INFLUENCE OF TILLAGE PRACTICES,CROPPING SYSTEMS AND ORGANIC INPUTS ON SOIL MOISTURE CONTENT, NUTRIENTS STATUS AND CROP YIELD IN MATUU,YATTA SUB COUNTY, KENYA.

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UON

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DECLARATION

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

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DEDICATION

This thesis is dedicated to my family, who has been a great source of motivation, and inspiration especially my father and mother who gave me love and support.

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ABSTRACT

Crop production in arid and semi-arid lands (ASALs) is constrained by insufficient and unreliable rainfall, and low soil fertility. Against this backdrop a survey and field experimentwas conducted in Matuu, Yatta sub-county. Survey was meant to determined farmers' perception on climate change, crop production trends and moisture conservation techniques whereas the on farm field experimentsevaluated the influence of tillage practices, cropping systems and organic inputs on soil moisture content, soil nutrient (NPK and organic carbon) and crop yield.The experimental was laid out in Randomized Complete Block Design with a split-split plot arrangement replicated thrice. The main plots were tillage practices (TP); Oxen plough (OP), tied ridges (TR) and furrows and ridges (FR). Split-plots were cropping systems (CS); mono cropping (MC), intercropping (IC) and crop rotation (CR) while split-split plots were organic inputs; Farm Yard manure (FYM), Minjingu Rock Phosphate (MRP), combined MRP and FYM (MRP+FYM) and their control. The test crops were sorghum and sweet potatoes with Dolichos (*Dolichos lablab*) and chickpea (*Cicerarietinum*L.) grown either as intercrops or in rotation. The experiment was carried out for two seasons between October 2012 to February 2013 and March to August 2013.Soil samples were taken from the test plots randomly at crops maturity, at a depth of 0–15, for determination of; soil moisture content on per cent dry weight basis, Nitrogen, Phosphorous, Potassium and organic Carbon. Crop yield was also determined by weighing grain and tuber. Most (92%) farmers have perceived climate change in the study area and the aspects include increasing temperature, erratic rainfall. Most (83.3%) farmers reported, unreliable rainfall, pests and diseases, drought, low soil fertility, lack of inputs and low soil moisture as constraints to agricultural production. The crop production trend showed that most farmers hadabandoned crops such as cassava, sorghum and sweet potatoes (also known as traditional crops) in favour of introduced crops such as beans, maize and wheat. About 15%, of the farmers stated manure application, basin and terraces respectively as methods of coping with low soil moisture. Significant ($p \leq 0.05$) increased in soil moisture content was recorded in TR under IC of dolichos with application of FYM (7.53% and 7.88%) for sorghum and sweet potato plots respectively. Least moisture levels were recorded in MRP applied plots across all TP and CS. Moisture content in the second season followed same pattern across TP and CS as for first season but not significantly ($P \leq 0.05$) different between seasons. There was a significant ($P \leq 0.05$) increased potassium (1.91 Cmol+Kg), phosphorous (51.45 ppm), Total nitrogen (0.19%) and organic carbon (2.19%), in TR underintercrop sorghum/chickpeawith application of MRP+FYM.There was a significant ($P \leq 0.05$) increase on the yield of sorghum and sweet potatoes with a significant ($P \leq 0.05$) increase yield in plots with MRP+ FYM and FYM across all the tillage practices and cropping systems. Mono cropped sweet potato (16.27t/ha) and sorghum (1.38 t/ha) yields were highest under tied ridges with application of MRP+FYM. The changing climate as perceived by the farmers vis-à-vis the emerging crop production trends calls for better methods of soil moisture conservation and production of adapted crops. The field experiment conformed from concern raised during the survey i.e. decreased soil fertility, crop yield and soil moisture these were as a result of climate change and crop production trends these led the researchers to carry out field experiment on tillage practices, cropping systems and oranic inputs identified by the farmers. Intercrop and crop rotation of sorghum and sweet potatoes with dolichos under tied ridges with application of MRP+FYM is a viable technology for increased soil moisture, nutrients, and crop yield.

Key words: Arid and semi arid areas; climate change; cropping systems; organic inputs; tillage practices; Traditional crops**.**

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LIST OF ACRONYMS AND ABBREVIATIONS

ASALs	Arid and Semi lands
ANOVA	Analysis of variance
BNF	Biological Nitrogen fixation
C: N: P	Carbon: Nitrogen : Phosphorous
FAO	Food Agricultural Organization
FYM	Farm Yard Manure
GoK,	Government of Kenya
ICRISAT	International Centre for Research in Semi-Arid Tropics
KARI	Kenya Agricultural Research Institute
MoA	Ministry of Agriculture
MRP	Minjingu Rock Phosphate
SSA	Sub-Saharan Africa

CHAPTER ONE

1.0 General Introduction

In developing countries, Arid and Semi-Arid Lands (ASALs) are the most vulnerable and likely to be affected hardest by climate change due to their low adaptive capacity (IPCC, 2000). For instance Kenya , the ASALs occupy over 80% of the country and host about 10 million people. These areas have the lowest development indicators and the highest incidence of poverty (United Nations, 2000). Over 60% of the ASALs inhabitants live below the poverty line (subsisting on one dollar per day) (GoK, 2004). The most limiting factor to crop production in the ASALs is unavailability of soil moisture especially Yatta sub county. The low rainfall together with its unreliability and poor distribution severely limits crop production (KARI, 1996). Additionally, the low quality of soil resource base which on one hand has been due to inherent and induced deficiencies of major nutrients N, P and K or low nutrient holding capacity, high acidity and low organic matter (Kaolo R. 2003) negatively affect crop production.

To combat soil fertility issue the application of manures to soil provide potential benefits including; improving the fertility, structure, increasing soil organic matter, water holding capacity and reducing the amount of synthetic fertilizer needed for crop production (Phan *et al.*, 2002, Blay *et al.*, 2002). Manures are the main sources of nitrogen (N) supply in organic production. The phosphorous content in rock phosphate is 25-31% P_2O_5 and has low solubility (Akande 2005, Adetuji, 2006). Application of ground rock phosphate has been proved beneficial to crops (Akande *et al.,* 2008a). Intercropping preferentially spreading types of crops legumes, pumpkins, or sweet potato contribute to a faster and denser ground cover and suppress weed growth at least during the growing season (Steiner and Towmlow, 2003). The rotation of crops with species that increase plant residues on the soil surface is fundamental to avoid erosion and to improve nutrient cycling through nutrient mobilization from deeper soil layers (Crusciol *et al.*, 2005) to the top. Plant residues of untilled crops form a nutrient reserve as wel as conserve soil moisture (Rosolem *et al.,* 2003).

In addition tillage practices such as; tied ridges and furrows and ridges would allow rainwater retained on open furrows for longer duration as the water infiltrates the soil or soil management techniques that favour prolonged rainwater infiltration and retention thus raising the overall soil moisture retention and soil water holding capacity and hence improved crop production in asals (Itabari, 2003). The traditional crops have the potential to contribute to food security, nutrition, health, income generation, and environmental services, have been abandoned because of a variety of socio-economic and cultural reasons (NEMRI, 2009). Traditional cropsinclude; sorghum and sweet potato also termed as abandoned crops especially in the ASALs. These crops are drought resistant and can withstand high temperature unlike the introduced crops. Planting of drought-resistant crops reduces the risk of total loss during drought. Sweet potato and cassava, for example, are typically hardy and adapted to the arid and semi arid climate, thus making them very valuable (Beehive, 2011). Sorghum and sweet potato are crops that were widely grown by the resource poor farmers in the ASALs of Kenya for subsistence and as a source of income (Macharia, 2004). Sweet potato (*Ipomoea batatas L*) is among the world`s most important and under- exploited crop. It is commonly referred to a subsistence, food security, or famine relief crop (Scott and Maldinado, 1999). In addition sweet potato provides good ground cover, and is usually cultivated with little or no fertilizer (Lusweti*et al.,* 1999). Sorghum (*sorghum bicolor L.*), on the other hand, is an important food security crop in Kenya. It is a drought resistant and performs well on a range of poor soils with low rainfall often out-yielding most cereals in hot and dry environments. It is particularly adapted to agro ecological zones of Kenya, which are arid and semi-arid. These include the semi-arid areas of Eastern Kenya, the coastal, the waterlogged areas (Kameri-Mbote, 2005).

There is however a dearth of literature on combined effects of tillage practices, cropping system and organic inputs on soil moisture content, soil nutrient status and yield of crops in the study areas as this has only been done singly.

From the study it is hypothesized that application of tillage practices, cropping systems and organic inputs improved soil productivity and crop production in Matuu Yatta sub-county.

1.1 Statement of the Problem

The most limiting factor to crop production in arid and semi-arid lands (ASALs) is unavailability of soil moisture. Most soils in arid and semi-arid areas of Kenya are sand which pose a great challenge because of their poor structure and course texture of sand soils results in low water holding capacity and low nutrient content and retention (Batiano, 1998).

Low productivity of agriculture especially in Yatta sub county is related to low quality of soil resource base, which on one hand has been due to inherent and induced deficiencies of major nutrients N, P and K or low nutrient holding capacity, high acidity, and low organic matter (Kaolo R. 2003).Fertilizer use is low because of their unavailability at the right time, high cost owing to the resource poor farmers. It is therefore a major challenge to sustain crop yields. (Rao and Mathuya, 2000). Typically, smallholder systems in the study area are characterized by continuous cropping with few external nutrient inputs and removal of crop field residues for feeding livestock with limited recycling of nutrients and organic matter back into the soil. The resulting depletion of soil nutrients and organic matter is threatening the sustainability of many agricultural systems (Place *et al.*,2003)

Furthermore, the traditional crops, which have the potential to contribute to food security, nutrition, health, income generation, and environmental services, have been abandoned because of a variety of socio-economic and cultural reasons (NEMRI, 2009) in favour of the so called introduced crops. These crops are drought resistant and can withstand high temperature unlike the introduced crops.

1.2 Justification of the study

In view of insufficient and unreliable rainfall of the ASALs and low soil fertility. Escalating poverty levels, sustainable technological techniques that conserve soil moisture and enhance soil fertility need to be developed and recommended to the smallholder farmers in the ASALs. These technologies will encompass the integration of legumes into the cropping systems, use of organic inputs and tillage practices.

Intercropping preferentially spreading types of crops legumes, pumpkins, or sweet potato contribute to a faster and denser ground cover and suppress weed growth at least during the growing season. The rotation of crops with species that increase plant residues on the soil surface is fundamental to avoid erosion and to improve nutrient cycling through nutrient mobilization from deeper soil layers to the top. Plant residues of untilled crops form a nutrient reserve. The use of rotational systems involving legumes for nitrogen fixation has gained importance. The amount of nitrogen fixed by leguminous crops can be quite high.

Application of manures to soil provide potential benefits including improving the fertility, structure, increasing soil organic matter, water holding capacity and reducing the amount of synthetic fertilizer needed for crop production. The use of indigenous-rock phosphate would improve the phosphorous content of the soil. These practices applied in the production of the abandoned crops such as sweet potatoes and sorghum (traditional crops) will help improve food production in ASALS. The traditional crops which are drought resistant and can withstand high temperature unlike the modern crops and have the potential of contributing to improved nutrition and food security.Tillage practices techniques like the tied ridges and furrows and ridges would allow rainwater to be retained on open furrows and in ridges for longer duration as the water infiltrates the soil thus raising the overall soil moisture.

1.3 Research objectives

1.3.1 Broad objective

To evaluate the influence of tillage practices,cropping systems and organic inputson soil productivity and crop yield.

1.3.2 Specific objectives

i. To assess farmers' perception on climate change crop production trends, and moisture conservation techniques.

ii. To evaluate the efficiency of combined tillage practices, cropping systems and organic inputs on soil moisture retention.

iii. To evaluate the effects of tillage practices, cropping systems and organic inputs on soil Nitrogen, phosphorous, potassium, and organic carbon.

iv. To evaluate the effects of tillage practices, cropping systems and organic inputs on crop yield.

1.4 Hypothesis

i. Farmers' have perceived climate change, crop production trends, and moisture conservation techniques.

ii. Combined tillage practices, cropping systems and organic inputs have an effect on soil moisture retention .

iii. Tillage practices, cropping systems and organic inputs have an effect on soil Nitrogen, phosphorous, potassium, and organic carbon.

iv. Tillage practices, cropping systems and organic inputs had an effect on crop yield.

CHAPTER TWO

2.0 GENERAL LITERATURE REVIEW

2.1 Agricultural production in the Arid and Semiarid Lands

Farmers in the semiarid lands of Eastern Kenya have traditionally relied on food staples such as sorghum, and in drier parts, pearl millet, generally grown in mixed stands with a range of legumes, including beans, cowpea, green gram, and pigeon pea. These crops are both used for consumption and sold for cash in local markets. The farming systems are relatively complex because of the high rainfall variability typical of the semiarid tropics (Government of Kenya, 2005). Inadequate soil moisture is the most limiting constraint to land productivity in the semi-arid lands of Kenya (Itabari *et al.,* 2004). Research conducted in this region over the years has pointed out that rainwater harvesting in combination with significantly increase crop production (Itabari and Wamuongo 2003, Gichangi *et al.,* 2007). Tied ridges and furrows ridges or that allow rainwater retained on open furrows for longer duration as the water infiltrates the soil or soil management techniques that favor prolonged rainwater infiltration and retention thus raising the overall soil moisture retention and soil water holding capacity (Itabari, 2003).

The principal reasons for farmers to intercrop are flexibility, profit, resource maximization, risk minimization, soil conservation and maintenance, weed control and nutritional advantages (Kaolo 2003). Leguminous plants are important for improving soil fertility all over the world including arid tropical countries (Wichema *et al.*, 2004; Muhammad *et al.*, 2006). Traditionally, farmers in the semi-arid tropics intercrop cereals with grain legumes, especially pigeon pea (*Cajanus cajan*),as a strategy for diversifying food production and household income since legumes are both cash and food crops, (Mafongoya *et al.*,2000) also pigeon pea plants are drought tolerant due to deep rooting, thus providing insurance against total crop failure in low rainfall seasons. (Rao and Mathuya, 2000). The legume improves soil fertility and yields of associated as well through biological (N) fixation, nutrient pumping and incorporation of green manure (Chikowo *et al* .,2004).

2.2 Tillage practice

Inadequate soil moisture is the most limiting constraint to land productivity in the semi-arid lands of Kenya (Itabari *et al.*, 2004). Research conducted in this region over the years has pointed out that rainwater harvesting in combination with significantly increase crop production (Itabari and Wamuongo 2003, Gichangi *et al.*, 2007). Tied ridges and open ridges or that allow rain water to be retained on open furrows for longer duration as the water infiltrates the soil or soil management techniques that favor prolonged rainwater infiltration and retention thus raising the overall soil moisture retention and soil water holding capacity (Itabari, 2003).

Tied ridge system involve the use of semi-permanent ridges about 20-25 cm high with additional ridge with additional stress between the furrows at a short interval. In soils with low organic matter, fine textured, compacted soils with low infiltration rates high run-off and soil loss tied ridges has been found to be efficient and effective method for conserving soil moisture it enhance rapid buildup of soil moisture needed for rapid germination and early plant growth (Yitebitu, 2004).Ridge tillage is a conservation tillage system that is fast gaining popularity in many dry land areas of the world improves soil density and reducing soil resistance to root elongation (Chiroma *et al.*, 2005).

Many techniques have been tried to utilize rain water of these are ridges and furrows and tied ridges with mulching is one of the most effective measures (Li *et al.*,2000). The traditional method that was used to plant sweet potatoes was the flat method (Yuan et *al.*, 2003.In Northern Ethiopia, Brhane *et al*., (2006) found sorghum (*Sorghum bicolour* L. Moench) yield increased by 62% with tied ridging compared with flat planting.Drought adapted early maturing crops combined with reduced tillage practices have the potential to stabilize and increase dry land crop yields in semi-arid regions of the world (Moroke, 2011)

2.3 Cropping systems

A suitable crop rotation combines cereals and legumes (Steiner 2002). The rotation of crops with species that increase plant residues on the soil surface is fundamental to avoid erosion and to improve nutrient cycling through nutrient mobilization from deeper soil layers (Crusciol *et al.*, 2005) to the top. Plant residues of untilled crops form a nutrient reserve (Rosolem *et al.*, 2003). Therefore, the use of species different from the main crop such as legumes contributes to the nutrient balance, which may consequently increase soil fertility over time. Leguminous species are known for their capacity to fix atmospheric nitrogen and narrow the C/N ratio, resulting in faster residue decomposition (Aita and Giacomini, 2003) and consequent release of accumulated N and other nutrients such as P and K, to the soil

(Borkert *et al.,* 2003). Well-managed crop rotations increase soil organic matter to sufficient levels help to moderate soil moisture, retain moisture in dry conditions, and allow excess moisture to drain away in wet seasons. Shifting crop types also helps vary water demand within the soil profile. The deep-rooted crops following shallow crops can access moisture reserves as well as capture any nutrients that have leached below the shallower root zones before they reach groundwater (Adam *et al.*, 2011).

According to (VAST 2007) the aims of crop rotation include; improve or maintain soil fertility, reduce soil erosion, reduce the buildup of pests and weeds and mitigate risk of weather changes.Studies have shown that cereals derive both yield and N benefits from rotation from grain legumes compared with cereal monoculture (Kirkegaard *et al.,* 2008). Legume green manures have the added benefit of producing plant-available N through biological N2 fixation (BNF) from the atmosphere, and greatly improve the residue biomass quality. Legumes are also efficient at mobilizing P from the soil (Knight and Shirtliffe, 2005), and the stimulation of rhizosphere activity increases P uptake by other crops in the rotation (Johnston *et al.,* 2008). The C: N: P ratios of legumes are narrow, which results in rapid release of N and P from the residues (Lupwayi *et al.*, 2006a, 2007).

In crop rotation, legumes are known to contribute significantly to the yields of subsequent crops like cereals and tubers (Nottidge *et al.,* 2008), due to the amount of nitrogen and other nutrients returned into the soil by the legumes. Traditionally, farmers in the semi-arid tropics intercrop cereals with grain legumes, especially pigeon pea (*Cajanus cajan*), as a strategy for diversifying food production and household income since legumes are both cash and food crops, (Mafongoya *et al.,* 2000) also pigeon pea plants are drought tolerant due to deep rooting, thus providing insurance against total crop failure in low rainfall seasons, (Rao and Mathuya, 2000). The legume improves soil fertility and yields of associated as well through biological (N) fixation, nutrient pumping, and incorporation of green manure. (Chikowo *et al.*, 2004).

Intercropping plays an important role in agriculture because of the effective utilization of resources, significantly enhancing crop productivity compared with that of monoculture crops. Two or more crops planted together were known as intercropping system in order to maximize beneficial interactions. Intercropping is a sustainable soil management means in many developed and developing countries. Introduction of a grain legume in cereal-based cropping system aims at increased productivity and profitability to achieve food and nutritional security and sustainability (Mehdi *et al.,* 2010).Intercropping generate beneficial biological interaction between crops increasing grain yield and stability, more efficient use of available resources and reducing weed pressure (Kadziuliene 2009). The main principle of better resource use in intercropping is that if crops differ in the way they utilize environmental resources when grown together, they can complement each other and make better combined use of resources than when they grown separately (Bonjar, 2000). Intercropping preferentially spreading types of crops legumes, pumpkins, or sweet potato contribute to a faster and denser ground cover and suppress weed growth at least during the growing season (Steiner and Towmlow, 2003).According to (Terhan *et al.,* 2009) combination of a legume and cereal are most common among small scale farmers in semi-arids tropics and it benefit them in resource limiting conditions compared with corresponding sole crops. Yield advantages have been recorded in cereal- legume intercropping. The reason for yield advantage are mainly that environmental resources such as water, light and nutrients can be utilized more efficiently in intercropping than in the respective sole cropping systems.

According to (Faroda *et al., 2007,* Sheorena *et al., 2009*) intercropping stabilizes crop production and provides insurance mechanism against aberrant weather situation characterized by rainfed agriculture intercropping could be a viable agronomic means of risk minimizing.Intercropping increase light interception and shading reduce water evaporation, and improve conservation of soil moisture compared to sole crops, (Ahmad *et al., 2009*).Intercropping sweet potato with legume will ensure the supply of dietary carbohydrates, proteins fats, vitamins, and minerals of the rural household. Furthermore intercropping legumes and sweet potatoes would not only ensure better environmental resource utilization but would also provide better yield stability, reduce pests and diseases and diversify rural income (Egbe, 2005, N jogu *et al.,*2007).Legume green manures are efficient at mobilizing P from the soil (Knight and Shirtliffe, 2005). As green manures decompose, the P is released in a labile form that enhances the P nutrition of succeeding crops (Cavigelli and Thien, 2003).

2.4 Organic inputs

To be sustainable, organic farming needs to be self-sufficient in nitrogen (N) through the fixation of atmospheric nitrogen (N) by legumes (Berry *et al.*, 2002); recycling of crop residue (green manures) (Elfsstrand *et al.*, 2007) and application of farm yard manure (FYM) and compost (Rokhzadi and Toashih, 2011). The efficient use of nutrients within crop production system has been in focus for several decades. The application of manures to soil provide potential benefits including improving the fertility, structure, increasing soil organic matter, water holding capacity and reducing the amount of synthetic fertilizer needed for crop production (Phan *et al.*, 2002, Blay *et al.*, 2002). Manures are the main sources of nitrogen (N) supply in organic production.

