was observed to decrease.
5. In terms of nutrient use efficiency, the nitrogen use efficiency (NUE) was higher than that of P at both sites but with lower NUE and PUE levels at Katumani.
6. In general, however, rainfall pattern and amounts have a big influence in the magnitude of crop performance in dry lands. Sorghum performed better in Kampi ya Mawe which received evenly distributed rainfall than Katumani which received very low and erratic rainfall

5.2. Recommendations

From the findings of this study, the following recommendations are suggested:

- Farmers growing sorghum in semi-arid eastern Kenya are encouraged to use the combination of NP at 50 kg/ha and manure at 10 tons/ha of high quality farmyard manure during the short rains.
- Application of enough manure is recommended for it has many advantages in dry land soils such as water retention, improved microbial activities and soil fertility sustainability.
- Further research to be conducted for a longer period using different rates of FYM and inorganic fertilizer in the different ecological zones

in the semi-arid regions of Kenya in order to come up with a robust figure on the optimum rates for increased sorghum production.

- Farmers should be encouraged and assisted by the respective counties to conduct soil analysis in order to determine the fertility status of their soils and consequently be advised accordingly on inputs to be added in order to improve and sustain soil productivity.

6.0. REFERENCES

Abunyewa, A.A. (2008). Efficient utilization of water and nitrogen resources of grain sorghum under rain-fed conditions. Theses, dissertations and student research in agronomy and horticulture. Paper 2.*http://digital commons.unl/agronhort diss/2*

Achieng', J.O., Ouma, G., Odhiambo, G. & Muyekho, F. (2010). Effects of farmyard manure and inorganic fertilizer on maize production of Alfisols and Ultisols in Kakamega, western Kenya. Agriculture and biology journal of North America.

Akram, A., Fatima, M., Ali, S., Jilani, G. and Asghar, R. (2007). Growth, yield and nutrient uptake of sorghum in response to integrated phosphorus and potassium management. Pakistan Journal of Botany, 39(4): 1083-1087.

Alemau, B.F. (2012). Resilience, reliability and risk analyses of maize, sorghum and sunflower in rain-fed systems using a soil moisture modeling approach. Journal of agricultural sciences, 3 (1): 114-123.

Alemu, G. and Bayo, W. (2005). Effects of farmyard manure and combined N and P fertilizer on sorghum and soil characteristics in North Eastern, Ethiopia. Journal of sustainable agriculture, 26 (2): 23-41.

Ashiono, G.B., Ouma, J.P. and Gatwiku, S.W. (2006). Farmyard manure as an alternative source in production of cold tolerant sorghum in the dry highlands of Kenya. Journal of agronomy, 5(2): 201-204.

Azevedo, D.M., Landivar, J., Vieira, R.M. and Moseley, D. (1999). Effect of cover crop and crop rotation on soil water storage and sorghum yield. Pesq. Agro pec. Brasilia, 34 (3): 391-398.

Barrow, E. and Mogaka, H. (2007). Kenya's dry lands- wasteland or undervalued national economic resource. The world Conservation union. www.iucn.org.

Berral, J.H., Navas, G.E. and Clark, R.B. (2002). Developments in plant and soil sciences: Sorghum nitrogen use efficiency in Colombia. Plant nutrition journal, 92: 66-67.

Biamah, E.K., Sterk, G. and Stroosnyder, L. (2003). Hydrological effects of tillage and farmyard manure on crusting and compacting soils in semi-arid Kenya. In J. Tullberg &W. Hoogmoed (Eds.). Soil management for sustainability, proceeding of 16th international soil tillage research organization conference: 150-158.

Bloom, P.R., Gollany, H.T., Lewandowski, A., Hansen, N.C., Allan, D. and Cheng, H.H. (1999). Generic environmental impact assessment for animal agriculture: A summary of literature related to soil. Minnesota, college of agriculture, food and environmental sciences.