Low soil fertility and moisture deficits are major constraints to crop production in the semi-arid areas of Kenya. Farmers in these areas use farmyard manure (FYM) as a cheaper alternative source of plant nutrients as opposed to the more costly inorganic fertilizers (E.M Gichagi *et al.,* 2007).Farmyard manure is heterogeneous composted organic material consisting of dung, crop residue, and/ or household sweeping in various stages of decomposition. It is mostly available, produced in farms, and is an important organic resource for agricultural production in livestock based farming system in many countries including semi-arid areas of Kenya (Marcel, 2002).Farmyard manure acts as an alternative source of fertility enhancement for inorganic fertilizer as they release nutrients slowly and steadily over long periods and improve the soil fertility status by activating the soil microbial biomass (Ayuso *et al.,* 1996, Belay *et al., 2001*). It contains all the nutrients needed for crop growth including trace elements.

Economic and environmental considerations, as well as availability make their use unsuitable since they are rather expensive and not readily available to resource poor-African farmer. Therefore, the use of locally available alternatives such as indegenous-rock phosphate is now being advocated. The phosphorous content in rock phosphate is 25-31% P_2O_5 and has low solubility (Akande 2005, Adetuji, 2006). Application of ground rock phosphate has been proved beneficial to crops (Akande *et al.,* 2008a).Incorporation of poultry manure and cow dung with phosphate rock significantly improves the release of P and performance of crops (Akande *et al.,* 2005, Akande *et al.,* 2008).The efficacy of cow dung in facilitating the release of phosphate from the applied rock phosphate has been reported by (Akande *et al.,* 2005 & 2006). Tied ridging in combination with integrated nutrient management can improve crop production in semiarid areas. Tillage practices together with cropping systems have been used to improve yields (Mwalley *et al.,* 2008).

2.5 sorghum (*sorghum bicolor L.*)and sweet potato (*Ipomoea batatas L*)

Sweet potato (*Ipomoea batatas L*) is among the world`s most important and under- exploited. Commonly referred to a subsistence, food security, or famine relief crop; its uses have diversified considerably in the developing countries (Scott and Maldinado, 1999). Alternative utilization option namely flour for porridge, *mandazi or chapatti* and making of sweet potato chips were developed because sweet potato is cooked and eaten in a limited range of forms (Wanjekeche *et al.,* 1999). Sweet potato is receiving increased attention in eastern province region`s production system because it can be grown on soils of limited fertility and is relatively drought tolerant. In addition, sweet potato provides good ground cover, and is usually cultivated with little or no fertilizer (Lusweti *et al.,* 1999).

Sweet potato has a long history as a crop to save off famine especially as a cheap source of calories (Adam, 2005). It is the world seventh major food crop (Gichuki *et al.,* 2003) and rank third among the tubers and roots in Kenya after potatoes and cassava. In Kenya, over 75% of sweet potatoes production is concentrated in western, central, and coastal areas of the country. Out of this, over 80% is grown in the Lake Victoria basin (Gruneberg *et al.,* 2004). Its production is however limited due to high prevalence of pests and diseases (Ateka *et al.,* 2004).Sorghum (*sorghum bicolor L.*) is an important food security crop in Kenya, economically rated as the fifth most important cereal after maize, wheat, barley, and rice. It is a drought resistant and performs well on a range of poor soils with low rainfall often out-yielding most cereals in hot and dry environments. It is particularly adapted to agroecological zones of Kenya, which are arid and semi-arid. These include the semi-arid areas of Eastern Kenya, the coastal, the waterlogged areas (Kameri-Mbote, 2005). In Africa, sorghum is largely a subsistence food crop. It is crucially important to food security in Africa as it is uniquely drought resistant among cereals and can withstand high temperatures, grow in areas of annual rainfall 500-700mm per year. Noted also is that sorghum is an important crop in East Africa (Taylor, 2010).

2.6Dolichos (*Lablab purpureus*) and chickpea(*Cicer arietinum* L.)

Dolichos (*Lablab purpureus)* can grow in a variety of soils, from sand to clay, in a pH range of 4.5–7.5 (Cook et al., 2005). It does not grow well in saline or poorly-drained soils, but it grows better than most legumes under acidic conditions (Valenzuela and Smith, 2002). It can continue to grow in drought or shady conditions, and will grow in areas with an average annual rainfall is 25–120 in. (Cook et al., 2005). It is more drought resistant than other similar legumes like common beans (*Phaseolus vulgaris*) and cowpea Maass et al., 2010), and can access soil water 6 feet deep (Cook et al., 2005).Dolichos (*Lablab purpureus)* is a climbing or erect perennial herbaceous crop often grown as an annual. It is popular as a nitrogen-fixing green manure contributing to soil N and improve soil quality, as a cover crop to suppress weeds and provide soil erosion control on infertile, acidic soils, and it is drought tolerant once established. Like other legumes, also incorporated into a grazing rotation (Valenzuela1 and Smith, 2002).

Chickpea (*Cicer arietinum* L.) is the largest produced food legume in South Asia and the third largest produced food legume globally, after common bean (*Phaseolus vulgaris* L.) and field pea (*Pisum sativum* L.) (ICRISAT, 2010).*It* is the third most important pulse crop globaly, with a production of 9.8m tons from an area of 11.1 m ha (FAO STAT, 2009) and plays a significant role in improving soil fertility by fixing the atmospheric nitrogen, meets 80% of its nitrogen (N) requirement from symbiotic nitrogen fixation and can fix up to 140 kg N ha-1 from air. It leaves substantial amount of residual nitrogen for subsequent crops and adds plenty of organic matter to maintain and improve soil health and fertility. Because of its deep tap root system, chickpea can withstand drought conditions by extracting water from deeper layers in the soil profile (ICRISAT, 2010).

CHAPTER THREE

3.0 GENERAL MATERIALS AND METHODS

3.1 Study Site

The study was conducted in Yatta sub-county, Kenya (longitude -1.4667 °S, latitude 37.8333°E, 944m asl) (Fig 1). The sub-county falls under agro- ecological zones IV, which is, classified as semi-arid lands (Jaetzold and Schmidt, 2006).

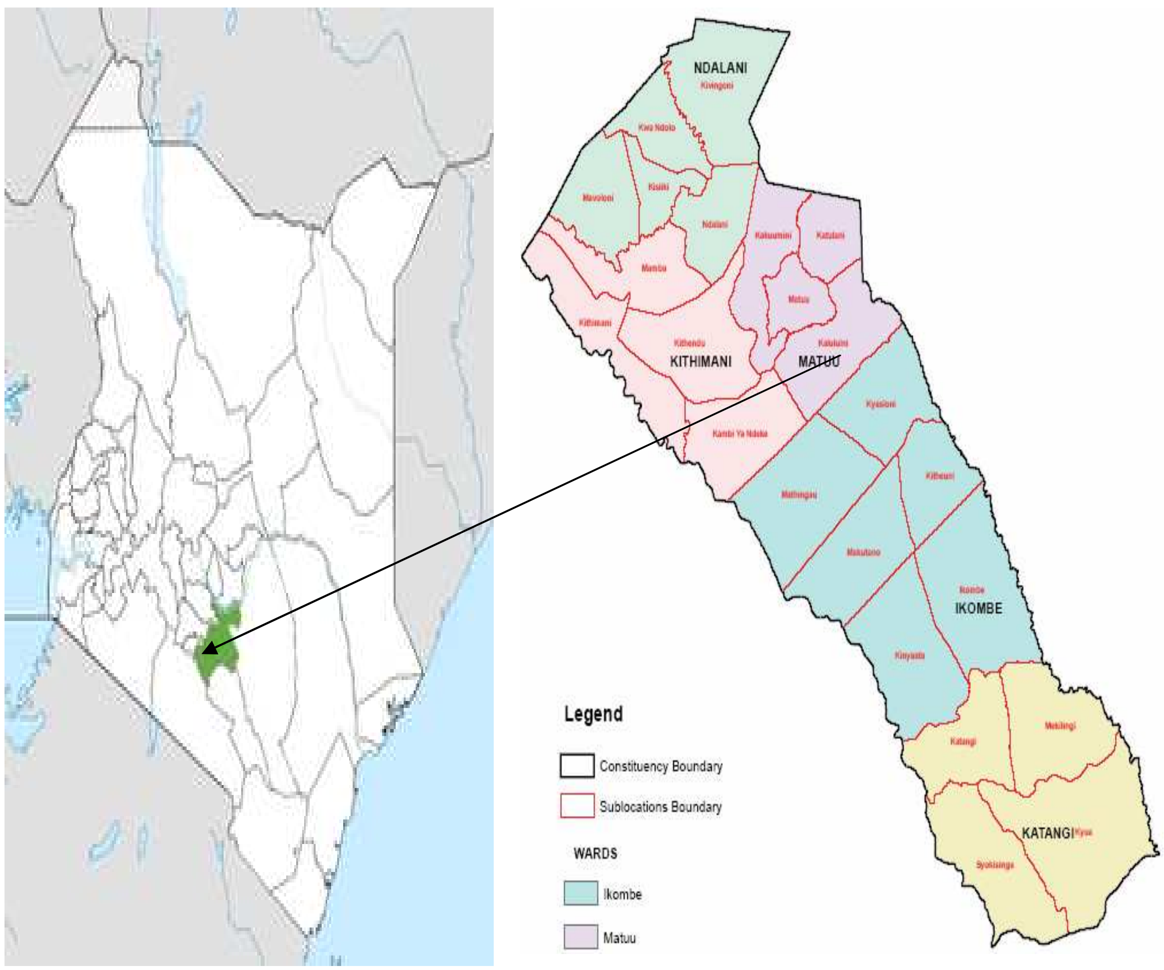


Figure 1: Map of the study area

The soils in Yatta Sub County are a combination of Acrisols and Luvisols with Ferralsols (WRB, 2006). Initial soil analysis indicated that the soils at the site were sandy clay, low in fertility, acidic, with low amounts of total N, organic carbon and. Phosphorus (Table 1).

Table 1: initial soil physical and chemical properties

Soil chemical properties	% Org.C	% Total N	P (ppm)	K (M ol/Kg)	PH H_20	PH $CACL_2$	CEC
	1.86	0.1	26.84	1.91	5	5.63	14.65
Soil physical properties	%Clay	% loam	% sand	Textural class			
	54	22	24	Sand clay			

This was attributed to farmers' reliance on one method of cropping systems and continuous cropping systems by the farmers in the area without the application of organic inputs.The same was reported by Smalling *et al.* (1997) who stated that continuous cropping of land with little or no nutrient returns, results into nutrient depletion and decline in soil fertility. In most places, they have topsoil that is loamy sand to sandy loam, sandy clay to clay with low nutrient availability (Kibunja *et al.,* 2010)

It has a semi-arid climate with mean annual temperature varying from 18^{o}C to 24^{o}C and experiences bimodal rainfall with long rains season commencing early April to May (about 400 mm) and short rains season commencing from early October to December (500 mm). Most of the farmers in the sub county are small-scale mixed farmers. Crops grown in the area include maize, beans, pigeon pea, green grams, sorghum, and cowpea (Macharia, 2004).

4.0 RESULTS AND DISCUSSION

4.1 Farmers' climate change perception, crop production trends and moisture conservation techniques.

Abstract

The Arid and Semi Arid Lands (ASALs) are the most affected by climate change and this includes Kenya whose 80% of its landmass is considered ASALs. Despite this, crops mostly grown in these areas are introduced crops that are not adapted to the climatic variability of the ASALs unlike traditional crops. Against this backdrop survey study was conducted in Matuu,Yatta sub-county late September 2012 to assess crop farmers' perception climate change, production trends and moisture conservation techniques. A sample of 60 farmers was used in the study. A stratified random sampling procedure was used to select respondents with locations forming the stratum. A computer random number generator was employed to select the number of households in each stratum. Higher percentages of farmers (92%) are aware of climate change. The main indicators of climate change among the farmers in Yatta Sub County include; rising temperatures (23%), erratic rainfall (23%), low rainfall (22%) and increase drought conditions (18%). 38.9% of the farmers had abandoned production of some crops such as cassava, sorghum and sweet potatoes. The said crops, had been abandoned in favor of introduced crops such as beans, maize and wheat. Most farmers (83.3%) reported, unreliable rainfall, pests and diseases, drought, low soil fertility, lack of inputs and low soil moisture as constraints to agricultural production.15% stated manure application, basin and terraces and terraces respectively as methods of coping with low soil moisture. Farmers in Yatta Sub County have perceived climate change, which has led to changes in crop production and influenced soil moisture content thus; farmers applied a number of soil moisture conservation techniques to improve on soil moisture content.

Key words: climate change, crop production trend, soil moisture conservation techniques.

4.1.1 Introduction

Climate change is one of the biggest risk factors affecting agricultural systems performance and management in many parts of the world (Kurukulasuriya and Mendelson, 2006). Scientific evidence about the seriousness of the climate threat to agriculture is now unambiguous, but the exact magnitude is uncertain because of the complex interactions and feedback processes in the ecosystem and the economy (World Bank Annual Report, 2007). The indicators include; higher temperature, reduced rainfall, and increased rainfall variability reduces crop yield and threatens food security in low-income and agriculture-based economies especially the ASALs. This could have negative impacts on nutrition and health of the population (IAC, 2004; Dixon, Gulliver and Gibbon, 2001; IPCC, 2001). These effects have a direct impact on smallholder farmers, who mostly rely on rain-fed agriculture for their production and have a limited means of coping with this adverse weather variability (FAO 2012).

Another factor that farmers battle with is low soil moisture content, in the semi-arid regions of Africa; it is evident that in systems reliant on rainfall as a sole source of moisture for crop production, seasonal rainfall variability inevitably leads to highly variable production levels and risks. This as a result has led to introduction of adaptation methods in agriculture which include use of new crop varieties and livestock species that are better suited to drier conditions, irrigation, crop diversification, adoption of mixed crop and livestock farming systems, and changing planting dates (Bradshaw *et al.,*2004; Kurukulasuriya and Mendelsohn, 2008; Nhemachena and Hassan, 2007).

Farmers in the ASAL areas cultivate a variety of crops of which the main ones are maize, sorghum, green grams, beans and cowpeas under rain-fed agriculture as well as horticultural crops such as mangoes, bananas, tomato, onions, kale, capsicum, pawpaw and citrus (NEMR, 2009). Most of these are introduced crops mostly preferred over traditional crops due to their economic importance though they are not adaptable to the harsh climate conditions of ASAL areas.

The study carried out was to determine farmers’ perception on climate change, crop production trends, and moisture conservation techniques in Yatta Sub County.

4.1.2 Materials and methods

The study site is as described in in general materialns and methods (section 3.1)

4.1.2.1 Study approach

A Farmer survey was conducted in Matuu Yatta sub-county late September 2012 using questionnaires to determine farmers' climate change perception,crop production trends and moisture conservation methods.A sample size of 60 farmers was arrived at using the table on sample size selection and standardization equation,

$$n = \frac{n_0}{1 + \frac{(n_0 - 1)}{N}}$$

where; N is the known population; n is sample size; and no is the unknown population.A stratified random sampling procedure was then used to select respondents with locations forming the stratum. A computer random number generator was employed to select the number of households in each stratum. Computer random number generator is an online process that produces random numbers. Random Number Generator produces a listing of random numbers, based on the following User specifications; the quantity of random numbers desired, the maximum and minimum values of random numbers in the table and whether or not duplicate random Numbers are permitted. The minimum value identifies the smallest number in the range; and the maximum value identifies the largest number. Key elements of the semi-structured questionnaire: farmers' perceptions on climate change, crop production trend and soil moisture conservation techniques.

4.1.2.2 Statistical analysis

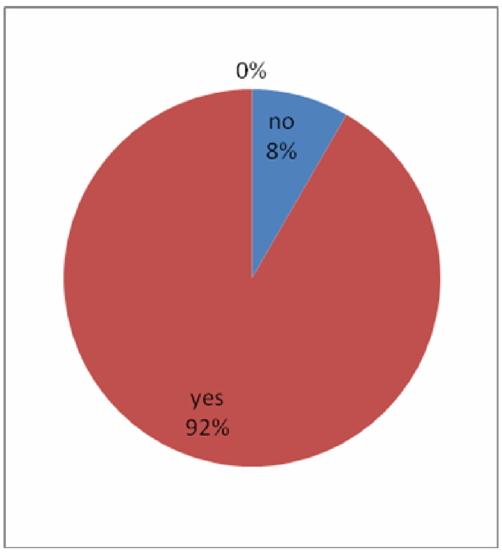
The semi-structured questionnaires were analyzed using the Statistical packages for social Sciences (SPSS version 14).

4.1.3 Results and discussion

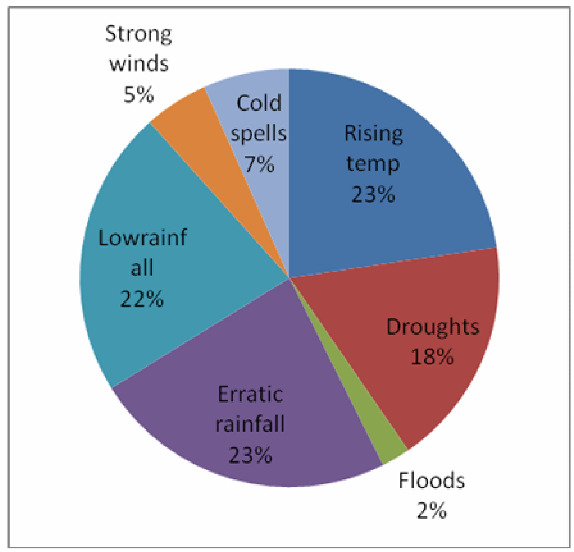
4.1.3.1 Climate change

Climate change aspects

About 92 % of the farmers were aware of climate change. The main indicators of climate change reported by farmers in Matuu, Yatta Sub County included; rising temperatures (23%), erratic rainfall (23%), low rainfall (22%) and increase drought conditions (18%) (Fig.2).



perception on climate change



aspects of climate change

Figure 2: Farmers' perception and aspects of climate change

This was attributed to the fact that farmers in the study area depended on rain fed agriculture therefore could easily notice effects of climate change that included reduction of agricultural productivity which causes production instability and poor incomes in the area.

The results of a study conformed to the study by Macharia *et al.,* (2012) found that the main indicators of climate change among communities in arid and semi arid areas were erratic rainfall, high and low temperatures, low crop yields and increase of droughts. Barrios et al., (2008) also reported that rainfall and temperature are a major determinant of agricultural production in sub-Saharan Africa

Farming practices in response to climate change

The common farming practices used included increasing the application rates of organic inputs (56%), using a variety of cropping systems (51%), planting drought tolerant crops (42%) and rain water harvesting (34%) (Fig.3).

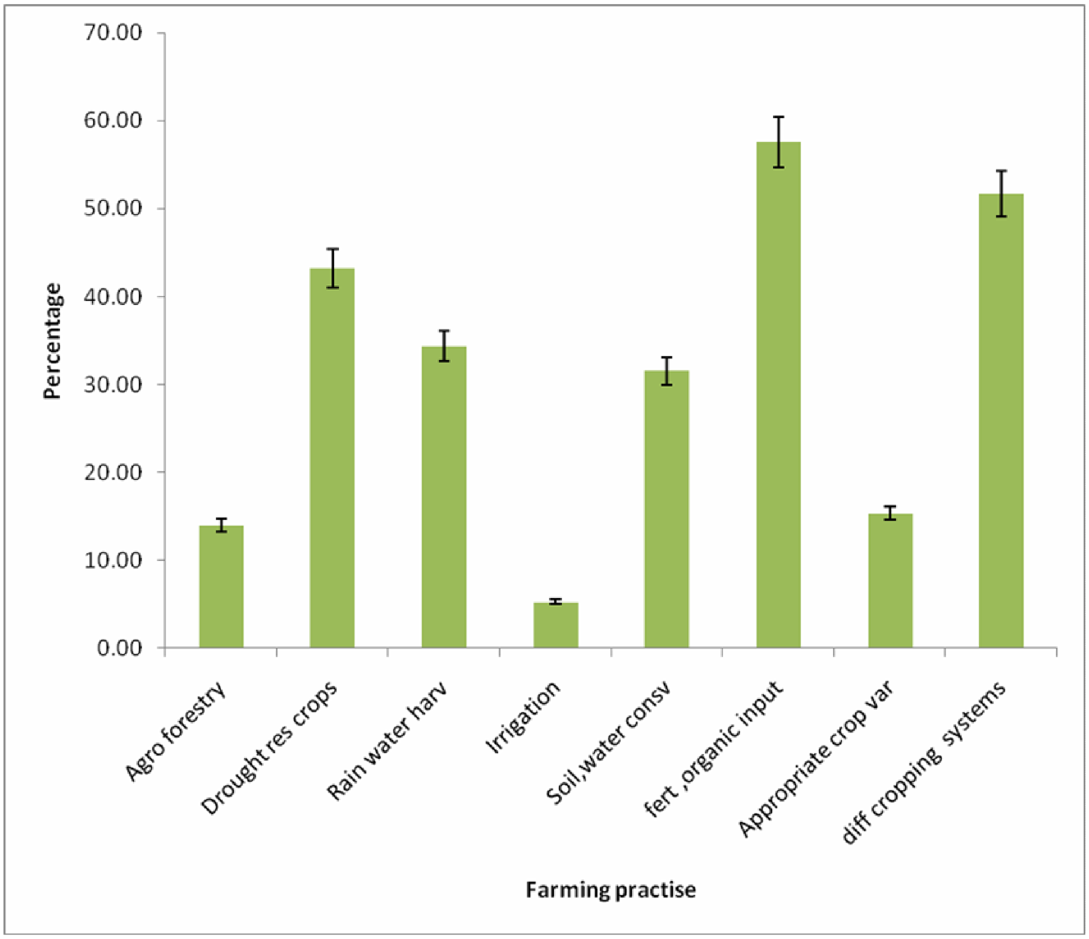


Figure 3: Farmers response to climate change

In an effort to increase productivity and adapt to climate change, farmers employ a variety of farming practices which included; application fertilizers/manures , using a variety of cropping systems, planting drought tolerant crops , rain water harvesting and soil and water conservation techniques. The farmer in the study indicated manures as the cheap source and readily available organic input for improved soil fertility and thus commonly used as compared to the artificial fertilizers which are expensive to the resource poor farmers and unavailable at the right time and quantity. The farmers stated that by adapting a number of cropping system such as intercropping and crop rotation ensured improved soil fertility and reduced risk of food insecurity incase crop failed due to production of a number of crops under one farm as opposed to mono cropping. Farmers stated that Water harvesting has enabled them undertake agricultural production regardless of rainfall failure since farmers can irrigate their crops during such seasons.Gichagi *et al.*, 2007 also found out farmers in the Eastern part of Kenya use farmyard manure (FYM) as a cheaper alternative source of plant nutrients as opposed to the more costly inorganic fertilizers. Aita and Giacomini, (2003) the use of species different from the main crop such as legumes contributes to the nutrient balance, which may consequently increase soil fertility level over time. Leguminous species are known for their capacity to fix atmospheric di-nitrogen and narrow the C/N ratio, resulting in faster residue decomposition. According to Mugerwa (2007) water harvesting and storage would be vital to ensure water availability especially during prolonged dry season and drought.