Blumenthal, J., Baltensperger, D., Cassman, K.G., Mason, S. and Pavilista, A. (2008). Importance and effects of nitrogen on crop quality and health. Agronomy and Horticulture faculty publications paper 200. http://digitalcommons.un/.edu/agronomyfacpub/200

Brentrup, F. and Palliere, C. (2010). Nitrogen Use Efficiency as an agro-environmental indicator. OECD Workshop, "Agri-environmental indicators: lessons learned and future directions". 23-26 March 2010, Leysen, Switzerland. www.fertilizer.europe

Buah, S.S.J. and Mwinkaara, S. (2009). Response of sorghum to nitrogen fertilizer and plant density in the Guinea savannah zone. Journal of agronomy, 8 (4): 124-130.

Cakmak, D., Saljnikov, E., Perovic, N., Jaramaz, D. and Mrvic V. (2010). Effect of long-term nitrogen fertilization on main soil chemical properties in Cambisol. 19th World congress of soil science, soil solutions for changing world, Brisbane, Australia.

Canadian Fertilizer Institute (CFI) (1998). Nutrient uptake and removal by field crops. Eastern Canada.

Chandy, K.T. (2010). A booklet on Farmyard manure. Booklet no. 63. Manures and fertilizers. MFS-2/1.www.inseda.org

Cholick, F.A. (1991). The effects of nitrogen fertilizer on soil. Kansas State University, Department of Agronomy.

Creswell, R. and Martin, F. W. (1998). Dryland farming: crops and techniques for arid regions, ECHO Technical note, Durrance Rd. USA. www.echonet.org

Dejene, M. and Lemlem, M. (2012). Integrated agronomic crop management to improve teff productivity under terminal drought. In I.M. Rahmand and H. Hasegawa (Eds). Water stress. Tech Open Science (2012): 235-254.

Drechsel, Gyiele, L., Kunze, D. and Olufunke, C. (2001). Population density, soil nutrient depletion, and economic growth in SSA. Ecological Economics, 38: 251-258.

Dubey, V., Patel, A.K., Shukla, A., Shukla, S. and Singh, S. (2012). Impact of continuous use of chemical fertilizer. International Journal of Engineering Research Development 3(11):13-16.

Esipisu, I., 2011. Gadam sorghum in semi-arid Eastern Kenya.*Http://ipsnews.net/news.asp?idnews=55737 Sorghum Proving Popular with Kenyan Farmers*.

FAO Kenya (2007). Food security profiles. District profiles for 23 districts: pp. 28-34.

FAO/ UNESCO (1970). Soil map of the world, Volume 1. Paris: UNESCO.

FOSS Analytical (2010). Flow Injection analysis. Slangerupgade 69, Denmark.

Gardner, J.C., Maranville, J.W. and Paparozzi, E.T. (1994). Nitrogen use efficiency among diverse sorghum cultivars. Journal of Crop Science, 34(2).

Ghoshal, N. (2002). Available pool and mineralization rate of soil N in a dry land agro-ecosystem: Effect of organic soil amendment and chemical fertilizer. Tropical Ecology, 43(2): 363-366.

Gikonyo, E.W. and Smithson, P.C. (2004). Effects of farmyard manure, K and their combination on maize yields in the high and medium rainfall areas of Kenya. In Bationo, A. (Ed.) Managing nutrient cycles to sustain soil fertility in Sub-Saharan Africa: (pp137-149). Nairobi, Kenya: Academic science publishers.

Goings, K.A. (1999). Basic biological factors of soil carbon and nitrogen. National soil survey Centre. Lincoln, Nebraska.

Government of Kenya, 2011, National food and nutrition security policy

Grant, C., Bittman, S., Montreal, M., Plenchette, C. and Morel, C. (2005). Soil and fertilizer phosphorus: Effects on plant P supply and mycorrhizal development. Canadian Journal of Plant Science 85(1): 3-14.

Gruhn, P., Goletti, F. and Yudelman, M. (2000). Integrated nutrient management, soil fertility and sustainable agriculture: current issues and future challenges. Food, Agriculture and Environment discussion paper 32.

Guang-hua, Y., Yeyie-Shen, Na Tong, JianGu, Hao Liang and Zuo-Xin-Liu (2012). Drought induced changes of physio-biochemical parameters in maize. Journal of Food. Agriculture and Environment, 10 (1): 853-858.

IIRR. (2002). Managing dryland resources- An extension manual for Eastern and Southern Africa. International Institute of Rural Reconstruction, Nairobi, Kenya.