Relationship between soil moisture and climate change

The farmers generally associate amount of rainfall received and temperature as having an influence on soil moisture. About 14% of the farmers indicate high temperatures as the main cause of low soil moisture presumably due to high evaporation whereas 10% indicated that low rainfall results to low soil moisture content (Fig. 4).

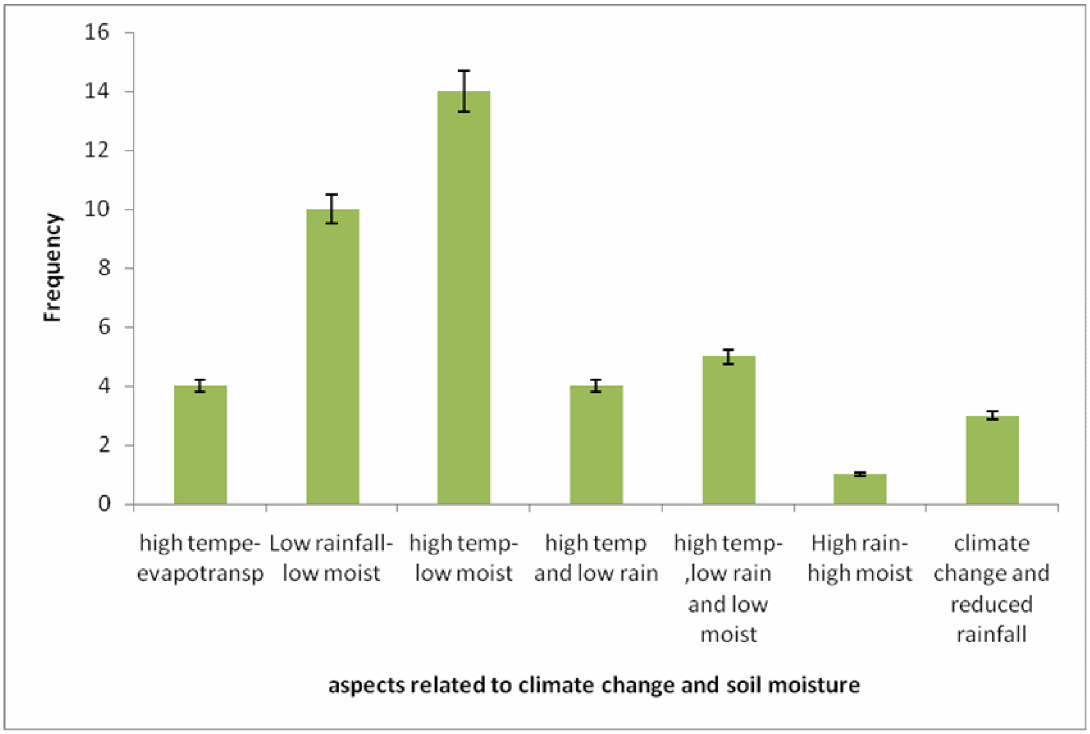


Figure 4: Relationship between soil moisture and climate change

These reduced soil moisture content resulted from increased loss of water through evapotranspiration from the soil and bodies of water and increased transpiration from plants. The farmers indicated that with low rainfall it results into low moisture content due to reduced amount of water percolating into the soil thus reduced soil moisture content.

This conforms to the study by Ogutu *et al., (*2007) who found that increase in temperature have a tremendous impact on the water availability and thus exacerbating conditions of drought. In addition Wilson et al., 2004 found out that the exchanges between the atmosphere and the soil (precipitation and evapotranspiration) dominate changes in soil moisture, with moisture being replenished by infiltration and depleted by soil evaporation and plant transpiration.

Coping mechanisms for improved crop production

Majority 78% of the farmers used ashes as a way of improving crop production whereas about 68% indicate drought resistant crops while approximately 36.7% of the farmers practiced early planting to cope with low rainfall through for improved crop production (Fig.5).

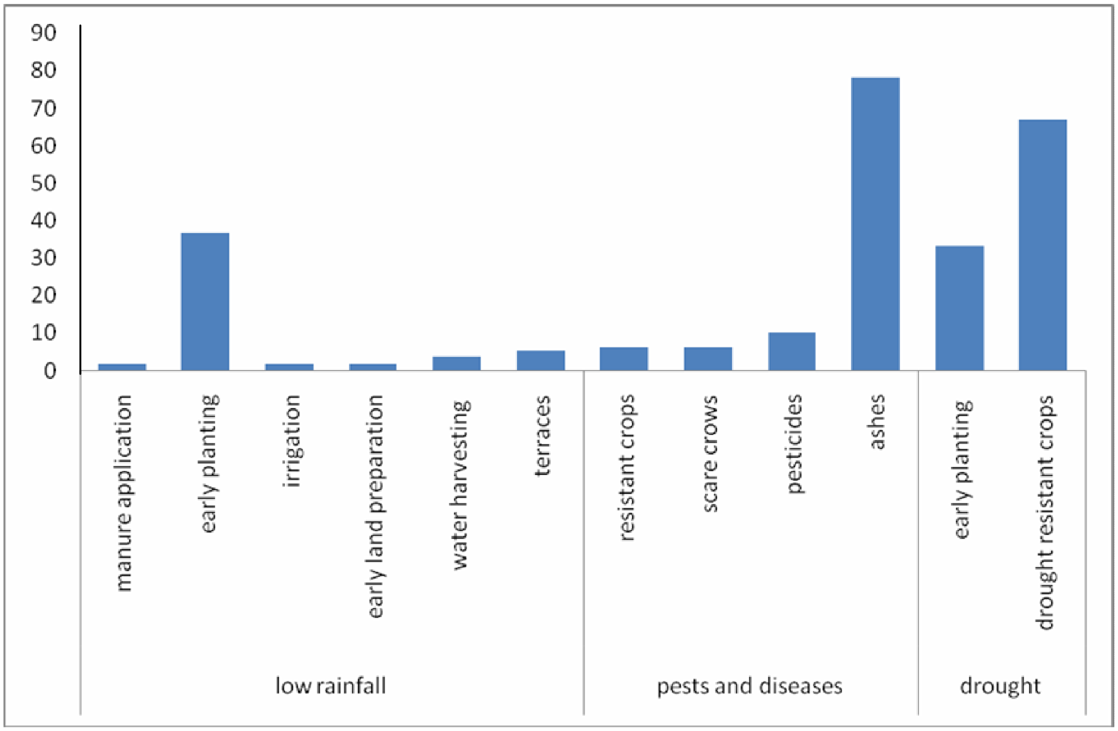


Figure 5: Coping mechanisms for improved crop production

Farmers stated that the used ashes to control pests as well direct application to soils stating that they are user friendly, cheap or free and locally available.Farmers planted drought resistant crops to cope with incidences of drought. Respondents stated that early planting ensured that the crops could utilize the first rains since rainfall distribution is no longer predictable. This conformed to the study by Mureithi, (2005) who stated that ashes are not poisonous to human and livestock, they do not stay long on the plants or in the environment, the plants can be eaten three days after spraying, they also do not usually harm the natural enemies of the pests such as the ladybird beetle..

The same was also stated by Steve and Gelson, (2003) that early planting enables farmers to sow with the first rains when their plants will benefit from the initial nitrogen flush in the soil. Farmers enjoy the benefits of timely planting, improved water retention and infiltration, good root development, soil investment and greater precision in input use. In addition Mureithi (2005) found out that early planting allows germinating seeds to benefit from the warm soil temperatures and good aeration.

Other coping mechanisms to low rainfall were construction of terraces, manure application, irrigation, early land preparation and water harvesting about (Fig. 5) farmers stated that this ensured improved soil moisture content due improved water conservation and reduced loss through evapotranspiration and erosion. This was in conformity with the study by Mutunga, (2001), who reported that terraces, manure application conserve moisture in the soil for a long period of time and hence sustaining agricultural productivity and improving the living conditions of land users.

Pesticides not used frequently due to their residue effect and negative impact on health; these results are consistent with those of Johan *et al.* (2002).Planting drought resistant crops such as sorghum and finger millet, which are said to be adapted to low moisture content and high temperatures, reduces the effect of crop failure. These results are in agreement with those of Parry *et al.* (2008).

4.1.3.2 Crop production trend

Crop production trends from 1980 to 2013

There has been an increasing trend for pumpkin, finger millet and sorghum from 1980 to date.Higher percentage of farmers (38.9%) were found to have abandoned pumpkin whereas 32%, fingermillet and 28% sorghum from 2000 to date(Fig. 6)

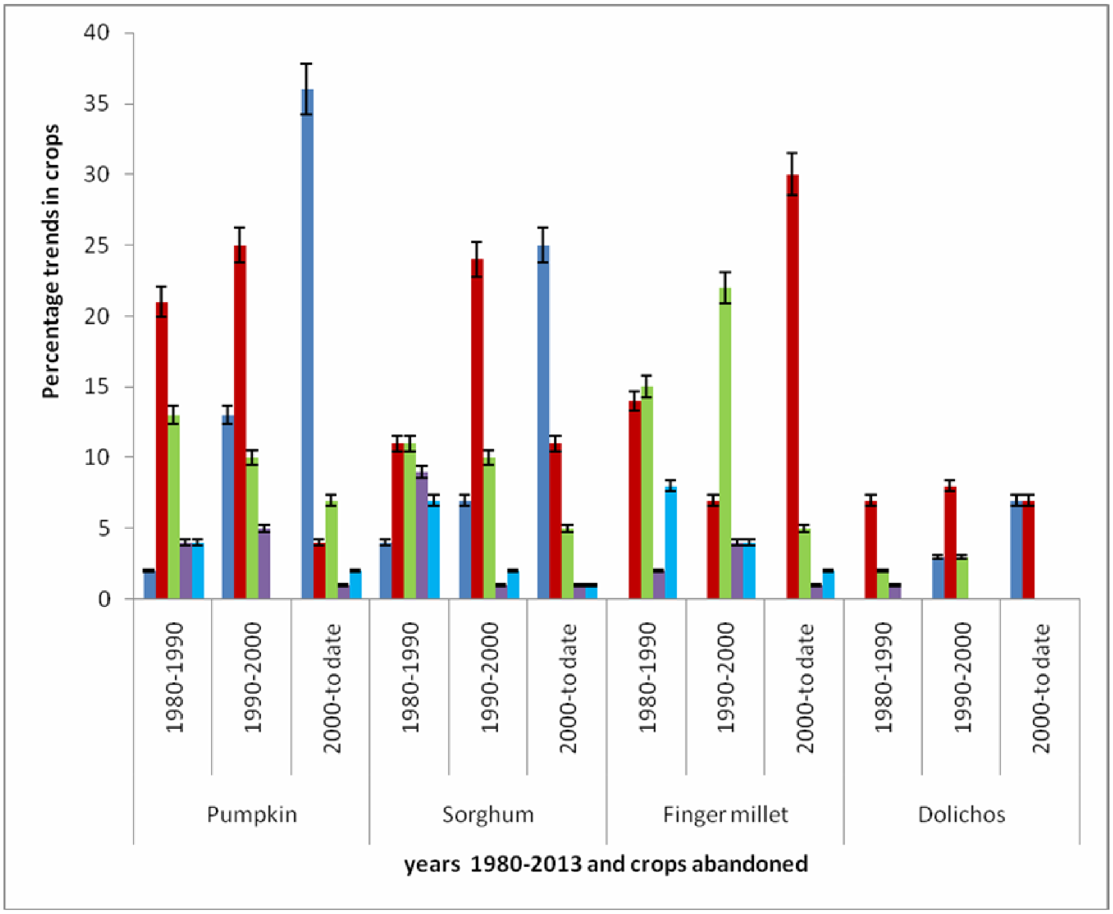


Figure 6: Crop production trends from 1980-2013

The said crops, also known as traditional crops, had been abandoned for introduced crops such as beans, maize and wheat. This is because the introduced crops have high economic importance compared to the traditional crops which are highly susceptible to pests and diseases.

Crops such as pumpkin, sorghum and finger millet are highly susceptible to pests such as birds according to TOF, (2012).

Abandoned crops and reasons for abandonment

Most farmers (85%) were found to have abandoned finger millet due to insufficient labour stating that to grow fingermillet it is cumbersome, also requires children to assist in quarding them in case of bird feeding on it, requires a nummber of people to assist during weeding and harvestion.About 50% had abandoned sorghum for the same reason while 40 % had abandoned cassava due lack of seeds they stated that they are not availble locally since most farmers in the area aro not growing cassava. (Fig. 7).

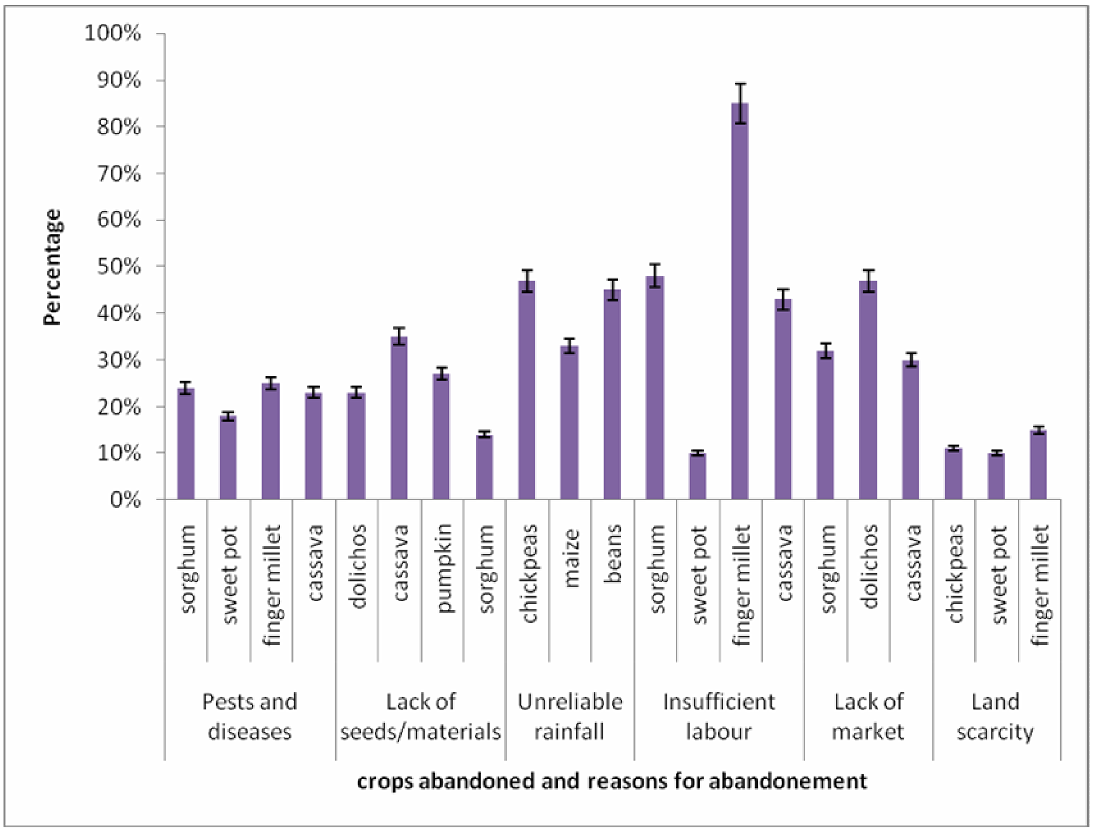


Figure 7: Abandoned crops and reasons for abandonment

The crops which had been abandoned due pests and disease include sweet potatoes, dolichos, beans, chick peas, pumpkin, sorghum, finger millet and cassava. Farmers perceived that there has been an increase in pests and disease due to warming for instance, stalk borers (*Calidea dregii)* which attacks maize, sorghum and finger millet. These findings are also supported by results reported by Shao (1999) that pests and diseases are among the critical factors contributing to unsustainable agriculture in semiarid areas.

Other farmers reported land scarcity as a reason for change in crop production(Fig 6). This is caused by increased land fragmentation which is as a result of increased population. These results were agreement with those of Gachimbi *et al., (*2006) who found out that as population increases the land for cultivation also reduces.

Ecological importance of the abandoned crops

The abandoned crops were reported to be of immense ecological significance . These included soil moisture conservation, soil fertility improvement, drought resistant crops and cover crops.Majority of the farmers 90% and 45% stated sweet potatoes as crop which conserve soil moisture and cover crops respectively while 50% and 40% stated dolichos and cassava for improvement of soil fertility and as a drought resistant crop respectively(Fig.8).

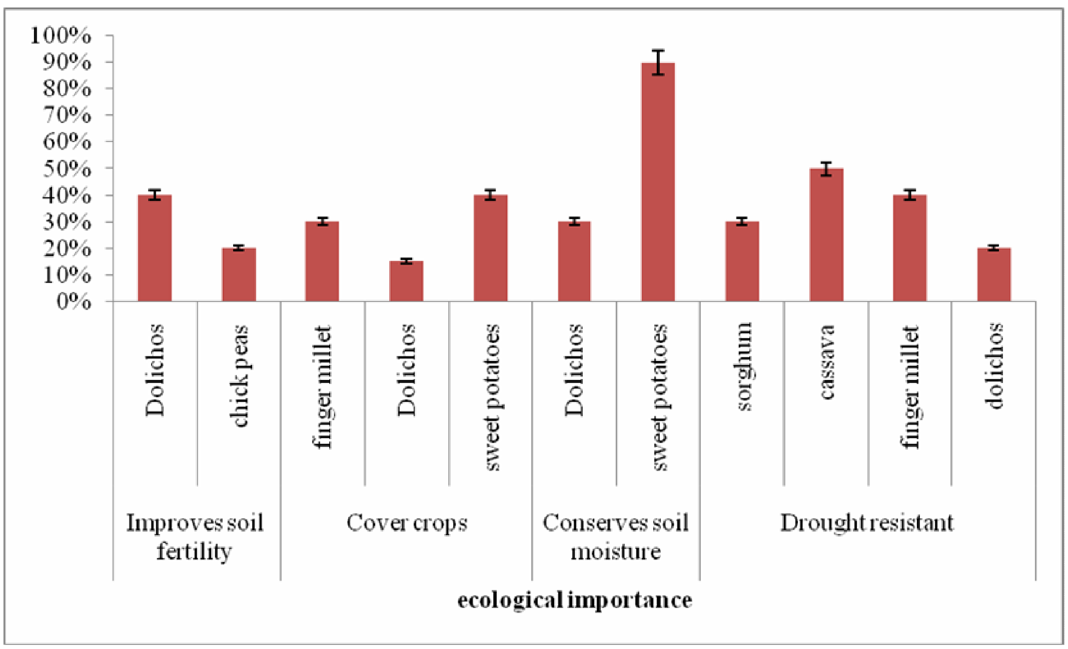


Figure 8: Ecological importance of the abandoned crops

Farmers stated that due sweet potato broad leaves they ensures that there is a full ground coverage and thus reduces evapotranspiration ensuring soil moisture conservation which in turn increases soil moisture content. Dolichos as one of the legumes ensures soil fertility as a result of nitrogen fixation. These results are in agreement to those of Gachene *et al., (*2004) and Khisa *et al., (*2002). According to Mureithi, (2000) dolichos, beans and chick peas are nitrogen fixing legumes and hence they improve the fertility of the soil. Mukarumbwa and

Mushunje, (2010**)** stated that Sorghum, finger millet and cassava are drought resistant crops which can be used as food crops when other crops such as maize fail.

Enhancing crop productivity

About 70 % and 68% of the farmers used organic inputs and tillage practices respectively to enhance crop production while 60 % of the farmers stated cropping systems in the study area (Fig. 9).

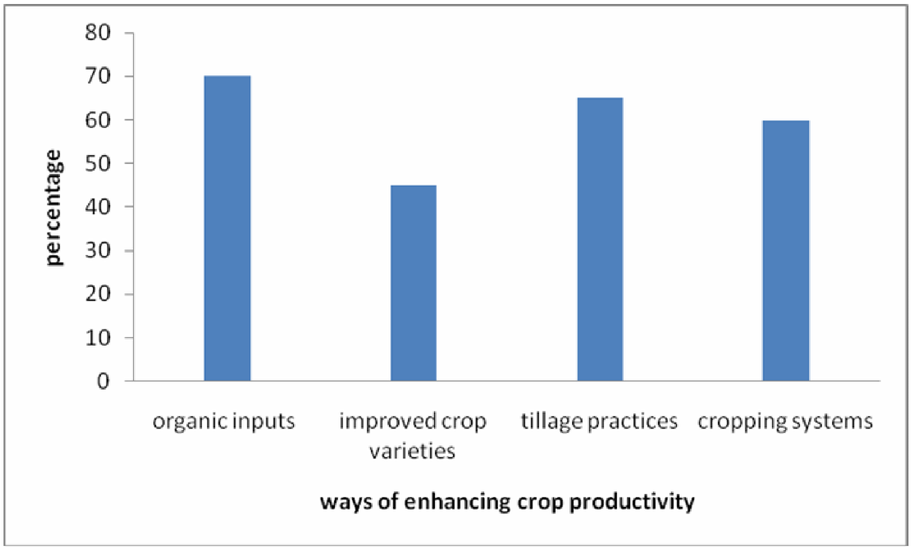


Figure 9: Ways of enhancing crop productivity

Different cropping systems ensured diversify crop production while addition of organic inputs to the soil are known to improve the chemical, physical, and biological soil properties that will enhance the availability of nutrients and their uptake by crops. Tillage practices ensure improved soil moisture content in turn improving crop performance resulting to enhanced crop productivity. The tillage practices used include use of ridges and tied ridges. The technique involves digging major ridges that run across the predominant slope and then creating smaller sub ridges (or cross ties) within the main furrows. Furrows conserve soil moisture while crops planted on the ridges.