International Fertilizer Development Centre (IFDC) (2013). Integrated Soil Fertility Management. IFDC, Alabama, USA.

Iqbal, M., A.G. Khan, A.U. Hassan, M.W. Raza, and M.Amjad (2012). Soil health indices: Soil organic carbon, nitrate contents, physical properties and maize growth as influenced by dairy manure and nitrogen rates. International Journal of Agriculture and , 14: 20-28.

Irungu, P., Ndirangu, L. and Omiti, J. (2009). Social protection and Agricultural Development in Kenya. Future Agricultures working paper 005. www.futureagricultures.org.

Johnston, A.E. and Syres, J.S. (2009). A new approach to assessing phosphorus use efficiency in agriculture, Better Crops 93(3): 14-16.

Jones C. and Jacobsen J. (2001), Plant Nutrients and Soil fertility. Nutrient Management module 2. Montana State University.

Jones C., Dinkins, C.P. and Olson-Rutz, K. (2011), Nutrient uptake timing by crops: to assist with fertilizing decisions. Montana State University.

Julio, H. and Carlos, B. (1999). Nutrient depletion in agricultural soils of Africa. A 2020 vision for food, agriculture and environment (brief 62).

Julio, H. and Carlos, B. (2006). Agricultural production and soil nutrient mining in Africa: implication for resource conservation and policy development. International Centre for Soil Fertility and Agriculture Development. Alabama, U.S.A.

Kayuki, C.K., Byalebeka, J., Semalulu, O., Alou, I., Zimwanguyizza, W. and Wortmann, S.C. (2012). Sorghum response to fertilizer and nitrogen use efficiency in Uganda. Agronomy journal, 104(1): 83-90.

Kenya Agricultural Research Institute (KARI) (2006). Variety, Characteristics and Production Guidelines of Traditional Food Crops

Kenya Arid and Semi-Arid Land Programme (KASAL) of KARI 2010 report.

Keshavarz, A., Mohammadan, N.R., Moraditochae, M., Azarpour, E. and Fekr, A.S. (2012). Study of effects of biological, manure and chemicals nitrogen fertilizer application under irrigation management in lentil farming on physiochemical properties of soil. Journal of Basic and Applied Scientific Research 2(7): 6483-6487.

Kissel, D.E. and Sonon, L. (2008). Soil test handbook for Georgia, Bulletin 62, The University of Georgia, Athens, Georgia.

Kogbe, J.O.S. and Adediran, J.A. (2003). Effect of nitrogen, phosphorus and potassium application on the yield of maize in the savannah zone of Nigeria. African Journal of Biotechnology 2(10): 345-349.

Kothari, C.R. (2004). Research Methodology: Methods and techniques, 2nd edition. New Age International (P) Limited, Publishers, New Delhi, India.

Kotschi, J. (2013). A soiled reputation: Adverse effects of mineral fertilizers on tropical agriculture, Heinrich Boll Stiftung, WWF Germany.

Krotz, L. Ragaglia, L., and Giazzi, G. (2013). Quick, accurate nitrogen, total Carbon and total Organic carbon determination in soils by elemental analysis, Strada, Rivoltana, Italy.

Luu, H.M., Khang, V.T. and Takeshi, W. (2013). Effect of manure and fertilizer on soil fertility and soil quality. Delta rice research institute, Omon, Vietnam.

Magagula, N.E., Ossom, E.M., Rhykerd, R.L. and Rhykerd, C.L. (2010). Effects of chicken manure on soil properties under sweet potato (ipomoea balatas (L.) Iam) culture in Swaziland. American-Eurasian Journal of Agronomy, 3(2): 36-43.

Mahmoud, E., Nasser, A.E., Robin, P., Nouraya, A.C. and Lamyaa, A.E. (2009). Effect of different organic and inorganic fertilizers on cucumber yield and some soil properties. World Journal of Agricultural Sciences, 5(4): 408-414.

Malathesh G.H. (2005), Nutrient Substitution through Organics in Maize (Master’s Thesis), University of Agricultural Sciences, Dhār ward.