Manures provide both N and P and other nutrients, these results are in agreement with those of Okwuagwu *et al., (*2003)**.** According to Jonathan, (2008) the cropping systems include monocropping, crop rotation and intercropping. Crop rotation will lead to improved soil fertility especially where legumes which are nitrogen fixing are rotated with cereals. It will also break disease and pest cycles. Intercropping will lead to increased output from a given piece of land. Intercropping will also lead to food diversification.These results also agree to those of Mati, (2005) who found out that series of micro- basins that store rainwater in situ enhances infiltration.

4.1.3.3 Soil moisture conservation

Effects of low soil moisture on crop production

On proportion of the effects of low soil moisture on crop production drying of crops had the highest percentage with 36% of the respondents (Fig. 10).

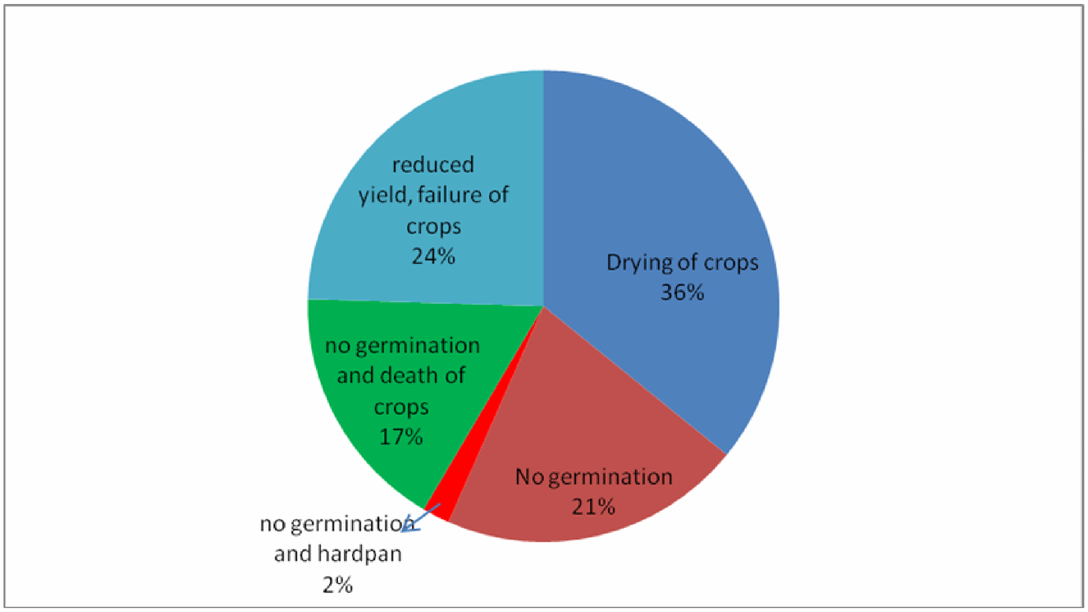


Figure 10: Effects of low soil moisture in crop production

Whereas 24%, 21% and 17% of the respondents cited reduced yield and failure of crops, no germinationand no germination and death respectively.

The most limiting factor to crop production in the ASALs is availability of soil moisture. The low rainfall together with its unreliability and poor distribution severely limits crop Production KARI, (1996).

Methods of coping with low soil moisture

About 15%, 13%, and 11% of the farmers stated manure application, basin and terraces and terraces respectively as methods of coping with low soil moisture (Fig. 11).

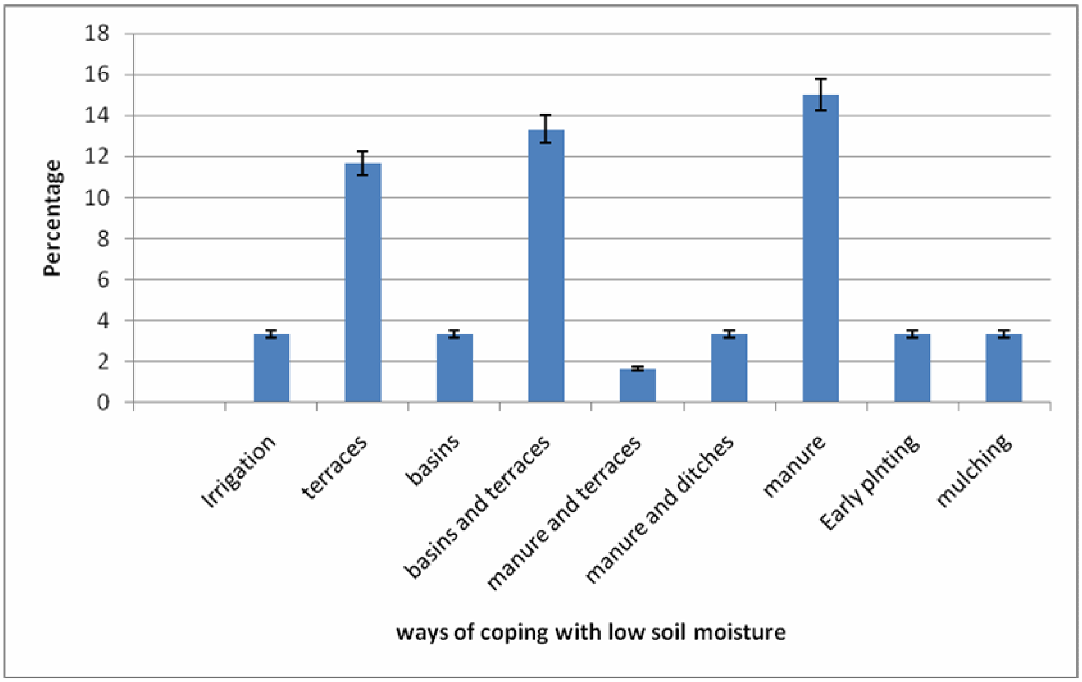


Figure 11: Ways of coping with low soil moisture

The application of manures to soil similarly provide potential benefits including improving the fertility, structure, increasing soil organic matter, water holding capacity and reducing the amount of synthetic fertilizer needed for crop production (Phan *et al.*,2002, Blay *et al.*,2002).

Innovative soil moisture conservation measures

About 15% of the respondents rated tied ridges and furrows as one of the innovative soil moisture conservation measures (Fig. 12).

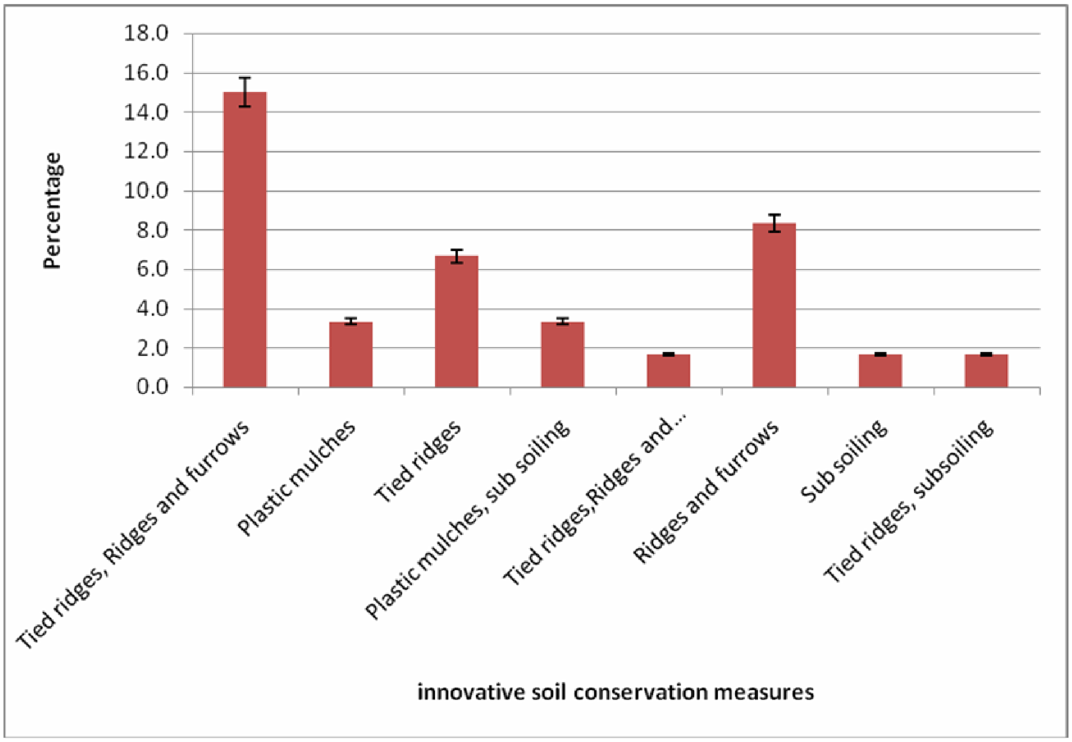


Figure 12: Innovative soil moisture conservation measures

Plastic mulch was rated by 3% of the respondents as one of the innovative soil conservation measure. Tied ridges were cited 7% of the respondents as another method for innovative soil conservation measures. Plastic mulches and sub soiling was cited by 3% of the respondents as one of the innovative soil conservation measures.

Tillage practices techniques like the tied ridges and open ridges would allow rainwater be retained on open furrows for longer duration as the water infiltrates into the soil or soil management techniques that favors prolonged rainwater infiltration and retention thus raising the overall soil moisture retention and soil water holding capacity (Itabari, 2003).

4.1.3 Conclusions

Farmers in Yatta Sub County have perceived climate change, which has led to changes in crop production and influenced soil moisture content thus; farmers applied a number of soil moisture conservation techniques to improve on soil moisture content. The main indicators of climate change among the farmers include; rising temperatures, erratic/ low rainfall and increase drought conditions. Most farmers had abandoned most of the traditional crops such as cassava, sorghum and sweet potatoes for production of introduced crops such as maize, wheat and beans.

4.2 Efficiency and Interactive effects of tillage practices, cropping systems and organic inputs on soil moisture content

Abstract

The study evaluated the efficiency and interactive effects of tillage practices, cropping systems and organic inputs (soil moisture conservation techniques) on soil moisture retention. The study was carried out in semi-arid Yatta sub-county between October 2012 and February 2013 short rain season (SRS) and March to August 2013 long rain season (LRS). The experiment was laid out in Randomized Complete Block Design with a split-split plot arrangement. Main plots were; tillage practices (TP); Oxen plough (OP), tied ridges (TR) and furrows and ridges (FR). The Split-plots were; cropping systems (CS); mono cropping (MC), intercropping (IC) and crop rotation (CR) while the split-split plots were organic inputs; Farmyard manure (FYM), Minjingu Rock Phosphate (MRP), combined MRP and FYM (MRP+FYM) and control. Sorghum and sweet potatoes were grown as intercrops or in rotation with Dolichos (*Dolichos lablab*) and chickpea (*Cicer arietinum* L.). Soil samples taken at 0-30 cm depth at the start of the experiment and maturity of test crops for determination of soil moisture content (expressed as %) and efficiency of soil moisture conservation techniques. Significant ($p \leq 0.05$) increased in soil moisture content was recorded in TR under IC of dolichos with application of FYM (7.53% and 7.88%) for sorghum and sweet potato plots respectively. Tied ridges with an intercrop of dolichos and sorghum and, dolichos and sweet potato with application of FYM +MRP were the most efficient techniques for moisture conservation (6.73%) LRS 2013.Tied ridges with intercrop and/or rotation with Dolichos and application of MRP+FYM is a feasible methods for moisture conservation in the Yatta Sub-county.

Key words: cropping systems; tillage practices; organic inputs; Semi-arid; soil moisture

4.2.1 Introduction

Agricultural production in Sub-Saharan Africa (SSA) primarily relies on rain-fed production that is climate sensitive (IITA, 1993). The most limiting factor to crop production in the arid and semi arid lands of Kenya especially Yatta Sub County is availability of soil moisture. The low rainfall together with its unreliability and poor distribution severely limits crop production (KARI, 1996). Additionally, the low quality of soil resource base which on one hand has been due to inherent and induced deficiencies of major nutrients N, P and K or low nutrient holding capacity and low organic matter (Okalebo *et al.,* 1992; Kaolo R. 2003) negatively affect crop production. To ensure increased crop production and food security, farmers in the semi-arid tropics intercrop cereals with grain legumes, such as pigeon pea (*Cajanus cajan*), as a strategy for diversifying food production and household income since legumes are both cash and food crops (Mafongoya *et al.,*2006). The legume improves soil fertility and yields of associated cereals, as well, through atmospheric di-nitrogen fixation in association with rhizobia bacteria, nutrient pumping and incorporation of green manure (Chikowo *et al.*, 2004).

In addition to intercropping, farmers practice well-managed crop rotations with the aim of increasing soil organic matter to sufficient levels that help to moderate and retain soil moisture under dry conditions, and allow excess moisture to drain away in wet seasons thus recharging the ground water aquifers. The deep rooted crops following shallow rooted crops can access moisture reserves as well as capture any nutrients that have leached below the shallower root zones before they reach groundwater (Adam *et al.,* 2011). Further, the application of manures to soil provide benefits such as fertility, structure, increased soil organic matter, better water holding capacity (Phan *et al.,*2002, Blay *et al.,*2001) and transmission properties. Besides use of organic inputs to enhance and conserve soil moisture, various tillage practices; furrows and ridges and tied ridges, have been found to conserve soil moisture (Gebrekidan and Yohannes 2002) in semi-arid areas.

Tillage modifies soil surface structure by breaking the pan layer, total porosity and macro-porosity, pore continuity and pore size distribution and therefore has great influence on the hydrology of an agricultural catchment (Mwendera, 2002). These have shown positive response in terms of yield increase in maize and other crops. These moisture conservation methods contribute to increased infiltration, reduction of run-off hence reduced erosion episodes and increasing rooting volume in shallow soils (Vogel *et al* ., 2001). There is however a dearth of information on the efficiency and interactive effects of tillage practices, cropping systems and organic inputs (soil moisture conservation techniques) on soil moisture retention in the ASALs, thus necessitating the current study.

4.2.2 Materials and methods

Study site as described under general materials and methods in section 3.1

4.2.2.1 Treatments and Experimental design

The treatments were tillage practices (Oxen plough, tied ridges and, furrows and ridges), cropping systems (mono cropping, intercropping, and crop rotation) and organic inputs (farmyard manure, rock phosphate, and combined Farmyard manure and rock phosphate) and control. The farm yard manure used was slightly alkaline with a pH of 8.2. It had an organic carbon content of 18.6 %. Total nitrogen content was 2.1 % with P and K contents of 0.4 % and 2.7 % respectively. The calcium content was 3.4 % (Table 2).

Table 2:Farm yard Manure chemical analysis

Soil chemical properties of FYM	% Org.C	% Total N	% P	% K	% Ca	% Na	PH H_20
	18.6	2.1	0.4	2.7	3.5	0.8	8.2

The experiment was in a Randomized Complete Block Design with split-split plot arrangement. The main plots (150 by 60metres) were; tillage practices (Oxen plough, tied ridges and furrows, and ridges). Split plots (10 by 4metres) were cropping systems (mono cropping, intercropping, and crop rotation) and split-split plots (2.5 by 1metres) were organic inputs (farmyard manure, rock phosphate and combined Farmyard manure and rock phosphate). A control (no organic input applied) was also included as a split-split plot (Table 3). The test crops were sweet potatoes (*i pomeabatatas*l.lam) and sorghum (*sorghum bicolor l.*) with Dolichos (*Dolichos lablab)* and chickpea Chickpea (*Cicerarietinum*L.) either as intercrops or in rotation.

Table 3: treatment and experimental design

Tillage practice	TR					FR					OP				
Cropping systems	MC	IC[2a]	IC [2b]	CR [3a]	CR [3b]	MC	IC[2a]	IC [2b]	CR [3a]	CR [3b]	MC	IC[2a]	IC [2b]	CR [3a]	CR [3b]
Organic Inputs	MRP	FYM +MRP	CTRL	CTRL	CTRL	MRP	FYM+ MRP	CTRL	CTRL	CTRL	MRP	FYM+ MRP	CTRL	CTRL	CTRL
	FYM	MRP	FYM+ MRP	FYM+ MRP	MRP	FYM	MRP	FYM+ MRP	FYM+ MRP	MRP	FYM	MRP	FYM+ MRP	FYM +MRP	MRP
	FYM +MRP	FYM	MRP	FYM	FYM	FYM+ MRP	FYM	MRP	FYM	FYM	FYM+ MRP	FYM	MRP	FYM	FYM
	CTRL	CTRL	FYM	MRP	FYM+ MRP	CTRL	CTRL	FYM	MRP	FYM+ MRP	CTRL	CTRL	FYM	MRP	FYM+ MRP

Legend/key

[1]**MC** –sorghum, sweet potatoes,

[2a]**IC-** sweet potato/dolichos, sweet potato/chickpea,

[2b]**IC-** sorghum/dolichos and sorghum/chickpea

[3a]**CR-** dolichos -sweet potato, chickpea -sweet potato,

[3b]**CR-** Dolichos-sorghum, chickpea—sorghum

CR-Crop rotation

FR-Furrows and ridges

IC-Intercropping

MC –Mono cropping

OP-Oxen plough

TR-Tied ridges

4.2.2.3 Field Practices

Land was prepared manually using oxen plough in late September and planted in October short rain season 2012 and April long rain season 2013. Tillage practices (tied ridges and furrows and ridges) were constructed during planting with measurements according to crop spacing. Manure was broadcasted at a rate of 5t/ha and minjingu rock phosphate (MRP) at 498 Kg/ha equivalent to 60 Kg P/ ha and mixed thoroughly with the soil before the vines and seeds were placed in the holes (KARI, 2004). Sweet potatoes (wabolinge variety) were propagated through cuttings of 30 cm long at spacing of 90 cm between rows and 30 cm within rows. Weeding was done 5 weeks after planting and harvesting was done after 6 months when the leaves were yellow and dry. Harvesting was done using a sharp hoe by removal of all tubers (Mureithi, 2005). Sorghum (serendo variety) was sown at spacing of 75 cm by 30 cm while dolichos and chickpea were planted at a spacing of 30 cm within the sorghum and sweet potato rows. Weeding was done after 5 weeks of planting. Harvesting was done after three months when it had reached physiological maturity.

4.2.2.4 Soil sampling and analysis

Soil samples were taken in a zig-zag manner, from 0-30 cm depth, at the start of the experiment and composited. Thereafter soil samples were similarly taken, from each plot, at maturity of the test crops and thoroughly mixed to form one composite sample per treatment. The soil moisture content (% volume) and efficiency of soil moisture conservation techniques (expressed as percentage) were determined as follows;.

Soil moisture determination: soil moisture content (% volume) was determined using gravimetric method (RNAM, 1995).

$$MC = \frac{(Ww-Wd)}{Wd} * 100$$

Where;

MC = Moisture content (%)

Ww = Weight of wet soil (g)

Wd = Weight of dry soil (g)

Efficiency of soil moisture conservation techniques: Performance of moisture conservation techniques was quantified by their efficiency in percentage. The efficiency of the techniques on moisture conservation was calculated from initial and final soil moisture content.

$$E = \frac{M_2}{(M_1+R)} *100$$

Where;

E - Efficiency of moisture conservation

M_1 – moisture content at the beginning of cropping period;

M_2 – moisture content at the end of cropping period;

R - Rainfall received during cropping period

2.5 Statistical analysis

Data was subjected to general analysis of variance using Genstat statistical software (Payne 2005b). Means were separated using least significant difference and Duncan Multiple Range Test (where interactions occurred) at a probability level of 5%.

4.2.3 Results and discussion

4.2.3.1 Interactive effects of tillage practices, cropping systems and organic inputs on soil moisture content

An increased soil moisture content was recorded in all the tillage practices and cropping systems with application of FYM and MRP+FYM (Table 1).

Tied ridges under sorghum chickpea intercrop with application of MRP+FYM recorded an increased moisture content (8.37% and 8.44%) followed by chickpea –sorghum rotation (7.89% and 7.95% for the SRS of 2012 and LRS of 2013, respectively, whereas under furrows and ridges under the intercrop of sorghum chickpea with the application of MRP+FYM increased moisture content was observed (5.58%), then the rotation of chickpea and sorghum (5.26%) while under oxen plough in sorghum chickpea intercrop with the application of MRP+FYM improved moisture content was recorded (4.18%) followed by the rotation of chickpea and sorghum (3.94%) (Table 4).

Table 4: Interactive effects of tillage practices, cropping systems and organic inputs on soil moisturecontent(%) in sorghum plots during SRS of 2012 and LRS of 2013.

			SRS 2012				**LRS 2013**			
TP	CS		CTRL	FYM	MRP	MRP+FYM	CTRL	FYM	MRP	MRP+FYM
FR	crop rotation	CP-SOR	3.5^{fg}	5.26^{o}	4.38^{k}	4.73^{lm}	3.89^{jk}	5.3^{pqrs}	3.93^{jk}	4.91^{p}
	crop rotation	DOL-SOR	3.32^{f}	4.98^{n}	4.15^{ij}	4.48^{k}	3.58^{hi}	5.02^{pq}	3.72^{ij}	4.65^{o}
	inter cropping	SOR/DOL	3.01^{e}	4.51^{k}	3.76^{h}	4.06^{hi}	3.23^{eg}	4.55^{n}	3.37^{gh}	4.21^{m}
	inter cropping	SOR/CP	3.72^{h}	5.58^{p}	4.65^{kl}	5.02^{n}	4^{kl}	5.63^{t}	4.17^{m}	5.21^{pqr}
	mono cropping	SOR	3.05^{e}	4.58^{kl}	3.8^{1h}	4.12^{ij}	3.24^{eg}	4.62^{o}	3.42^{gh}	4.27^{m}
OP	crop rotation	CP-SOR	2.63^{b}	3.94^{h}	3.29^{f}	3.55^{fg}	2.92^{bc}	3.98^{k}l	2.95^{bd}	3.68^{ij}
	crop rotation	DOL-SOR	2.49^{b}	3.74^{h}	3.11^{e}	3.36^{f}	2.68^{ab}	3.77^{ij}	2.79^{bc}	3.49^{gh}
	inter cropping	SOR/DOL	2.26^{a}	3.38^{f}	2.82^{bc}	3.04^{e}	2.42^{a}	3.41^{gh}	2.53^{a}	3.16^{de}
	inter cropping	SOR/CP	2.79^{bc}	4.18^{ij}	3.49^{fg}	3.77^{h}	3^{cd}	4.22^{m}	3.13^{de}	3.91^{jk}
	mono cropping	SOR	2.29^{a}	3.43^{f}	2.56^{b}	3.09^{e}	2.43^{a}	3.46^{gh}	2.86^{bc}	3.21^{eg}
TR	crop rotation	CP-SOR	5.26^{o}	7.89^{x}	6.57^{s}	7.1^{uv}	5.83^{u}	7.95^{z}	5.89^{u}	7.36^{x}
	crop rotation	DOL-SOR	4.98^{n}	7.47^{w}	6.23^{r}	6.72^{s}	5.37^{pqrs}	7.54^{y}	5.58^{t}	6.98^{w}
	inter cropping	SOR/DOL	4.51^{k}	6.77st	5.64^{p}	6.09^{q}	4.85^{p}	6.82^{w}	5.06^{pq}	6.32^{v}
	inter cropping	SOR/CP	5.58^{p}	8.37^{y}	6.97^{tu}	7.53^{w}	5.99^{u}	8.44^{z}	6.25^{v}	7.81^{z}
	mono cropping	SOR	4.58^{k}l	6.86st	5.72^{p}	6.18^{r}	4.86^{p}	6.92^{w}	5.13^{pq}	6.41^{v}

Legend: SOR-sorghum, DOL-dolichos, CP-chickpea, MRP-minjingu rock phosphate, FYM-farm yard manure, TR-tied ridges, FR-furrows and ridges, SRS-Short Rain Season, LRS-Long Rain Season. Means per season followed by the same letter are not significantly different at $P \leq 0.05$

improved soil moisture content was observed under tied ridges as compared to furrows and ridges and oxen plough this was attributed to improved water retention thus enabling percolation of the same to the soil under tied ridges as opposed to furrows and ridges and oxen plough. The increased in soil moisture content with combined application of MRP+FYM is attributable to addition of organic manure, which contributed to the maintenance of soil physical structure, and results in better soil moisture retention. MRP recorded low moisture content as compared to FYM and MRP+FYM this is due low solubility rate of MRP thus requires more moisture for it to solubilise leading to low soil moisture where applied. The low solubility of MRP has been reported by Akande 2005 and Adetuji, 2006

Addition of organic inputs conserves rainwater, reduce runoff and improve the soil moisture content. These has also been reported by Sugeet et al. (2011) and Lemlem (2012), who found that addition of Organic fertilizers improved soil water holding capacity. Boateng et al. (2006) and Adeleye et al. (2010) also found out that application of FYM increased the soil water content.

Control had significantly ($p \leq 0.05$) lowest soil moisture and this was attributed to the soils of the study site being naturally low in organic matter. Due to low residue returns and high temperature causing fast decomposition as well as reduced rainfall hence the low water holding capacity.

This observation is in agreement with research by Cornelis, (2006) who found out that the soils of arid and semiarid zones are very susceptible of water erosion mostly due to the scarce vegetation cover, low organic matter content and the small resistance to the erosion forces.

Soil moisture was significantly low in the mono crop of sorghum for all tillage practices (Table 4) due to high evapotranspiration potential; to the contrary, soil moisture increased in the mono crop of sweet potato (Table 5) across all tillage practices due to low evapotranspiration potential. The sweet potato covers the ground adequately thus reducing direct losses from soil surface unlike in sorghum. According to Lusweti *et al. (*1999) Sweet potato provides good ground cover thereby reducing evapotransipiration and consequently enhancing moisture retention.

There were significant ($p \leq 0.05$) increases in soil moisture content undertied ridges following intercropping of sweet potato with chickpea (8.55%), and sweet potatoes mono cropping (8.07%)

with application FYM. The water evaporation at soil surface was therefore low and soil moisture retention high compared to intercrop of dolichos (6.95%).

With the intercropping of sweet potato chickpea and sweet potato monocropping there was an adequate ground cover as opposed to intercrop of dolichos. Intercropping of dolichos and sweet potato affects the growth of sweet potato due to light interception by the leafy dolichos.

Table 5: Interactive effects of tillage practices, cropping systems and organic inputs on soil moisturecontent(%) in sweet potato plots during SRS of 2012 and LRS of 2013

			SRS 2012				LRS 2013			
			CTRL	FYM	MRP	MRP+FYM	CTRL	FYM	MRP	MRP+FYM
FR	crop rotation	CP-SP	3.25e	4.76kl	4h	4.28ij	3.39eg	4.8o	3.6gh	4.46m
	crop rotation	DOL-SP	3.52f	5.16n	4.34ij	4.64k	3.73hi	5.2pq	3.9ij	4.84o
	inter cropping	SP/DOL	3.21e	4.69k	3.95h	4.22hi	3.38eg	4.73n	3.55gh	4.4m
	inter cropping	SP/CP	3.92h	5.76p	4.84kl	5.18n	4.15kl	5.81t	4.35m	5.4pqr
	mono cropping	SP	3.7fg	5.44o	4.57k	4.89lm	4.04jk	5.48pqrs	4.11jk	5.1p
OP	crop rotation	CP-SP	2.49a	3.61f	2.75b	3.25e	2.58a	3.64gh	3.04bc	3.4eg
	crop rotation	DOL-SP	2.69b	3.92h	3.3e	3.52f	2.83ab	3.95ij	2.97bc	3.68gh
	inter cropping	SP/DOL	2.46a	3.56f	3.01bc	3.2e	2.57a	3.59gh	2.71a	3.35de
	inter cropping	SP/CP	2.99bc	4.36ij	3.68fg	3.93h	3.15cd	4.4m	3.31de	4.1jk
	mono cropping	SP	2.83b	4.12h	3.48f	3.71fg	3.07bc	4.16kl	3.13bd	3.87ij
TR	crop rotation	CP-SP	4.78kl	7.04st	5.91p	6.34r	5.01p	7.1w	5.31pq	6.6v
	crop rotation	DOL-SP	5.18n	7.65w	6.42r	6.88s	5.52pqrs	7.72y	5.76t	7.17w
	inter cropping	SP/DOL	4.71k	6.95st	5.83p	6.25q	5p	7w	5.24pq	6.51v
	inter cropping	SP/CP	5.78p	8.55y	7.16tu	7.69w	6.14u	8.62z	6.43v	8z
	mono cropping	SP	5.46o	8.07x	6.76s	7.26uv	5.98u	8.13z	6.07u	7.55x

Legend: SP-Sweet Potato, DOL-dolichos, CP-chickpea, MRP-minjingu rock phosphate, FYM-farm yard manure, TR-tied ridges, FR-furrows and ridges, SRS-Short Rain Season, LRS-Long Rain Season. Means per season followed by the same letter are not significantly different at P ≤0.05

Additionally, distribution of root systems among species and cropping system influenced the soil moisture content in that when crops are intercropped the distribution of the roots in the soil is more intense as opposed to mono cropping. Ogindo and Walker (2005) also observed that under intercropping, water conservation was largely due to early high leaf area index and higher leaf area. Intercropping has also been reported to reduce water evaporation, and improve soil moisture conservation compared with sole cropping (Ghanbari *et al.,* 2010)

The high moisture retention recorded the soil moisture conservation techniques involving tied ridges further conforms to the findings of KARI (2005) who stated that there is a positive effect of the tied ridges and furrows and ridges in conservation of soil moisture and prolonged moisture availability in arid and semi-arid regions due to reduced soil loss through erosion and runoff. Vogel *et al. (*1994) similarly reported that moisture conservation method such as tied ridges and furrows and ridges contribute to increased infiltration, reduction of run-off and increasing rooting volume in shallow soils.

Changes in moisture content across the seasons

There was an increased in moisture content across all the tillage during the long rain season TR (8.44%), FR (5.63%) and OP (4.22%) as compared to short rain season (8.37%) FR (5.58%) and OP (4.18%) though not significantly ($p \leq 0.05$) different. The same trend was observed as short rain season with increased moisture content under the intercrop of sorghum chickpea with application of MRP+FYM. The increased in moisture content during the long rain season was attributed to prolonged rain during the long rain season as compared to the short rain season.

4.2.3.2Interactive effects of tillage practices, cropping systems and organic inputs on soil moisture conservation efficiency

Tied ridges with an intercrop of dolichos and sorghum (6.73%) (Fig. 1) and dolichos and sweet potato (7%) (Fig 2) with application of MRP + FYM were the efficient techniques for moisture conservation during the LRS of 2013 whereas oxen plough showed very poor moisture efficiency (3.2%) under intercrop of sorghum dolichos with the application of MRP+FYM (Fig.13).

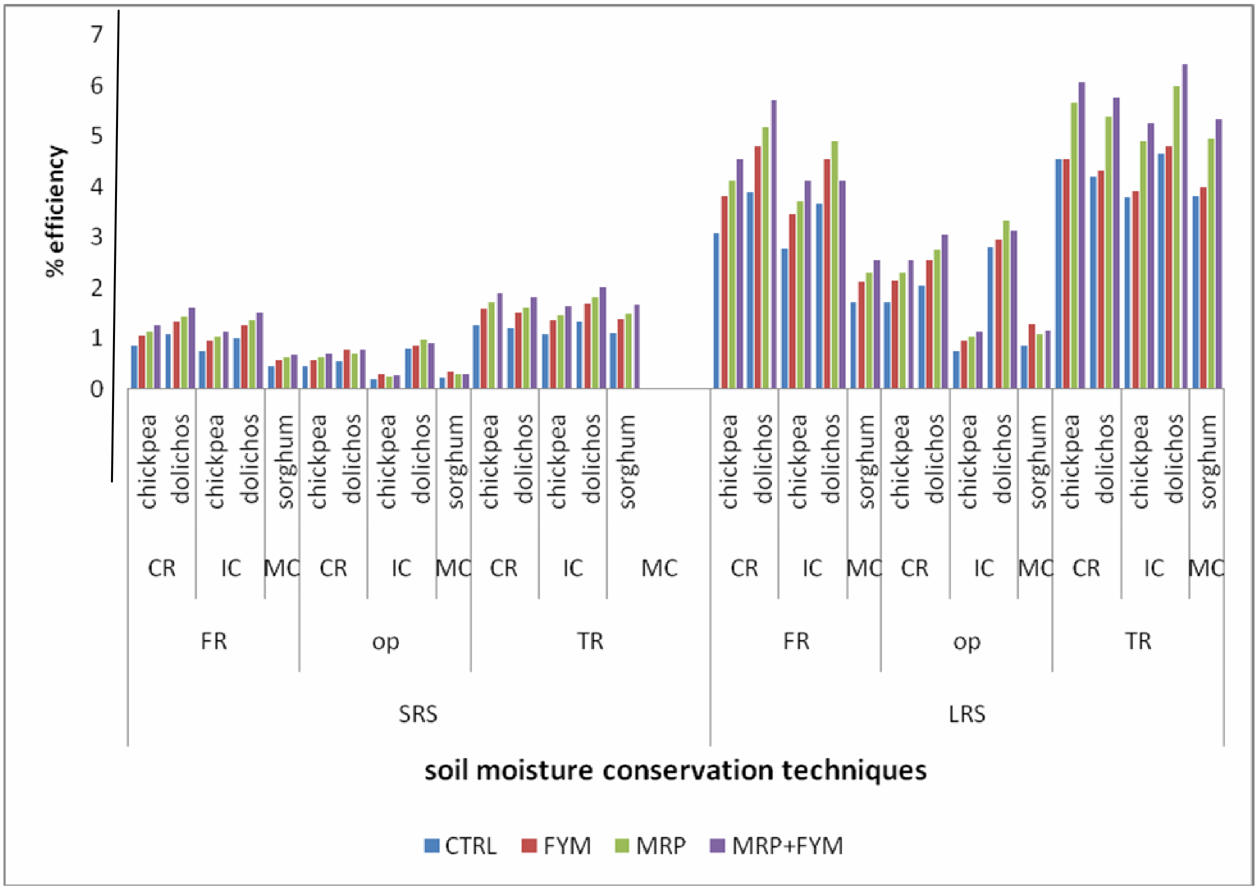


Figure 13: Efficiency of combined tillage practices, cropping systems and organic inputs on soil moisture retention under sorghum based plots

Legend: CR-crop rotation, IC-intercropping, Mc-Mono cropping, CTRL-control, FR-furrows and Ridges, FYM-farm yard, MRP-minjingu rock phosphate OP-oxen plough, LRS-long rain season, SRS-short rain season

The improved soil moisture conservation efficiency recorded in techniques involving tied ridges is due to the fact that they allow rainwater to be retained on the furrows for longer duration. This is in addition to improved ground cover and increased amount of organic matter that results into improved soil structure and reduced water losses through soil erosion, reduced evapotranspiration following intercropping and moisture conservation by application of FYM.

Itabari *et al*. (2003) made similar observation that furrows and ridges and tied ridges favored prolonged rainwater infiltration and retention, thus raising the overall soil moisture retention and soil water holding capacity. Crusciol *et al.* (2005) also found that rotation and intercropping of crops with species that increase plant residues on the soil surface is fundamental to avoid erosion.

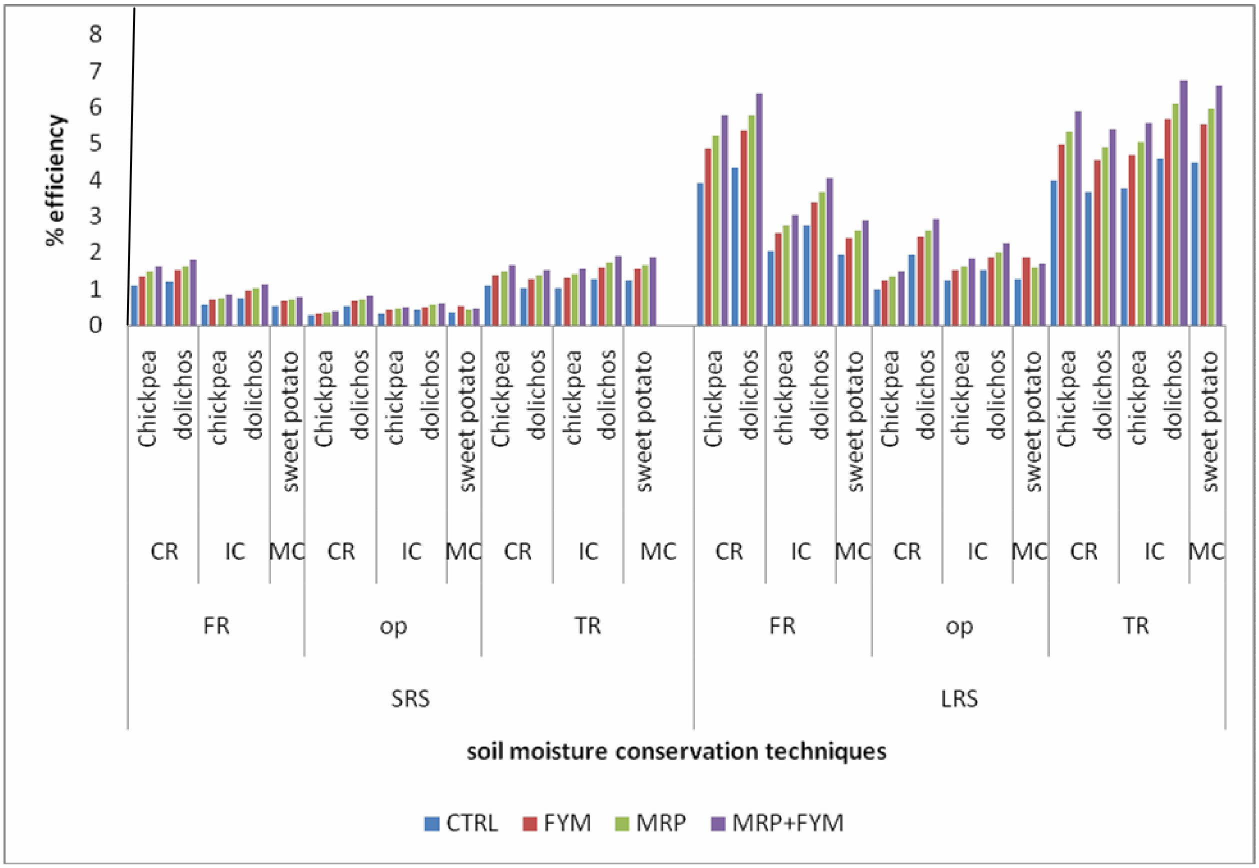


Figure 14: Efficiency of combined tillage practices, cropping systems and organic inputs on soil moisture retention under sweet potato based plots

Legend: CR-crop rotation, IC-intercropping, Mc-Mono cropping, CTRL-control, FR-furrows and Ridges, FYM-farm yard, MRP-minjingu rock phosphate OP-oxen plough, LRS-long rain season, SRS-short rain season

This was attributed to the improved ground cover and increased amount of organic matter in the soil ensuring reduced loss of soil moisture through evapotranspiration. In addition improved ground cover results into improved soil structure and reduced water losses through soil erosion.

The soil moisture conservation techniques were more efficient in the LRS as compared to the SRS of but the same trend was observed with more efficiency under tied ridges; Intercrop of dolichos with the application of MRP+FYM as the most efficient techniques for moisture conservation. The high rainfall during the second season as opposed to the first season, may have led to increased soil moisture content. This resulted into an increased biomass, which further increased the moisture content by reducing the evapotranspiration and erosion, hence increased infiltration. The effects of conservation agriculture on higher infiltration and reduced runoff and flooding have been well documented in Brazil in particular (FAO, 2000e).

4.2.4 Conclusion

Significant increase in soil moisture content was recorded in tied ridges following sorghum and dolichos and sweet potato and dolichos intercrops with application of MRP+FYM. The same treatments were similarly the most efficient techniques for moisture conservation. A combination of tied ridges and dolichos/sorghum and/or dolichos/sweet potato intercrops with application of MRP+FYM are viable methods for soil moisture conservation in the semi-arid areas of Yatta Sub County.

4.3 Effects of tillage practices, cropping systems and organic inputs on soil nutrient status

Abstract

Low use efficiencies of inorganic fertilizers coupled with their rising costs has directed the attention of farmers towards organic sources. Against this backdrop study was conducted, in Matuu, Yatta sub-county, to evaluate the influence of tillage practices, cropping systems and organic inputs on soil nutrient status. It was carried out between October 2012 to February 2013 short rain season (SRS) and April-August 2013 long rain season (LRS). Randomized Complete Block Design with a split-split plot arrangement replicated three times was used. Main plots tillage practices (TP); Oxen plough (OP), tied ridges (TR) and furrows and ridges (FR). Split-plots were cropping systems (CS); monocropping (MC), intercropping (IC), and crop rotation (CR) while split-split plots were organic inputs; Farmyard manure (FYM), Minjingu Rock Phosphate (MRP), combined MRP and FYM (MRP+FYM) and control. Test crops were sorghum and sweet potatoes with Dolichos (*Dolichos lablab*) and chickpea (*Cicerarietinum*L) either as intercrops or in rotation. Soil samples were taken randomly at 0-30 cm depth at the start of experiment for initial soil analysis and at crop maturity of test crops for soil (NPK and Organic carbon) analysis. There was a significant ($P \leq 0.05$) high level of potassium (1.91 Cmol+Kg), phosphorous (51.45 ppm), Total nitrogen (0.19%) and organic carbon (2.19%), in combined TR, intercrop sorghum/chickpea with application of MRP+FYM during SRS of 2012. Comparing different organic inputs, tillage practices and cropping systems combined TR, intercrop of sorghum/chickpea and MRP+FYM and FYM improved the soil nutrients status.

Key words: cropping systems; tillage practices; organic inputs; Semi-arid; soil nutrients

1.0 Introduction

Low soil fertility and moisture deficits are major constraints to crop production in the semi-arid areas of Kenya. Many interrelated factors, both natural and managerial, lead to soil fertility decline either through leaching, erosion, and crop harvesting (Donovan and Casey 1998). The low soil fertility is majorly contributed by extensive agriculture production particularly in developing countries (Rezig *et al.,* 2012) due to the ever-increasing demand of the rising population. Unless the nutrients are replenished using organic or mineral fertilizers, partially returned through crop residues, or rebuilt more comprehensively through traditional fallow systems that allow restoration of nutrients and reconstruction of soil organic matter, soil nutrient levels decline continuously. Therefore, the use of species different from the main crop such as legumes contributes to the nutrient balance, which may consequently increase soil fertility level over time. Leguminous species are known for their capacity to fix atmospheric di-nitrogen and narrow the C/N ratio, resulting in faster residue decomposition (Aita and Giacomini, 2003) and consequent release of accumulated N and other nutrients such as P and K, to the soil (Borkert *et al.,*2003). Legume green manures are efficient at mobilizing P from the soil (Knight and Shirtliffe, 2005). As green manures decompose, the P is released in a labile form that enhances the P nutrition of succeeding crops (Cavigelli and Thien, 2003).