Malhi, S.S., Haderlein, L.K., Pauly, D.G. and Johnston, A.M. (2002). Improving fertilizer phosphorus use efficiency, Better crops 86(4): 8-9.

Maranville, J.W., Pandey, R.K. and Sirifi, S. (2002). Comparison of nitrogen use efficiency of a newly developed sorghum hybrid and two improved cultivars in the Sahel of West Africa. Communications in Soil Science and Plant Analysis, 33: 9-10.

Miano, M.D., Karanja, D., Mutuku, R., and Maina, L. (2010). The role of the market in addressing climate change in arid and semi-arid lands of Kenya: the case of Gadam sorghum

Mikkelsen, R. (2005). Nutrient Use Efficiency: Using nutrient budgets, Western Nutrient Management conference 2005, Vol. 6. Salt Lack City, UT.

Mochoge B.O., S. Kanyanjua and S. Obanyi (1997). Response of maize, Maize-cowpea intercrop and pigeon pea to N and P fertilizer and farmyard manure. African Crop Science Conference proceedings vol.3 pp. 439-448, printed Uganda

Mohanty, M., Probert, M.E., Sammi Reddy, K., Dalal, R.C., Subba Rao, A. and Menzies, N.W. (2010). Modeling N mineralization from green manure and farmyard manure from Laboratory incubation study. 19th World Congress of Soil Science, soil solutions for a changing world. Brisbane, Australia.

Mohsin, A.U., Ahmad, J., Ahmad, A. U. H., Ikram, R.M. and Mubeen, K. (2010). Effect of nitrogen application through different combinations of urea and farmyard manure on the performance of spring maize. Journal of Animal and Plant Science, 195-198.

Moore, K.P. (1992). Determination of phosphorus in plant tissue by colorimetry. In Plank, C.O. (Ed.), Plant analysis reference procedures for southern region on the United States. Plant Anal. Ref. Proc.for US (SC SB#368) (pp. 27-29).

Mubarak, A.R., Gali, E.A.M., Mohamad, A.G., Steffens, D. and Awadelkarim, A.H. (2010). Nitrogen mineralization from five manures as influenced by chemical composition and soil type. Communications in Soil Science and Plant Analysis, 41(10): 1903-1920.

Muchena, F.N. (1975). Soils of Kampi ya Mawe: Agricultural experimental sub-station. Detailed soil survey report no. D1, 1975.

Mugenda, O.M. and Mugenda, A.G. (2003). Research Methods, Quantitative and Qualitative Approaches. African Centre for Technology Studies (ACTS), Nairobi, Kenya.

Munir, I., Ranjha, A.M., Sarfraz, M., Obaid-ur-rehman, Mehdi, S.M. and Mahmood (2006). Effect of residual phosphorus on sorghum fodder in two different textured soils. International Journal of Agriculture and Biology, 6(6): 967-969.

Muriu, F., Kung'u, J., Karega, R., Njuki, J., Mucheru-Muna, M. and Mugendi, D. (2005). Adoption of nutrient replenishment technologies by farmers in Kirege sub-location of Central Kenya. African Crop Ccience Proceedings. 7:1501-1505.

Mwangi, T.J., Moebe, S.N., Wanjekenche, E., Onyango, R., Ngeny, J. & Osore, Z. (2010). Improving and sustaining soil fertility by using farmyard manure and inorganic fertilizer for economical maize production in West Pokot, Kenya. World Journal of Agricultural Sciences, 6(3):313-321.

Nahm, K.H. (2004). Mineralizing during poultry litter composting and calculations for available N. Feed and nutrition laboratory college of natural resources, Taegu University, South Korea.

Nareed, Iqbal, K. Asmaut, U. Malik, Umer, F. and Irfan, M. (2010). Effects of tillage and farmyard manure on physical properties of the soil. International Research Journal of Plant Science, 1 (4): 075-082.

Nikus, O., Munir, A.T. and Abdel, R.M. (2004). Yield response of sorghum (sorghum bicolor L.) to manure supplemented with phosphate fertilizer under semi-arid Mediterranean conditions. International Journal of Agriculture and Biology, 6 (5): 889-893.

Obia, A. (2011). Use of soil amendment on adaptation strategy to global climate change. A master's thesis, Vrije University, Brussels, Belgium.