In addition, the farmers in the Eastern part of Kenya use farmyard manure (FYM) as a cheaper alternative source of plant nutrients as opposed to the more costly inorganic fertilizers (Gichagi *et al.,* 2007). Farmyard manure acts as an alternative source of fertility enhancement for inorganic fertilizer as they release nutrients slowly and steadily over a long period of time and also improve the soil fertility status by activating the soil microbial biomass (Belay *et al.,* 2001). Consequently, inputs from organic sources, for example, FYM, play a pivotal role in the productivity of many farming systems by providing nutrients through decomposition and substrate for the synthesis of soil organic matter (SOM). SOM is shown to improve crop growth and yield by supplying nutrients or by modifying soil physical properties (Rees *et al.,* 2000)

Furthermore, SOM acts as a bonding and dispersing agent by increasing inter-particle hydrophobicity and cohesion within aggregates (Mullins 2000; Abiven *et al.*, 2009). It is well known that manures are a source of all-necessary macro- and micronutrients in available forms, thereby improving the physical and biological properties of the soil (El-Magd *et al.*, 2005). Because the decomposition of manures is a slow process, manures are usually applied at higher rates, relative to that of inorganic fertilizers, to meet crop nutrient requirements. When applied at high rates, they give positive residual effects on the growth and yield of succeeding crops (Makinde and Ayoola 2008). The application of manures to soil similarly provide potential benefits including improving the fertility, structure, increasing soil organic matter and improved water holding capacity (Phan *et al.*, 2002, Blay *et al.*, 2002). Ridge tillage reduces bulk density and concentrates fertility and organic matter stimulate seedling growth and establishment and reduces wind erosion (Kaij and Hoogmed, 1993).

The current study evaluated the effects of tillage practice, cropping system and organic inputs on soil nutrients N, P, K, and organic carbon in Yatta Sub County.

4.3.2.Materials and methods

Study site, treatments and experimental design and field practices were as described in section 3.1, 4.2.2.1 and 4.2.2.3 respectively.

4.3.2.4 Soil sampling and analysis

Initial soil samples were collected using the transect method (in a zigzag manner from one edge of the field) for initial soil analysis. Soil samples were also taken at crop maturity of the main crops sweet potato and sorghum, three samples per treatment were taken and composited into one sample and thoroughly mixed to form one composite sample per treatment then air-dried by spreading it out in a clean, warm, dry area for two days. They were then analyzed for Nitrogen, Phosphorous, and Potassium and organic Carbon using chemical analytical techniques. The Walkley Black method was used to determine soil organic carbon. 10 ml of dichromate and 20ml of sulfuric acid was added to a 5g soil sample. After the mixture cooled, the amount of dichromate used in the reaction was determined by reducing the remaining dichromate with ferrous sulphate of known normality in a simple titration using barium diphenylamine as an indicator. The percentage of carbon was calculated according to a formula which took account that 1ml of N dichromate oxidizes 3mg of carbon (Okalebo, 2002).

Determination of potassium involved extraction of nutrient from the soil through leaching with 1N ammonium acetate. Concentration of potassium was then determined through use of the flame photometry method. Flame photometry method is based on the fact that certain metallic ions when ignited with a flame emit a distinct light. When the light is compared to a standard, the distinct composition of potassium can be determined (Okalebo, 2002).

Kjeldahl method was used to determined total nitrogen. 2 g of the soil was weighed then transferred to 300 ml Kjeldahl flasks in duplicates.2 g of the catalyst were added and washed in with 5ml of distilled water.20ml of concentrated sulphuric acid was then added, mixed with the soil by gentle shaking and allowed to stand for 15 minutes. The flasks were then placed in a fume cupboard and gently heated for 6 hours. After completion of digestion, the flasks were allowed to cool after which 100ml of water was added and shaken to mix. The liquid was then transferred to small labeled plastic beakers and allowed to settle down.5 ml of the digest was transferred using a pipette into a 300 ml Kjeldahl flask and phenolphthalein indicator added. NaoH was then added drop wise till the colour changed to purple .It was connected to the distillation unit and switched on with a 250 ml conical flask containing 20 ml Boric acid with 3 drops of mixed indicator on the receiving end of the distillation unit. The ammonium-N in the distillate was determined by titrating with 0.01 M Hcl (Okalebo *et al.,* 2002).

Available phosphorous was determined by weighing 5-g sample of soil was into a 100-ml extracting tube and 50ml of double acid reagent added. The tubes were stoppered tightly and shaken for 30 minutes in a mechanical reciprocating shaker .The soils were then filtered through Whatman No.42 filter paper and filtrate collected in specimen bottles. 5 ml of the 5ppm standard was pipeted into 50-ml volumetric flasks. 5ml of double acid was added followed by 20 ml of distilled water mixed and allowed to stand for 15 minutes after which the reading (absorbance) was taken the spectrophotometer.15 ml of the soil extract was pipetted into a 50 ml volumetric flask,25 ml of distilled water was added followed 8 ml of reagent B ,made up to volume and thoroughly mixed. It was allowed to stand for 25 minutes after which the readings were taken.

4.3.2.5 Statistical analysis

Data was subjected to general analysis of variance using Genstat statistical software (Payne 2005b). Means were separated using least significant difference at a probability level of 5%.

4.3.3 Results discussion

4.3.3.1 Effects of tillage practice, cropping systems and organic inputs on soil nutrients status.

Soil available potasium

Potassium was significantly ($P \leq 0.05$) affected by the organic inputs. Increased level of potassium content recorded with application of MRP + FYM in all tillage practices and cropping systems, compared to other organic inputs MRP, FYM and their controls. Combined TR , sorghum mono crop (3.37 Cmol+/Kg) and intercrop of sweet potatoes and chickpea (3.08 Cmol+/Kg) plots respectively during the short rain season of 2012 (Table 6 and 7).

Table 6: Effects of tillage practice, cropping systems and organic inputs on soil potassium Cmol+/Kg sorghum based plots during SRS of 2012 and LRS of 2013

			SRS 2012				LRS 2013			
TP	CS	CROP	CTRL	FYM	MRP	MRP+FYM	CTRL	FYM	MRP	MRP+FY
FR	crop rotation	CP-SOR	1.29^{bc}	1.4^{de}	1.48^{def}	1.67^{gh}	1.4^{bc}	1.52^{de}	1.6^{def}	1.81^{gh}
	crop rotation	DOL-SOR	1.08^{a}	1.13^{a}	1.18^{ab}	1.34^{cd}	1.17^{a}	1.22^{a}	1.28^{ab}	1.45^{cd}
	inter cropping	SOR/DOLb	1.62^{gh}	1.7^{ghi}	1.77^{ghi}	2.01^{k}	1.75^{gh}	1.84^{ghi}	1.92^{ghi}	2.18^{k}
	inter cropping	SOR/CP	1.55^{defg}	1.72^{gh}i	1.87^{ghi}	2.11^{k}	1.68^{defg}	1.84^{ghi}	1.92^{ghi}	l2.18^{k}
	mono cropping	SOR	1.19^{ab}	1.29^{bc}	1.36^{cd}	1.54^{defg}	1.29^{ab}	1.4^{bc}	1.47^{cd}	1.67^{defg}
OP	crop rotation	CP-SOR	2.54^{m}	2.66^{mn}	2.78^{o}	3.15^{q}	2.75^{m}	2.88^{mn}	3.01^{o}	3.41^{q}
	crop rotation	DOL-SOR	2.64^{mn}	2.77^{o}	2.9^{p}	3.28^{qr}	2.86^{mn}	3^{o}	3.14^{p}	3.56^{q}
	inter cropping	SOR/DOL	2.54^{m}	2.66^{mn}	2.78^{o}	3.15^{q}	2.75^{m}	2.88^{mn}	3.01^{o}	3.41^{q}
	inter cropping	SOR/CP	2.37^{ln}	2.49^{m}	2.6^{mn}	2.95^{p}	2.57^{l}	2.69^{m}	2.82^{mn}	3.19^{p}
	mono cropping	SOR	3.08^{q}	3.82^{t}	3.22^{qr}	3.37^{s}	3.33^{q}	4.14^{t}	3.49^{qr}	3.65^{s}
TR	crop rotation	CP-SOR	1.45^{def}	1.58^{defg}	1.66^{gh}	1.88^{ghij}	1.58^{def}	1.71^{defg}	1.8^{gh}	2.04^{ghij}
	crop rotation	DOL-SOR	1.16^{a}	1.26^{bc}	1.33^{cd}	1.51^{def}	1.26^{a}	1.37^{bc}	1.44^{cd}	1.63^{def}
	inter cropping	SOR/DOL	1.33^{cd}	1.44^{de}	1.52^{def}	1.72^{ghi}	1.44^{cd}	1.56^{de}	1.64^{def}	1.86^{ghi}
	inter cropping	SOR/CP	1.47^{def}	1.61^{gh}	1.68^{gh}	1.91^{ghij}	1.6^{def}	1.75^{gh}	1.82^{gh}	2.07^{ghij}
	mono cropping	SOR	1.13^{a}	1.23^{ab}	1.29^{bc}	1.46^{def}	1.22^{a}	1.33^{ab}	1.4^{bc}	1.59^{def}

Legend: SOR-sorghum, DOL-dolichos, CP-chickpea, TP-tillage practice, TR-tied ridges, FR-furrows and ridges, OP-oxen plough, FYM-farm yard -manure, MRP-minjingu rock phosphate, CTRL-contro, LRS-long rain season, SRS-short rain season, CS-cropping system.Under rotation legumes were harvested during the short rain season 2012 whereas sweet potatoes and sorghum were harvested during the long rain season 2013. Means followed by the same letters in the same season in a column are not significantly different at $P \leq 0.05$.

Table 7: Effects of tillage practice and organic cropping systems on soil potassium Cmol+/Kg sweet potato based plots during SRS of 2012 and LRS of 2013

			SRS 2012				LRS 2013			
TP	CS	CROP	CTRL	FYM	MRP	MRP+FYM	CTRL	FYM	MRP	MRP+FY
FR	crop rotation	CP-SP	1.58^{h}	1.66^{hi}	1.73^{hij}	1.96^{m}	1.74^{h}	1.82^{hi}	1.91^{hij}	2.16^{m}
	crop rotation	DOL-SP	1.04^{a}	1.09^{b}	1.14^{b}	1.29^{bcd}	1.14^{a}	1.2^{b}	1.25^{b}	1.42^{bcd}
	inter cropping	SP/DOL	1.73^{hij}	1.81^{k}	1.89^{l}	2.14^{o}	1.9^{hij}	1.99^{k}	2.08^{l}	2.36^{o}
	inter cropping	SP/CP	1.13^{b}	1.19^{bc}	1.24^{bcd}	1.41^{ef}	1.25^{b}	1.31^{bc}	1.37^{bcd}	1.55^{ef}
	mono cropping	SP	1.09^{b}	1.18^{bc}	1.24^{bcd}	1.41^{ef}	1.19^{b}	1.3^{bc}	1.37^{bcd}	1.55^{ef}
OP	crop rotation	CP-SP	2.28^{q}	2.38^{r}	2.49^{s}	2.82^{v}	2.5^{q}	2.62^{r}	2.74^{s}	3.11^{v}
	crop rotation	DOL-SP	1.19^{bc}	1.24^{bcd}	1.3^{bcde}	1.47^{efg}	1.31^{bc}	1.37^{bcd}	1.43^{bcde}	1.62^{efg}
	inter cropping	SP/DOL	2.48^{s}	2.6^{t}	2.72^{u}	3.08^{w}	2.73^{s}	2.86^{t}	2.99^{u}	3.39^{w}
	inter cropping	SP/CP	1.29^{bcd}	1.36^{ef}	1.42^{efg}	1.61^{h}	1.42^{bcd}	1.49^{ef}	1.56^{efg}	1.77^{h}
	mono cropping	SP	2.21^{p}	2.75^{u}	2.32^{q}	2.42^{r}	2.43^{p}	3.02^{u}	2.55^{q}	2.67^{r}
TR	crop rotation	CP-SP	1.27^{bcd}	1.38^{ef}	1.45^{efg}	1.65^{hi}	1.4^{bcd}	1.52^{ef}	1.6^{efg}	1.81^{hi}
	crop rotation	DOL-SP	1.02^{a}	1.11^{b}	1.16^{bc}	1.32^{bcde}	1.12^{a}	1.22^{b}	1.28^{bc}	1.45^{bcde}
	inter cropping	SP/DOL	1.57^{h}	1.71^{hij}	1.8^{k}	2.04^{n}	1.73^{h}	1.88^{hij}	1.98^{k}	2.24^{n}
	inter cropping	SP/CP	1.58^{h}	1.73^{hij}	1.81^{k}	2.06^{n}	1.75^{h}	1.89^{hij}	1.99^{k}	2.26^{n}
	mono cropping	SP	1.03^{a}	1.12^{b}	1.18^{bc}	1.34^{bcde}	1.13^{a}	1.23^{b}	1.3^{bc}	1.47^{bcde}

Legend: SP-sweet potato, DOL-dolichos, CP-chickpea, TP-tillage practice, TR-tied ridges, FR-furrows and ridges, OP-oxen plough, FYM-farm yard -manure, MRP-minjingu rock phosphate, CTRL-control, LRS-long rain season, SRS-short rain season, CS-cropping system.. Means followed by the same letters in the same season in a column are not significantly different at $P \leq 0.05$.

Increased potassium content was observed under combined oxen plough, sorghum mono cropping with application of MRP+FYM (3.37 Cmol+/Kg) and intercropping sweet potato/dolichos (3.08 Cmol+/Kg) as compared to other tillage practices combined furrows and ridges, intercropping sorghum/ dolichos with application MRP+FYM (2.01 Cmol+/Kg) and intercropping sweet potato/dolichos (2.14 Cmol+/Kg) and tied ridges with intercropping of sorghum/chickpea (1.91 Cmol+/Kg) and intercropping of sweet potato /chickpea (2.06 Cmol+/Kg) . Increased potassium level under the application of MRP+FYM was attributed to the fact that when farmyard manure and minjingu rock phosphate are mixed it enhance the release of other nutrients such as potassium through improvement on the soil moisture content and increased activity of microorganisms in the soil the same applies when farmyard manure was applied. Low Potassium content under tied ridges (1.91 Cmol+/Kg) and furrows and ridges (2.11 Cmol+/Kg) as compared to oxen plough (2.95 Cmol+/Kg) was attributed to increased soil moisture content leading to loss of the nutrients down the profile due to leaching thus reducing the potassium content in the upper profile as compared to oxen plough.

Under different cropping system increased potassium content was observed under the intercrop and crop rotation of both chickpea and dolichos in all tillage practices. This was attributable to the effects of exudates released by the legumes which acts on the organic inputs applied thus releasing more nutrients to the soil. Moreover, inclusion of legumes in crop rotations protects the fragile soil surface by restoring the organic matter content and organic fertility of these soils.

Increased potassium level under intercropping and crop rotation of chickpea and dolichos was also reported by Ahmad et al., (2010) who found out that use of green manure especially legumes in a cropping pattern could help restore crop productivity. In addition Aziz *et al*. (2010) reported that manure application significantly increases soil K contents due to increased microbial activity in the soil. Another similar observation was made by Suge *et al.(2011)* , who found that addition ofOrganic fertilizers improve soil water holding capacity as well as the CEC and nutrients are released slowly to crop plants thus impacting on nutrients availability. The inclusion in a rotation of cover crops or green manures can also enhance the efficient use of nutrients by plants, mainly owing to the increase in soil microbial population and activity (Watson et al., 2002).

Changes in potassium content Cmol+/Kg across the seasons (SRS 2012 and LRS 2013)

Changes in potassium content across the two season was observed with increase during the LRS (3.65 Cmol+/Kg) and (3.39 Cmol+/Kg) as compared to the SRS (3.37 Cmol+/Kg) and (3.09 Cmol+/Kg) under oxen plough in sorghum mono cropping and intercropping of sweet potato/ dolichos with the application of MRP+FYM in sorghum and sweet potato plots respectively (Table 6 and 7). During the LRS of 2013 the soil moisture content increased as a result of prolonged rainfall as opposed to SRS of 2012.Soil moisture content affects the availability of K in soil, greater efficiency of K fertilizer with increasing soil moisture since it influence microbial activities responsible for decomposition for release of potassium. Decomposition of organic matter is chiefly carried out by heterotrophic microorganisms. This process is under the influence of temperature, moisture and ambient soil conditions and leads to the release and cycling of plant nutrients, especially nitrogen (N), potassium and phosphorus (Murphy et al., 2007).

Available phosphorous

The soil available phosphorus level was significantly ($P \leq 0.05$) increased in plots with MRP+FYM applied compared to other treatments FYM, MRP and control. Accordingly, combined TR, intercropping sweet potato and sorghum dolichos with application of MRP +FYM had increased level of phosphorous (51.45 ppm) and (46.31 ppm) respectively in the SRS of 2012 (Table 8 and 9).

Table 8: Effects of tillage practice and organic inputs on soil available phosphorous sorghum based plots during SRS of 2012 and LRS of 2013

TP	CS	CROPS	SRS 2012				LRS 2013			
			CTRL	FYM	MRP	MRP+FYM	CTRL	FYM	MRP	MRP+FYM
FR	crop rotation	CP-SOR	27.1^{g}	29.04^{j}	30.25^{k}	34.28^{p}	30.97^{g}	33.19^{j}	34.57^{k}	39.18^{p}
	crop rotation	DOL-SOR	30.78^{l}	32.98^{lmn}	34.35^{p}	38.93^{s}	35.18^{l}	37.69^{lmn}	39.26^{p}	44.5^{s}
	inter cropping	SOR/DOL	34.75^{p}	37.23^{r}	38.78^{s}	43.95^{x}	39.71^{p}	42.55^{r}	44.32^{s}	50.23^{x}
	inter cropping	SOR/CP	38.14^{s}	40.86^{v}	42.56^{v}	48.24^{y}	43.58^{s}	46.7^{v}	48.64^{v}	55.13^{y}
	mono cropping	SOR	25.17^{ef}	26.96^{g}	31.83^{lm}	28.09^{ghi}	28.76^{ef}	30.82^{g}	36.38^{lm}	32.1^{ghi}
OP	crop rotation	CP-SOR	21.68^{b}	23.23^{d}	24.2^{e}	27.42^{gh}	24.78^{b}	26.55^{d}	27.66^{e}	31.34^{gh}
	crop rotation	DOL-SOR	24.62^{e}	26.38^{g}	27.48^{gh}	31.15^{l}	28.14^{e}	30.15^{g}	31.41^{gh}	35.6^{l}
	inter cropping	SOR/DOL	27.8^{gh}	29.78^{k}	31.03^{l}	35.16^{q}	31.77^{gh}	34.04^{k}	35.46^{l}	40.19^{q}
	inter cropping	SOR/CP	30.51^{k}	32.69^{lmn}	34.05p	38.59^{s}	34.87^{k}	37.36^{lmn}	38.91^{p}	44.1^{s}
	mono cropping	SOR	20.13^{a}	22.47^{c}	21.57^{b}	25.47^{ef}	23.01^{a}	25.68^{c}	24.65^{b}	29.1^{ef}
TR	crop rotation	CP-SOR	28.91^{j}	30.97^{l}	32.26^{lm}	36.57^{r}	33.04^{j}	35.4^{l}	36.87^{lm}	41.79^{r}
	crop rotation	DOL-SOR	32.83^{lmn}	35.18^{q}	36.64^{r}	41.53^{v}	37.52^{lmn}	40.2^{q}	41.88^{r}	47.46^{v}
	inter cropping	SOR/DOL	37.07^{r}	39.71^{t}	41.37^{v}	46.88^{y}	42.36^{r}	45.39^{t}	47.28^{v}	53.58^{y}
	inter cropping	SOR/CP	40.68^{u}	43.58^{w}	45.4^{x}	51.45^{z}	46.49^{u}	49.81^{w}	51.89^{x}	58.8^{z}
	mono cropping	SOR	26.84^{g}	28.76^{j}	33.95^{o}	29.96^{k}	30.68^{g}	32.87^{j}	38.81^{o}	34.24^{k}

Legend: SOR-sorghum, DOL-dolichos, CP-chickpea, TP-tillage practice, TR-tied ridges, FR-furrows and ridges, OP-oxen plough, FYM-farm yard -manure, MRP-minjingu rock phosphate, CTRL-control, LRS-long rain season, SRS-short rain season, CS-cropping system.. Means followed by the same letters in the same season in a column are not significantly different at $P \leq 0.05$.

Table 9: Effects of tillage practice and organic inputs on soil available phosphorous sweet potato based plots during Short Rain Season 2012 and Long Rain Season 2013

			SRS 2012				LRS 2013			
TP	CS	CROPS	CTRL	FYM	MRP	MRP+FYM	CTRL	FYM	MRP	MRP+FYM
FR	crop rotation	CP-SP	24.39^{f}	26.13^{fghi}	27.22^{fghij}	30.85^{m}	27.88^{f}	29.87^{fghi}	31.11^{fghij}	35.26^{m}
	crop rotation	DOL-SP	27.7^{fghij}	29.68^{jkl}	30.92^{m}	35.04^{p}	31.66^{fghij}	33.92^{jkl}	35.33^{m}	40.05^{p}
	inter cropping	SP/DOL	31.27^{m}	33.51^{o}	34.9^{p}	39.56^{u}	35.74^{m}	38.29^{o}	39.89^{p}	45.21^{u}
	inter cropping	SP/CP	34.32^{p}	36.77^{r}	38.31^{t}	43.41^{x}	39.23^{p}	42.03^{r}	43.78^{t}	49.62^{x}
	mono cropping	SP	22.65^{de}	24.27^{f}	28.65^{jkl}	25.28^{fgh}	25.89^{de}	27.73^{f}	32.74^{jkl}	28.89^{fgh}
OP	crop rotation	CP-SP	19.51^{b}	20.91^{bc}	21.78^{d}	24.68^{fg}	22.3^{b}	23.89^{bc}	24.89^{d}	28.21^{fg}
	crop rotation	DOL-SP	22.16^{d}	23.74f	24.73^{fg}	28.03^{jk}	25.33^{d}	27.14^{f}	28.27^{fg}	32.04^{jk}
	inter cropping	SP/DOL	25.02^{fg}	26.81^{fghi}	27.92^{jk}	31.65^{mn}	28.59^{fg}	30.64^{fghi}	31.91^{jk}	36.17^{mn}
	inter cropping	SP/CP	27.46^{fghij}	29.42^{jkl}	30.65^{m}	34.73^{p}	31.38^{fghij}	33.62^{jkl}	35.02^{m}	39.69^{p}
	mono cropping	SP	18.12^{a}	20.22^{bc}	19.41^{b}	22.92^{de}	20.71a	23.11^{bc}	22.19^{b}	26.19^{de}
TR	crop rotation	CP-SP	26.02^{fgh}	27.88^{jk}	29.04^{jkl}	32.91^{o}	29.73f^{gh}	31.86^{jk}	33.19^{jkl}	37.61^{o}
	crop rotation	DOL-SP	29.55^{jkl}	31.66^{mn}	32.98^{o}	37.38^{rs}	33.77^{jkl}	36.18^{mn}	37.69^{o}	42.72^{rs}
	inter cropping	SP/DOL	33.36^{o}	35.74^{pq}	37.23^{r}	42.2^{w}	38.12^{o}	40.85^{pq}	42.55^{r}	48.22^{w}
	inter cropping	SP/CP	36.61^{r}	39.23^{u}	40.86^{v}	46.31^{y}	41.84^{r}	44.83^{u}	46.7^{v}	52.92^{y}
	mono cropping	SP	24.16^{f}	25.89^{fgh}	30.56^{m}	26.96^{fghij}	27.61^{f}	29.58^{fgh}	34.92^{m}	30.82^{fghij}

Legend: SP-sweet potato, DOL-dolichos, CP-chickpea, TP-tillage practice, TR-tied ridges, FR-furrows and ridges, OP-oxen plough, FYM-farm yard -manure, MRP-minjingu rock phosphate, CTRL-control, LRS-long rain season, SRS-short rain season, CS-cropping system.. Means followed by the same letters in the same season in a column are not significantly different at $P \leq 0.05$.

Increased available phosphorous with application of MRP+FYM was due to the enhanced release of Phosphorous from MRP when mixed with FYM since when FYM decomposes it releases humic acid which further enhance the release of phosphorous from the MRP. In addition it implies that MRP underwent considerable dissolution leading to the release of phosphorous in the MRP applied. Addition of FYM results into an increased microorganism decomposition rates and thus release phosphorous into the soil. Organic manures after decomposition may also provide organic acids and increase Phosphorous bioavailability after dissolution of MRP when combined with FYM and releases Phosphorous.

This conforms to a study by Mengel and Kirkby (2001); Marschner (2011) who found out that the increased P contents with addition of FYM are due to mineralization and increased water holding capacity, and thus making phosphorous readily available to crops. This is also in support of the study by KARI, (1993) which stated that application of farmyard manure **(**FYM) affect available Phosphorous level considerably. In addition farm yard manure increased soil moisture contents (Boateng *et al.*, 2006), which was the reason for improved Phoshorous availability in soil. Also as a result of added FYM there is an increased microbial activity and resultant biochemical transformations in soil, because of added organic manures may cause mineralization of more recalcitrant P fraction (Nziguheba *et al.*, 1998).

There was a significant difference across the tillage practices with increased available phosphorous content under tied ridges (51.45 ppm) as compared to furrows and ridges (48.24 ppm) and oxen plough (38.59 ppm) under intercropping sorghum chickpea with the application of MRP+FYM during the SRS of 2012.

The increased available phosphorous under tied ridges and furrows and ridges was due to the increased soil moisture content under tied ridges and ridges and furrows due to reduced runoff and soil erosion thus reduced phosphorous losses through erosion and runoff. (Kaushik and Gautam, 1997) found out that increased soil water storage reduces nutrients losses through erosion Oxen plough tillage practice may have had lower phosphorous levels due to increased loss through erosion and leaching. Kaumbutho and Simalenga (1999) documented that use of the oxen plough tillage practice could increase erosion due to the inappropriate width adjustment on the plough which led to formation of plough furrows acceleration the rate of rill erosion, especially in sloping lands causing nutrients losses.

There was also a significant difference across all the cropping systems with increased phosphorous content under the intercropping of chickpea (51.45 ppm) and dolichos (46.88 ppm) in tied ridges with the application of MRP+FYM during SRS 0f 2012 . This was due to enhanced release of the nutrients from the organic inputs due to the presence of the legumes, which led to enhanced release, fixation of nutrients and increased biological activity of decomposing the organic for the release of nutrients. This is supported by the findings of Singh *et al*. (2004) who attributed increasing available phosphon rous due to crop rotation, and Larkin, (2008) who also stated that crop rotation help in pests and diseases control thus increasing soil biological activity and Christen and Sieling, (1995) found out that there is rising water use efficiency and in turn increasing potassium and phosphorous content in the soil under crop rotation. It also conform to the study by Kamkar and Damghani (2009) who found out that application of crop rotation along with increasing soil organic matter, biodiversity and soil biological community.

Changes in phosphorous content ppm across the season (SRS 2012 and LRS 2013)

Changes in phosphorous content across the two season was observed with increase during the LRS (58.8 ppm) and (52.92 ppm) as compared to the SRS (51.45 ppm) and (46.31 ppm) under oxen plough in intercropping sorghum/ chickpea and intercropping of sweet potato/ chickpea with the application of MRP+FYM in sorghum and sweet potato plots respectively (Table 8 and 9).The higher amounts of soil available P in the LRS 2013 than SRS 2012 was due to the residual effects of the organic inputs applied MRP, MRP+FYM and FYM. According to Rowell 1994, the rapid adsorption of P onto soil particle surfaces is followed by a slower conversion into less available forms including mineral phosphates, thus P in the MPR and most phosphate fertilizers is available in the first season after application but remains over long periods of time hence their residual effects.

Total Nitrogen

Total N was significantly ($P \leq 0.05$) increased by the application of farmyard manure in all the tillage practices and cropping systems compared to other treatments. Significant ($P \leq 0.05$) increased % Total N content (0.19) was recorded under the application of FYM with the intercrop of dolichos sorghum in furrows and ridges (Table 10 and 11).

Table 10: Effects of tillage practices and organic cropping systems on soil total N sorghum based plots during SRS of 2012 and LRS of 2013

			SRS-2012				LRS-2013			
TP	CS	CROPS	CTRL	FYM	MRP	MRP+FYM	CTRL	FYM	MRP	MRP+FYM
FR	crop rotation	CP-SOR	0.1^{c}	0.13^{f}	0.1^{c}	0.11^{d}	0.1^{d}	0.14^{h}	0.11^{e}	0.12^{f}
	crop rotation	DOL-SOR	0.15^{h}	0.19^{l}	0.16^{i}	0.16^{i}	0.16^{j}	0.2^{n}	0.17^{k}	0.18^{l}
	inter cropping	SOR/DOL	0.09^{b}	0.12^{e}	0.09^{b}	0.1^{c}	0.09^{c}	0.13^{g}	0.1^{d}	0.11^{e}
	inter cropping	SOR/CP	0.13^{f}	0.17^{j}	0.14^{g}	0.15^{h}	0.14^{h}	0.18^{l}	0.15^{i}	0.16^{j}
	mono cropping	SOR	0.09^{b}	0.11^{d}	0.12^{e}	0.15^{h}	0.1^{d}	0.12^{f}	0.13^{g}	0.16^{j}
OP	crop rotation	CP-SOR	0.08^{a}	0.11^{d}	0.08^{a}	0.09^{b}	0.08^{b}	0.12^{f}	0.09^{c}	0.1^{d}
	crop rotation	DOL-SOR	0.12^{e}	0.15^{h}	0.12^{e}	0.13^{f}	0.13^{g}	0.16^{j}	0.14^{h}	0.14^{h}
	inter cropping	SOR/DOL	0.07^{a}	0.1^{c}	0.07^{a}	0.08^{a}	0.07^{a}	0.11^{e}	0.08^{b}	0.09^{c}
	inter cropping	SOR/CP	0.1^{c}	0.13^{f}	0.1^{c}	0.11^{d}	0.11e	0.14^{h}	0.12^{f}	0.12^{f}
	mono cropping	SOR	0.08^{a}	0.12^{e}	0.09^{b}	0.09^{b}	0.08^{b}	0.13^{g}	0.09^{c}	0.1^{d}
TR	crop rotation	CP-SOR	0.11^{d}	0.15^{h}	0.11^{d}	0.13^{f}	0.12^{f}	0.16^{j}	0.12^{f}	0.14^{h}
	crop rotation	DOL-SOR	0.16^{i}	0.21^{m}	0.17^{j}	0.18^{k}	0.18^{l}	0.23^{o}	0.19^{m}	0.2^{n}
	inter cropping	SOR/DOL	0.1^{c}	0.14^{g}	0.1^{c}	0.12^{e}	0.12^{f}	0.16^{j}	0.12^{f}	0.14^{h}
	inter cropping	SOR/CP	0.14^{g}	0.19^{l}	0.15^{h}	0.16^{i}	0.18^{l}	0.23^{o}	0.19^{m}	0.2^{n}
	mono cropping	SOR	0.11^{d}	0.12^{e}	0.13^{f}	0.16^{i}	0.11^{e}	0.13^{g}	0.14^{h}	0.18^{l}

Legend: SOR-sorghum, DOL-dolichos, CP-chickpea, TP-tillage practice, TR-tied ridges, FR-furrows and ridges, OI-Organic Inputs OP-oxen plough, FYM-farm yard -manure, MRP-minjingu rock phosphate, CTRL-control, LRS-long rain season, SRS-short rain season, CS-cropping system.. Means followed by the same letters in the same season in a column are not significantly different at $P \leq 0.05$.

Table 11: Effects of tillage practices and organic cropping systems on soil total N sweet potato based plots during SRS of 2012 and LRS of 2013

TP	CS		SRS 2012				LRS 2013			
			CTRL	FYM	MRP	MRP+ FYM	CTRL	FYM	MRP	MRP+ FYM
FR	crop rotation	CP-SP	0.08^{c}	0.12^{g}	0.09^{d}	0.1^{e}	0.09^{c}	0.13^{g}	0.09^{c}	0.11^{e}
	crop rotation	DOL-SP	0.13^{h}	0.17^{l}	0.14^{i}	0.15^{j}	0.14^{h}	0.19^{m}	0.15^{i}	0.16^{j}
	inter cropping	SP/DOL	0.07^{b}	0.11^{f}	0.08^{c}	0.09^{d}	0.08^{b}	0.12^{f}	0.08^{b}	0.1^{d}
	inter cropping	SP/CP	0.11^{f}	0.15^{j}	0.12^{g}	0.13^{h}	0.12^{f}	0.17^{k}	0.13^{g}	0.14^{h}
	mono cropping	SP	0.08^{c}	0.09^{d}	0.1^{e}	0.13^{h}	0.09^{c}	0.1^{d}	0.11^{e}	0.14^{h}
OP	crop rotation	CP-SP	0.07^{b}	0.11^{k}	0.08^{c}	0.09^{d}	0.08^{b}	0.12^{f}	0.09^{c}	0.1d
	crop rotation	DOL-SP	0.12^{g}	0.16^{k}	0.13^{h}	0.14^{i}	0.13^{g}	0.18^{l}	0.14^{h}	0.15^{i}
	inter cropping	SP/DOL	0.06^{a}	0.1^{e}	0.07^{b}	0.08^{c}	0.07^{g}	0.11^{e}	0.08^{b}	0.09^{c}
	inter cropping	SP/CP	0.1^{e}	0.14^{i}	0.11^{f}	0.12^{g}	0.11^{e}	0.16^{j}	0.12^{f}	0.13^{g}
	mono cropping	SP	0.07^{b}	0.12^{g}	0.08^{c}	0.09^{d}	0.08^{b}	0.13^{g}	0.09^{c}	0.1^{d}
TR	crop rotation	CP-SP	0.09^{d}	0.13^{h}	0.09^{d}	0.11^{f}	0.1^{d}	0.14^{h}	0.1^{d}	0.12^{f}
	crop rotation	DOL-SP	0.14^{i}	0.19^{m}	0.15^{j}	0.16^{k}	0.16^{j}	0.21^{n}	0.17^{k}	0.18^{l}
	inter cropping	SP/DOL	0.08^{c}	0.12^{g}	0.08^{c}	0.1^{e}	0.09^{c}	0.13^{g}	0.09^{c}	0.11^{e}
	inter cropping	SP/CP	0.12^{g}	0.17^{l}	0.13^{h}	0.14^{i}	0.14^{h}	0.19^{m}	0.15^{i}	0.16^{j}
	mono cropping	SP	0.09^{d}	0.1^{e}	0.11^{f}	0.14^{i}	0.09^{c}	0.16^{j}	0.12^{r}	0.11^{e}

Legend: SP-sweet potato, DOL-dolichos, CP-chickpea, TP-tillage practice, TR-tied ridges, FR-furrows and ridges, OI-Organic Inputs, OP-oxen plough, FYM-farm yard -manure, MRP-minjingu rock phosphate, CTRL-control, LRS-long rain season, SRS-short rain season, CS-cropping system.. Means followed by the same letters in the same season in column are not significantly different at $P \leq 0.05$.

The increase in soil total N after FYM application was due to the direct addition of N through decomposition of the FYM added to the soil and due to the higher contents of respective total N in the FYM. These results are in conformity with the findings of Thamaraiselvi *et al*. (2012) who reported increases in soil total N due to FYM application. This is also supported by Nyambati (2000) who reported that that MRP and organics (FYM) combinations provide cheap N inputs from organics and the solubilization of MRP through formation of favorable acid environments that result when organics FYM are in contact with MRP) decompose in soils.

There was a significant different in % total N content across cropping system with significant increase in crop rotation dolichos-sorghum (0.21%) and intercrop sorghum/chickpea (0.19%) under tied ridges with the application of FYM (Table 10) this same trend was observed under furrows and ridges (0.19% and 0.17%) and oxen plough (0.15% and 0.13%) in crop rotation of dolichos-sorghum and intercropping sorghum/chickpea respectively. In sweet potato plots the same trend was observed but the content was lower as compared to sorghum plots with increased content in dolichos sweet potato rotation (0.17%) and intercrop sweet potato chickpea (0.15%) under tied ridges. The increased in total N under dolichos intercrop and rotation was attributed to the legumes ability to fix Nitrogen and the amount of residue obtained from the legumes residues, which lead to an increase in the soil organic matter as opposed to the mono cropping. This conforms to a research by Aita and Giacomini, (2003) who found out that leguminous species are known for their capacity to fix atmospheric nitrogen and narrow the C/N ratio, resulting in faster residue decomposition and consequent release of accumulated N and other nutrients such as P and K, to the soil. Crop rotations usually increase organic matter and prompt changes in N sources, affecting their availability for plants and, as a consequence, the N efficiency is greater when a crop rotation is adopted as also reported by (Montemurro and Maiorana, 2008). This was due to the effect of ridges and furrows enhancing infiltration and reducing runoff and consequently nutrient losses this is in consistent with a publication by FAO (1993). Oxen plough having lower total nitrogen content than ridges and furrows and tied ridges may be attributed to increased soil erosion and runoff (Kambutho and Simalenga, 1999).

Changes in % Total Nitrogen across the season

Changes in % total N across the two season was observed with increase during the LRS (0.23%) and (0.21%) as compared to the SRS (0.19%) and (0.19%) under tied ridges in intercropping sorghum/ chickpea and crop rotation dolichos-sweet potato with the application of MRP+FYM in sorghum and sweet potato plots respectively (Table 10 and 11). This implies that total nitrogen increased due to an increased in soil moisture content during the LRS of 2013. Total nitrogen mineralization was determined by soil moisture content. This showed that there correlation between soil moisture and soil N mineralization, which agreed with the previous studies that soil N mineralization, was determined by soil moisture (Li et al. 1995; Zhou, Ouyang 2001).

Organic Carbon

There was a significant ($P \leq 0.05$) increase in the level of organic carbon as compared to initial soil analysis with application of FYM and MRP +FYM across all cropping system and tillage practices. An increase percentage of organic carbon (2.45) and (3.15) was recorded in a combined oxen plough, intercrop of sorghum and chickpea and dolichos sweet potato rotations respectively with the application of FYM (Table 12 and 13).

Table 12: Effects of tillage practices and organic cropping systems on % soil Carbon sorghum based plots during SRS of 2012 and LRS of 2013

			Organic Inputs-SRS 2012				Organic Inputs -LRS 2013			
TP	CS		CTRL	MRP+FYM	MRP	FYM	CTRL	MRP+FYM	MRP	FYM
FR	crop rotation	CP-SOR	1.2^{a}	1.29^{b}	1.34^{bc}	1.52^{de}	1.74^{m}	1.87^{o}	1.94^{opq}	2.2^{tu}
	crop rotation	DOL-SOR	1.51d^{e}	1.62^{f}	1.69^{g}	1.91^{ghijk}	1.35^{fg}	1.45^{hi}	1.51^{hij}	1.71^{m}
	inter cropping	SOR/DOL	1.74^{g}	1.87^{ghij}	1.95^{ghijkl}	2.21^{p}	1.9^{op}	2.03^{r}	2.12^{t}	2.4^{w}
	inter cropping	SOR/CP	1.82^{ghi}	1.95^{ghijkl}	2.03^{lmn}	2.3^{pqr}	1.47^{hi}	1.58^{k}	1.64^{l}	1.86^{o}
	mono cropping	SOR	1.93 ^{ghijkl}	2.06^{lmn}	2.14^{p}	2.43^{s}	1.16^{cde}	1.25^{f}	1.3^{fg}	1.47^{hi}
OP	crop rotation	CP-SOR	1.78^{gh}	1.91^{ghijk}	1.99^{lm}	2.26^{pq}	2.06^{s}	2.21^{tu}	2.3^{tuv}	2.61^{y}
	crop rotation	DOL-SOR	2.52^{t}	2.7^{u}	2.81^{v}	2.19^{p}	0.89^{a}	0.95^{b}	0.99^{b}	1.12^{cd}
	inter cropping	SOR/DOL	1.94^{ghijkl}	2.08^{lmn}	2.16^{p}	2.45^{s}	2.25^{tuv}	2.41^{w}	2.51^{x}	2.84^{z}
	inter cropping	SOR/CP	0.97^{b}	1.04^{c}	1.08^{cd}	1.23^{f}	1.63^{f}	1.74^{g}	1.82^{ghi}	2.06^{lmn}
	mono cropping	SOR	1.7^{m}	2.16^{t}	1.83^{o}	1.9^{op}	2.67^{y}	2.38^{w}	2.87^{w}	2.98^{x}
TR	crop rotation	CP-SOR	1.47^{d}	1.52^{de}	1.6^{f}	1.82^{ghi}	1.29^{fg}	1.33^{fg}	1.4^{h}	1.59^{k}
	crop rotation	DOL-SOR	1.17^{a}	1.21^{a}	1.27^{b}	1.44^{d}	1.02^{c}	1.06^{c}	1.11^{cd}	1.26^{f}
	inter cropping	SOR/DOL	1.7^{g}	1.76^{gh}	1.85^{ghij}	2.1^{lmno}	1.85^{o}	1.91^{op}	2.01^{r}	2.28^{tuv}
	inter cropping	SOR/CP	1.77^{gh}	1.83^{ghi}	1.93^{ghijk}	2.19^{p}	1.45^{hi}	1.48^{hij}	1.56^{k}	1.77^{mn}
	mono cropping	SOR	1.88^{ghij}	1.95^{ghijkl}	2.05^{lmn}	2.33^{pqr}	1.13^{cd}	1.17^{cde}	1.23^{f}	1.4^{h}

Legend: SOR-sorghum, DOL-dolichos, CP-chickpea, TP-tillage practice, TR-tied ridges, FR-furrows and ridges, OP-oxen plough, FYM-farm yard -manure, MRP-minjingu rock phosphate, CTRL-control, LRS-long rain season, SRS-short rain season, CS-cropping system.. Means followed by the same letters in the same season in a column are not significantly different at $P \leq 0.05$.