Ogunmwoyi, I.N., Igbinosa, O.E., and Odjadjare, E.E. (2008). Microbial analysis of different top soil samples of selected site in Obafemi Awolowo University, Nigeria. Scientific Research and Essay 3(3): 120-124.

Oikeh, S.O., Chude, V.O., Kling, G.J. and Horst, W.J. (2007). Comparative productivity of nitrogen-use efficient and nitrogen-use inefficient maize cultivars and traditional grain sorghum in the moist savanna of West Africa. African Journal of Agricultural Research, 2(3): 112-118.

Okalebo, J.R., Kenneth, W.G. and Woomer, P.L. (2002). Laboratory method of soil and plant analysis. Second edition, SACRED Office Nairobi, 128p.

Omotayo, O.E. and Chukwuka, K.S. (2009). Soil fertility techniques in SSA using organic resources. African Journal of Agricultural Research, 4 (3): 144-150.

Ongeko, T. (2011). Farmers in Makueni turn to drought tolerant crops (source: coast week news)

Ouedrago, E. and Mando, A. (2010). Effects of tillage and organic matter quality on sorghum fertilizer use and water use efficiency in semi-arid West Africa. 19th world congress of soil science, soil solutions for a changing world, Brisbane, Australia.

Pal, U.R., Upadhyay, Singh, S.P. and Umrani (1982). Mineral nutrition and fertilizer response of grain sorghum in India- A review of 25 years.

Fertilizer Research 3: 141-159. Indian Agricultural Institute, New Delhi India.

Peacock, A.D., Mullen, M.D., Ringerlberg, D.B., Tyler, D.D., Hedrick, D.B. and White, D.C. (2001). Soil microbial community responses to dairy manure or ammonium nitrate applications. Soil Biology and Biochemistry, 33(1): 1011-1019.

Penn State Extension (2013). Managing Phosphorus for crop production. Agronomy facts 13. College of Agricultural Sciences, Penn State University.

Rajendra, P. (2009). Efficient fertilizer use: The key to food security and better environment.

Reeves, D.W. (1997). The role of soil organic matter in maintaining soil quality in continuous cropping systems. Soil and Tillage research, 43:131-167.

Roberts, T.L. (2008). Improving nutrient-use efficiency. Turkey Journal of Agriculture, 32(1):177-182.

Sanchez, C. A. and Doerge, T. A. (1999). Using nutrient uptake patterns to develop efficient management strategies for vegetables. Horticulture Technology 9(4): The University of Arizona.

Satyanarayan, V., Prasad, P.V.V., Murthy, V.R.K. and Boote, K.J. (2002). Influence of integrated use of FYM and inorganic fertilizer on yield and yield components of irrigated lowland rice. Journal of Plant Nutrition, 25 (10): 2081-2090.

Savoy, H. (2009). Interpreting Mehlich 1 and 3 soil test extractant results for P and K in Tennessee, University of Tennessee, Institute of Agriculture.

Seghatoleslami, M.J., Kafi, M. and Majidi, E. (2008). Effect of drought stress at different growth stages on yield and water use efficiency of five proso millet (pancum miliaceum L.) genotypes. Pakistan journal of botany, 40 (4): 1427-1432.

Shirani, H., Hajabbasi, M.A., Afyuni, M. & Hemmat, A. (2002). Effects of farmyard manure and tillage systems on soil physical properties and corn yields in central Iran. Soil and Tillage Research. 68: 101-108.

Shisanya, C.A. (2003). A note on the response by smallholder farmers to soil nutrient depletion in the East African Highlands. Food Agriculture and Environment, 1 (3 and 4): 247-250.

Siderious, W. and Muchena, F.N. (1977). Soils and environmental conditions of agricultural research stations in Kenya. Ministry of Agriculture, National Agricultural Laboratories, Kenya soils. Miscellaneous soil paper No. Ms, 1977.

Smaling, E.M.A., and Braun, A.R. (1996). Soil fertility research in Sub-Saharan Africa: new dimensions, new challenges. Communication, Soil Science. Plant Analysis 27(3 and 4): 365-386.

Solhi, S., Solhi, M., Sief, A., Aghakhani, A., Farhad, S., Mousari and Jahangir, A.K. (2012). Effect of nitrogen fertilizers on nitrate leaching from a saline soil profile under corn and barley cultivation. International Research Journal of Applied and Basic Sciences 3(3):563-567.

Stewart, W.M. (2003). A regional newsletter published by the potash and phosphates institute of Canada, Texas

Syres, J.K., Johnston, A.E., Cortin, D. (2008). Efficiency of soil and fertilizer phosphorus use: Reconciling changing concepts of soil phosphorus behaviour with agronomic information- FAO fertilizer and plant nutrition bulletin 18, Rome, Italy.

Tadesse, T., Dechassa, N., Bayu, W. and Gebeyen, S. (2013). Effects of FYM and inorganic fertilizer application on soil physico-chemical properties and nutrient balance in rain fed lowland rice. American Journal of Plant Sciences, 4(1): 309-316. DOI:10.4236/ajaps.2013.42041.

Tasneem, K., Tariq, M. Kamal, J. & Masood, A. (2004).Effectiveness of farmyard manure, poultry manure and N for corn productivity. International Journal of Agriculture and Biology: 260-263.

Tayebeh, A., Alemzadeh, A. and Kazameini, S.A. (2010). Effect of organic and inorganic fertilizer on grain yield and protein banding pattern of wheat. Australian Journal of Crop Science 4(6): 384-389.

Taylor, J.R.N., 2003. Overview: importance of sorghum in Africa

The Centre for Science and Technology Innovation (CSTI) 2009 report.

Timu, A.G., Mulwa, M.R., Okello, J. and Kamau, M. (2012). The role of varietal attributes on adoption of improved seed varieties. The case of sorghum in Kenya. Tegemeo institute of agricultural policy development, Nairobi, Kenya.

Tolessa, D. and Friesen, D.K. (2001).Effects of enriching farmyard manure with mineral fertilizer on grain yield of maize at Bako, Western Ethiopia. Seventh eastern and southern Africa regional maize conference: 335-337.

Wakene, N. Negisho, K., Friesen, D.K., Ransom, J. and Abebe, Y. (2001). Determination of optimum farmyard manure and N P fertilizers for maize on farmers' fields. Seventh eastern and southern Africa regional maize conference: 387-393.

Whitney, D.V., Stone, L.R., Janssen, K.A. and Long, H.L. (1991). The effects of nitrogen fertilizer on soils of Kansas State University, Kansas, U.S.A.

Wopereis, M.C., Tamelokpo, A., Ezui, K., Gnakpenou, D., Fofana, B. and Breman, H. (2006). Mineral fertilizer management of maize on farmers' fields with differing inorganic inputs in the West African Savannah. Field Crop Research 96: 355-362. www.sciencedirect.com.

Yagathjoth, N., Ramamoorthy, K. & Kokita, V. (2008). Effect of farmyard manure with and without enrichment on soil microbial population, soil fertility, yield and economies. Research Journal of Agriculture and Biological science. 4 (6): 647-650.

Zentner, R.P., Spratt, E.D., Reisdorf, H. and Campbell, C.A. (1987). Effect of crop rotation and N and P fertilizer on yields of spring wheat on Black chernozemic clay. Journal of Plant Science 67(1): 967-982.

7.0. APPENDICES

Appendix I: Treatments and their randomization

EXPERIMENT 1 FIELD LAYOUT

PLOT SIZE: 4.5X4.5m

Table 21: Experiment 1 field layout.

BLOCK1	BLOCK2	BLOCK3
TRT	**TRT**	**TRT**
T1	**T8**	**T13**
T2	**T9**	**T14**
T3	**T10**	**T15**
T4	**T11**	**T16**
T5	**T12**	**T1**
T6	**T13**	**T2**
T7	**T14**	**T3**
T8	**T15**	**T4**
T9	**T16**	**T5**
T10	**T1**	**T6**
T11	**T2**	**T7**
T12	**T3**	**T8**
T13	**T4**	**T9**
T14	**T5**	**T10**
T15	**T6**	**T11**
T16	**T7**	**T12**

EXPERIMENT 2 LAYOUTS

PLOT SIZE: 4.5X4.5m

Table 22: Experiment 2 field layout.

BLOCK1	BLOCK2	BLOCK3
TRT	**TRT**	**TRT**
T1	**T5**	**T3**
T2	**T6**	**T4**
T3	**T1**	**T5**
T4	**T2**	**T6**
T5	**T3**	**T1**
T6	**T4**	**T2**

Appendix II: Formulas

1. **Calculating nitrates –N in the soil**

$$\boldsymbol{w = (C \times V)/W}$$

Where:

w= mg NO3-N/kg soil

C= concentration nitrate as mg/l NO3-N

V= volume of the extract in ml

W= weight of the sample in g

2. Calculating ammonium –N in the soil

$$\boldsymbol{w = (C \times V)/W}$$

Where:

w= mg NH_4-N/kg soil

C= concentration ammonium as mg/l NH_4-N

W= weight of soil sample in g

3. Determining soil moisture content (gravimetric method)

W= 100Mw/Ms

Where:

W= soil moisture content in %

Ms= dry mass of soil

Mw= mass of water in soil

4. Determining Agronomic fertilizer Use Efficiency (AE)

AE = (kg grain/ kg nutrient applied)

$$\boldsymbol{AE = (yf - yc)/Na}$$

Where:

yf = yields in fertilized plots (kg/ha)

yc = yields in the control plots (kg/ha)

Na = amount of nutrient applied (kg/ha)

5. Determining volumetric soil water content

Volumetric soil water= gravimetric soil water* bulk density/ density of water

6. Determining available soil N in kg/ha

Available soil N= available soil N (mg/kg)* bulk density* test depth*0.1

(Calvert et al., 2013)

Appendix III: laboratory methods used for soil and plant tissue analysis

Table 23: Laboratory methods used for soil and plant tissue analysis.

SOIL PROPERTIES	METHOD USED	INSTRUMENT USED
pH water	1:2.5 (soil: water)	pH meter
pH KCl	1:2.5 (soil: KCl)	pH meter
Soil total carbon	Flash combustion method	CN Analyzer
Soil total N	Flash combustion method	CN Analyzer
Available N	Flow injection method: 1. Cadmium reductor column for nitrates 2. Gas diffusion method for ammonium	Flow Injection Analyzer (FIA)
Available P	Mehlich 1 method	UV- Visible spectrophotometer
Magnesium	Mehlich 1 method	UV- Visible spectrophotometer
Cations (Ca, K, Na)	Mehlich 1 method	Flame photometer
Fungi population in soil	Dilution plate counting method	Colony counter
Bacteria population in soil	Dilution plate counting method	Colony counter
Plant total N	Flash combustion method	CN Analyzer

Appendix IV: laboratory procedures used

Grain yields

The Method used to determine sorghum grain yield was:

a) Method 1

- The grain was shelled from the panicle and then oven dried them at 70^0C for 48hrs in the same paper bag until a constant weight was observed. The dry weight of sorghum grain was obtained. The yields of sorghum were then calculated based on dry weights obtained.

b) Grain yield, dry weight (Kg/ha):

$$\frac{\text{(Total fresh wt.)* (subsample dry wt.) *10000}}{\text{(Subsample fresh wt.) * (area harvested)}}$$

Where fresh weights total is in kg and other weights are in grams, and the area harvested is in M^2. When total fresh weight is expressed in grams, the 10000 is replaced by 10.

Appendix V: Soil textural triangle.

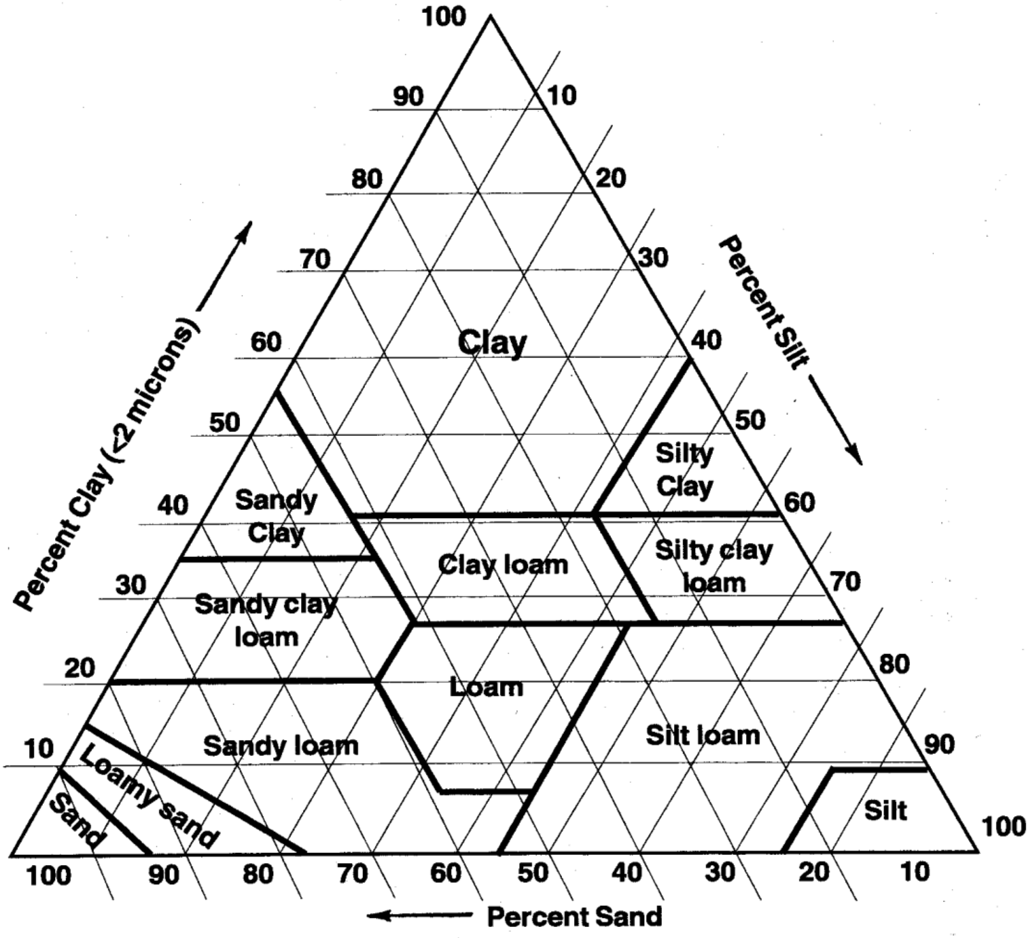

Figure 12: Soil textural triangle

Appendix vi: Nitrogen in soil Kg/ha N

Table 24: NO_3^- concentration in soil in Kg/ha.

SOIL AVAILABLE N						
	NO_3^- Kg/ha					
	KAMPI YA MAWE			KATUMANI		
TREATMENTS	WK4	WK8	WK12	WK4	WK8	WK12
N0-P0	16.56	8.18	3.60	27.48	32.62	32.62
N0-P75	19.19	5.93	1.92	19.98	27.13	27.13
N75-P0	25.48	14.28	6.53	59.66	75.66	75.66
N75-P75	28.22	11.41	3.59	72.77	40.44	40.44
NP0-M10	28.18	13.34	7.18	35.83	32.97	23.01
NP50-M0	32.53	15.76	6.11	44.98	44.72	36.37
NP50-M10	31.72	12.79	6.81	47.40	63.86	45.63

Table 25: NH_4^+ Concentration in soil in kg/ha.

	NH_4^+ Kg/ha					
	KAMPI YA MAWE			KATUMANI		
TREATMENTS	WK4	WK8	WK12	WK4	WK8	WK12
N0-P0	7.02	4.54	8.13	9.37	9.74	6.89
N0-P75	12.82	10.48	7.67	10.54	7.16	6.77
N75-P0	26.87	9.90	9.74	9.84	26.78	45.56
N75-P75	22.20	11.11	9.56	40.73	24.16	22.32
NP0-M10	15.78	8.40	15.24	15.68	11.36	10.06
NP50-M0	15.76	12.27	8.01	18.85	27.64	21.97
NP50-M10	50.31	8.58	9.67	10.87	14.66	31.56