Table 13: Effects of tillage practices and organic cropping systems on % soil Carbon sweet potato based plots during SRS of 2012 and LRS of 2013

			Organic Inputs-SRS 2012				Organic Inputs-LRS 2013			
TP	CS		CTRL	MRP+ FYM	MRP	FYM	CTRL	MRP+ FYM	MRP	FYM
FR	crop rotation	CP-SP	1.3^{a}	1.39^{b}	1.45^{bc}	1.65^{de}	1.91^{m}	2.05^{o}	2.14^{opq}	2.43^{tu}
	crop rotation	DOL-SP	1.64^{de}	1.75^{f}	1.83^{g}	2.07^{ghijk}	1.48^{fg}	1.59^{hi}	1.66^{hij}	1.88^{m}
	inter cropping	SP/DOL	1.89^{g}	2.02^{ghij}	2.11^{ghijkl}	2.39^{p}	2.09^{op}	2.24^{r}	2.33^{t}	2.64^{w}
	inter cropping	SP/CP	1.97^{ghi}	2.11^{ghijkl}	2.2^{lmn}	2.5^{pqr}	1.62^{hi}	1.74^{k}	1.81^{l}	2.05^{o}
	mono cropping	SP	2.1^{ghijkl}	2.25^{lmn}	2.34^{p}	2.66^{s}	1.28^{cde}	1.37^{f}	1.43^{fg}	1.62^{hi}
OP	crop rotation	CP-SP	1.93^{gh}	2.07^{ghijk}	2.16^{lm}	2.44^{pq}	2.26^{s}	2.42^{tu}	2.53^{tuv}	2.87^{y}
	crop rotation	DOL-SP	2.73^{t}	2.92^{u}	3.05^{v}	3.15^{y}	0.98^{a}	1.05^{b}	1.09^{b}	1.24^{cd}
	inter cropping	SP/DOL	2.11^{ghijkl}	2.26^{lmn}	2.35^{p}	2.67^{s}	2.47^{tuv}	2.65^{w}	2.76^{x}	3.13^{z}
	inter cropping	SP/CP	1.76^{f}	1.89^{g}	1.97^{ghi}	2.23^{lmn}	1.06^{b}	1.14^{c}	1.19^{cd}	1.35^{f}
	mono cropping	SP	1.87^{m}	2.37^{t}	2.01^{o}	2.09^{op}	2.89^{u}	3.66^{z}	3.1^{w}	3.23^{x}
TR	crop rotation	CP-SP	1.59^{d}	1.65^{de}	1.74^{f}	1.97^{ghi}	1.41^{fg}	1.47^{fg}	1.54^{h}	1.75^{k}
	crop rotation	DOL-SP	1.27^{a}	1.31^{a}	1.38^{b}	1.56^{d}	1.12^{c}	1.16^{c}	1.23^{cd}	1.39^{f}
	inter cropping	SP/DOL	1.84^{g}	1.9^{gh}	2^{ghij}	2.27^{lmno}	2.03^{o}	2.1^{op}	2.22^{r}	2.51^{tuv}
	inter cropping	SP/CP	1.92^{gh}	1.99^{ghi}	2.09^{ghijk}	2.37^{p}	1.57^{h}	1.63^{hij}	1.72^{k}	1.95^{mn}
	mono cropping	SP	2.04^{ghij}	2.11^{ghijkl}	2.23^{lmn}	2.52^{pqr}	1.24^{cd}	1.29^{cde}	1.36^{f}	1.54^{h}

Legend: SP-sweet potato, DOL-dolichos, CP-chickpea, TP-tillage practice, TR-tied ridges, FR-furrows and ridges, OP-oxen plough, FYM-farm yard -manure, MRP-minjingu rock phosphate, CTRL-control, LRS-long rain season, SRS-short rain season, CS-cropping system.. Means followed by the same letters in the same season in a column are not significantly different at $P \leq 0.05$.

This is due presence of high carbon content in FYM applied as opposed to the application of MRP alone and increased residue from the legumes used which further increased the carbon content. Across the cropping systems increased % organic carbon was observed under sorghum dolichos intercropping (2.45%) then rotation of sorghum chickpea (2.26%) and rotation of sorghum dolichos(2.19%) under oxen plough with the application of FYM. Cover crops are generally grown to provide soil cover during the winter months, thus preventing soil erosion by wind and rainwater strength, which reduces organic matter content in the long run. Komatsuzaki (2004) indicated that cover crop utilization is a technique that limits nutrient leaching, scavenging the soil residual N and making it available for subsequent cultivation.

There was also a significant difference across the three tillage practices with improved % organic carbon under oxen plough followed by furrows and ridges then tied ridges but under different cropping systems with the application of FYM. Increased organic carbon level under application of FYM conform to the study by Bayu *et al*. (2006) who also concluded that FYM application increased soil organic carbon content by up to 67% over the control treatment. The crop residues from the legumes would further act as manures thus increasing the soil % total N and % organic carbon. This was in agreement with study by Knight and Shirtliffe, (2005) who found out that legume green manure have increased benefits such as the ability to fix atmospheric N2 and mobilize P from the soil, also observed this.

Changes in % organic carbon across the season (SRS 2012 and LRS 2013)

Changes in % organic Carbon across the two season was observed with increase during the LRS (2.28%)   and (2.27%) as compared to the SRS (2.1 %) and (2.51%) under tied ridges in intercropping sorghum/ dolichos and intercropping sweet potato/ dolichos with the application of MRP+FYM in sorghum and sweet potato plots respectively (Table 12 and 13). A higher % organic carbonvalue during long rain season seen in the present study was attributed to higher biomass production, which increases fresh inputs into the soil which upon decomposition releases CO_2 thus increasing organic carbon level. Earlier studies by (Davi et al., 2006, 2009) also reported that high rate of CO_2 released during the LRS could be due to a congenial environment for the microorganisms dwelling in the soil decomposing organic matter. The low % organic carbon in the SRS seen in the present study is attributed to low moisture content of the soil, temperature and relative humidity, thereby inhibiting the microbial activity and decomposition (Davi et al., 2006 and Kosugi et al., 2007). Ginting et al. (2003), for example, found out that 4 years after the last application of farm yard manure that the residual effects resulted in 20 to 40% higher soil microbial biomass C.

4.0 Conclusions

The soil organic inputs, MPR and FYM are viable alternatives to the expensive inorganic fertilizers for improving the soil nutrient status in Matuu, Yatta sub County. Combined TR, intercropping of sorghum and sweet potato with dolichos with application of MRP +FYM significantly increased soil potassium and phosphorous whereas combined TR, intercropping of dolichos with sorghum and sweet potatoes with application of FYM led to an increase in soil % organic carbon and total nitrogen. Moreover, the MRP, FYM are locally available, thus making it an ideal source of nutrients for smallholders economically.

4.4.Effects of tillage practices and organic cropping systems on the crop yield

Abstract

The study was conducted, in semi-arid Yatta sub-county, to evaluate the influence of tillage practices, cropping systems and organic inputs on the yield of sorghum and sweet potato.It was carried out between October 2012 to February 2013 short rain season (SRS) and April 2013 to August 2013 long rain season (LRS). Randomized Complete Block Design with a split-split plot arrangement replicated thrice was used. Main plots were tillage practices (TP); Oxen plough (OP), tied ridges (TR) and furrows and ridges (FR). Split-plots were cropping systems (CS); monocropping (MC), intercropping (IC), and crop rotation (CR) while split-split plots were organic inputs; Farm Yard manure (FYM), Minjingu Rock Phosphate (MRP), combined MRP and FYM (MRP+FYM) and control. Test crops were sorghum and sweet potatoes with Dolichos (*Dolichos lablab*) and chickpea (*Cicerarietinum*L) either as intercrops or in rotation. Plant sampling was done by harvesting the grain and tuber and yield determined by weighing. There was a significant (P≤0.05) increased in yield with application of MRP+FYM of 16.27 t/ha and 1.38 t/ha for sweet potatoes and sorghum mono crop respectively under TR. There was a significant (P≤0.05) increased yield of chickpea and dolichos under combined tied ridges, intercropping of sorghum with chickpea (1.44 tha$^{-1)}$ and dolichos (1.38 tha$^{-1)}$ with application of MRP+FYM during SRS of 2012 Improved yield of sorghum and sweet potatoes attained with the combined TR, mono cropping with application of MRP + FYM.

Key words: cropping systems; organic inputs; semi arid; tillage practices, yield;

4.4.1 Introduction

Sweet potato (*Ipomoea batatas L*) is among the world`s most important and under- exploited crop. It is commonly referred to a subsistence, food security, or famine relief crop (Scott and Maldinado, 1999). In addition sweet potato provides good ground cover, and is usually cultivated with little or no fertilizer (Lusweti*et al.*, 1999). In Africa, sorghum is largely a subsistence food crop. It is crucially important to food security in Africa as it is uniquely drought resistant among cereals and can withstand high temperatures, grow in areas of annual rainfall 500-700mm per year. Noted also is that sorghum is an important crop in East Africa (Taylor, 2010).Sorghum (*sorghum bicolor L.*) economically rated as the fifth most important cereal after maize, wheat, barley, and rice. It is a drought resistant and performs well on a range of poor soils with low rainfall often out-yielding most cereals in hot and dry environments. It is particularly adapted to agroecological zones of Kenya, which are arid and semi-arid. These include the semi-arid areas of Eastern Kenya, the coastal, the waterlogged areas (Kameri-Mbote, 2005). Sorghum and sweet potato are crops that were widely grown by the resource poor farmers in the ASALs of Kenya for subsistence and as a source of income (Macharia, 2004). Sweet potato and sorghum are typically hardy and adapted to the local climate, thus making them very valuable (Beehive, 2011).

To the contrary farmers in the arid and semi arid lands areas cultivate a variety of crops of which the main ones are maize, beans, green grams and cowpeas under rain-fed agriculture and horticultural crops such as oranges, mangoes, bananas, tomato, onions, kale, pawpaw and citrus ((KARI-NDFRC, 1995). The farmers in Yatta Sub County have abandoned the traditional crops, which have the potential to contribute to food security, nutrition, health, income generation, and environmental services (NEMRI, 2009). These crops are drought resistant and can withstand high temperature unlike the introduced crops. Planting of drought-resistant crops reduces the risk of total loss during drought as a result of overreliance in one crop. Intercropping generate beneficial biological interaction between crops increasing grain yield and stability, more efficient use of available resources and reducing weed pressure (Kadziuliene 2009). Well-managed crop rotations increase soil organic matter to sufficient levels help to moderate soil moisture, retain moisture in dry conditions, and allow excess moisture to drain away in wet seasons. Shifting crop types also helps vary water demand within the soil profile. The deep-rooted crops following shallow crops can access moisture reserves as well as capture any nutrients that have leached below the shallower root zones before they reach groundwater (Adam *et al.,* 2011).

Many techniques have been tried to utilize rain water of these are ridges and furrows and tied ridges with mulching is one of the most effective measures (Li *et al.,*2000). The traditional method that was used to plant sweet potatoes was the oxen plough (Yuan *et al.,* 2003) which produced low yield. In order to ensure high yield some new cultivation systems such as ridge planting and hole planting need to be tested (Duan*et al.,* 1998).Drought adapted early maturing crops combined with reduced tillage practices have the potential to stabilize and increase dry land crop yields in semi-arid regions of the world (Moroke, 2011). In addition Farmyard manure acts as an alternative source of fertility enhancement for inorganic fertilizer as they release nutrients slowly and steadily over long periods and improve the soil fertility status by activating the soil microbial biomass (Ayuso *et al.,* 1996, Belay *et al., 2001*). It contains all the nutrients needed for crop growth including trace elements.

The current study investigated the effects of tillage practices, cropping systems and organic inputs on crop yield in Yatta sub-county, Kenya.

4.4.2 Materials and methods

Study site, treatments and experimental design and field practices were as described in section 3.1, 4.2.2.1 and 4.2.2.3 respectively.

4.4.2.4 Plant sampling

Plant sampling for the grain and tuber was done at the crop maturity within the middle rows and two rows left on the sides during the harvesting stage for sorghum and for sweet potato by harvesting within a one metre square area selected using 1 m^2 quadrant was harvested. The grain yield for sorghum, chickpea and dolichos were determined by weighing the grains in Kg/m^2 whereas for the sweet potato yield was determined by weighing the tuber in Kg/m^2. This was then converted into tha^{-1} using the formula:

$$\text{Grain/tuber yield } (tha^{-1}) = \frac{10000m^2 * kgha^{-1}}{\text{Area in } m^2} /1000kg$$

4.4.2.5 Statistical analysis

Data was subjected to general analysis of variance using Genstat statistical software (Payne *et al.,* 2005b). Means were separated using least significant difference and Duncan Multiple Range Test (where interactions occurred) at a probability level of 5%.

4.4.3 Results and discussion

4.4.3.1 Effects of tillage practice, cropping systems and organic inputs on the crop yield Dolichos (Lablab purpureus) and chickpea (Cicer arietinum L.) yield

There was a significant ($P \leq 0.05$) increased yield of chickpea and dolichos for combined tied ridges, intercropping of sorghum with chickpea (1.44 $tha^{-1)}$ and dolichos (1.38 $tha^{-1)}$ with application of MRP+FYM during SRS of 2012. The yield of the legumes also increased under the intercropping or rotation with sweet potato as compared to with sorghum under tied ridges with the application of MRP+FYM. Accordingly intercropping chickpea and dolichos with sweet potato (1.54 tha^{-1}) and (1.48 tha^{-1}) while with sorghum (1.38 tha^{-1}) and (1.44 tha^{-1}) respectively during the SRS of 2012(Table 14).

Table 14: Effects of tillage practice, cropping systems and organic inputs on of dolichos and chickpea yield during SRS of 2012 and LRS of 2013

	TP	CS	CROPS	CROP	SRS 2012 CTRL	SRS 2012 MRP	SRS 2012 FYM	SRS 2012 MRP+ FYM	LRS 2013 CTRL	LRS 2013 MRP	LRS 2013 FYM	LRS 2013 MRP+ FYM
SOR PLOTS	FR	Intercropping	SOR/CP	CP	1.23^{f}	1.28^{fg}	1.29^{fg}	1.31^{fgh}	1.34^{e}	1.38^{efg}	1.39^{efg}	1.41^{gh}
		Intercropping	SOR/DOL	DOL	1.21^{defg}	1.23^{gh}	1.25^{gh}	1.31^{ghi}	1.32^{e}	1.33^{e}	1.35^{ef}	1.39^{efg}
		Crop Rotation	CP-SOR	CP	1.13^{def}	1.16^{def}	1.17^{def}	1.23^{gh}	-	-	-	-
		Crop Rotation	DOL-SOR	DOL	1.05^{bc}	1.14^{def}	1.18^{defg}	1.23^{gh}	-	-	-	-
	OP	Intercropping	SOR/CP	CP	1.06^{bc}	1.08^{cd}	1.09^{cd}	1.15^{def}	1.16^{a}	1.18^{a}	1.20^{ab}	1.25^{c}
		Intercropping	SOR/DOL	DOL	1.19^{efg}	1.26^{fg}	1.28^{fg}	1.29^{fg}	1.29^{d}	1.36^{ef}	1.38^{efg}	1.39^{efg}
		Crop Rotation	CP-SOR	CP	1.27^{gh}	1.32^{ghi}	1.33^{ghij}	1.41^{jk}	-	-	-	-
		Crop Rotation	DOL-SOR	DOL	1.04^{abcd}	1.12^{def}	1.16^{def}	1.22^{defg}	-	-	-	-
	TR	Intercropping	SOR/CP	CP	1.34^{ghij}	1.37^{ghij}	1.39^{jk}	1.44^{jk}	1.43^{gh}	1.46^{i}	1.48^{ij}	1.49^{ij}
		Intercropping	SOR/DOL	DOL	1.19^{efg}	1.33^{fgh}	1.36^{fghi}	1.38^{fghi}	1.29^{d}	1.43^{gh}	1.46^{i}	1.48^{ij}
		Crop Rotation	CP-SOR	CP	1.17^{efg}	1.29^{ghi}	1.34^{ghij}	1.39^{jk}	-	-	-	-
		Crop Rotation	DOL-SOR	DOL	1.01^{a}	1.1^{de}	1.13^{def}	1.19^{defg}	-	-	-	-
SP PLOTS	FR	Intercropping	SP /CP	CP	1.33^{f}	1.38^{fg}	1.39^{fg}	1.41^{fgh}	1.44^{e}	1.48^{efg}	1.49^{efg}	1.51^{gh}
		Intercropping	SP /DOL	DOL	1.31^{defg}	1.33^{gh}	1.35^{gh}	1.41^{ghi}	1.42^{e}	1.43^{e}	1.45^{ef}	1.49^{efg}
		Crop Rotation	CP- SP	CP	1.23^{def}	1.36^{def}	1.27^{def}	1.33^{gh}	-	-	-	-
		Crop Rotation	DOL- SP	DOL	1.15^{abcd}	1.24^{def}	1.28^{defg}	1.33^{gh}	-	-	-	-
	OP	Intercropping	SP /CP	CP	1.16^{abcd}	1.18^{de}	1.19^{de}	1.25^{def}	1.26^{a}	1.28^{a}	1.30^{ab}	1.35^{c}
		Intercropping	SP /DOL	DOL	1.29^{f}	1.36^{fg}	1.38^{fg}	1.39^{fg}	1.39^{d}	1.46^{ef}	1.48^{efg}	1.49^{efg}
		Crop Rotation	CP- SP	CP	1.37^{gh}	1.42^{ghi}	1.43^{ghij}	1.51^{jk}	-	-	-	-
		Crop Rotation	DOL- SP	DOL	1.14^{abcd}	1.32^{def}	1.26^{def}	1.32^{defg}	-	-	-	-
	TR	Intercropping	SP /CP	CP	1.44^{ghij}	1.47^{ghij}	1. 49^{jk}	1.54^{jk}	1.53^{gh}	1.56^{i}	1.58^{ij}	1.59^{ij}
		Intercropping	SP /DOL	DOL	1.29^{a}	1.43^{fgh}	1.46^{fghi}	1.48^{fghi}	1.39^{d}	1.43^{gh}	1.56^{i}	1.58^{ij}
		Crop Rotation	CP- SP	CP	1.27^{def}	1.39^{ghi}	1.44^{ghij}	1.49^{jk}	-	-	-	-
		Crop Rotation	DOL- SP	DOL	1.11^{abc}	1.2^{de}	1.23^{def}	1.29^{defg}	-	-	-	-

Legend: SOR-sorghum, SP-sweet potato, DOL-dolichos, CP-chickpea, TP-tillage practice, TR-tied ridges, FR-furrows and ridges, OP-oxen plough, FYM-farm yard -manure, MRP-minjingu rock phosphate, CTRL-control, LRS-long rain season, SRS-short rain season, CS-cropping system. Dash (-) indicates in Rotation SP/SOR wereharvested during LRS 2013. Means followed by the same letters in the same season are not significantly different at P ≤ 0.05.

The retained soil cover under intercropping of sweet potato reduces evaporative loss, thereby retaining the soil moisture for longer crop use.Increased dolichos and chickpea yield under combined TR, intercropping sorghum chickpea was attributed to increased moisture content and improved soil nutrient status due to the application of MRP+FYM, intercropping and tied ridges as compared to oxen plough and furrows and ridges. Tied ridges conserve soil moisture that was then availed for crop consumptive use. Crop roots absorb this available moisture for growth and development, giving the crop under this treatment better performance in terms of grain yield. Kumar et al. (2000) observed that availability of higher amounts of moisture during various stages of crop growth resulted in better crop growth and thus improved yield.

Dolichos and chickpea grain yields were significantly greater in the LRS of 2013 (1.48 tha^{-1}) across treatments compared to SRS of 2012 (1.38 tha^{-1}) intercropping sorghum with dolichos (table 14) .The higher grain yields in the LRS of 2013 were as a result of improved soil nutrient status and soil moisture content in soil due to residual effect of the of the organic inputs MRP+FYM and FYM and its subsequent uptake by the crops. Rainfall was less in SRS of 2012 compared to LRS of 2013, resulting in the crop depending mainly on the stored soil moisture. Chickpea seed yield was reported by Lopez *et al*. (2004) to strongly depend on rainfall during flowering and seed filling stages,

Sorghum (*sorghum bicolor L.*) and sweet potato (*Ipomoea batatas L*) yield

There was a significant ($P \leq 0.05$) high yield for combined tied ridges, mono cropping and MRP+FYM led to improved yield (1.38 tha^{-1} and 16.27 tha^{-1}) sorghum and sweet potato respectively as compared to furrows and ridges (1.31 tha^{-1} and 15.67 tha^{-1}) and oxen plough (1.29 tha^{-1} and 16.17 tha^{-1}) during SRS 2012 this was attributed to increased moisture content under tied ridges as compared to oxen plough and furrows and ridges (Table 15 and 16)

Table 15: Effects of tillage practice, cropping systems and organic inputs on sorghum yield during SRS 2012 and LRS 2013.

				SRS 2012				LRS 2013			
		CROPS	CROP				MRP+				MRP+
TP	CS			CTRL	MRP	FYM	FYM	CTRL	MRP	FYM	FYM
FR	Intercropping	SOR/CP	SOR	0.92^{ab}	0.97^{abc}	0.94^{abc}	0.98^{abc}	0.91^{a}	0.92^{ab}	0.94^{ab}	0.97^{ab}
	Intercropping	SOR/DOL	SOR	0.95^{abc}	0.98^{abc}	0.99^{abcd}	1.01^{abcd}	0.93^{ab}	0.94^{ab}	0.95^{ab}	1.01^{abc}
	Mono cropping	SOR	SOR	1.23^{f}	1.28^{fg}	1.29^{fg}	1.31^{fgh}	1.21^{defg}	1.23^{gh}	1.25^{gh}	1.31^{ghi}
	Crop Rotation	CP-SOR	SOR	-	-	-	-	1.13^{def}	1.16^{def}	1.17^{def}	1.23^{gh}
	Crop Rotation	DOL-SOR	SOR	-	-	-	-	1.05^{abcd}	1.14^{def}	1.18^{defg}	1.23^{gh}
OP	Intercropping	SOR/CP	SOR	0.81^{a}	0.95^{abc}	0.96^{abc}	1^{abcd}	1.06^{abcd}	1.08^{de}	1.09^{de}	1.15^{def}
	Intercropping	SOR/DOL	SOR	0.87^{a}	1.07^{abcde}	1.17^{f}	1.27^{fg}	0.93^{ab}	1.12^{def}	1.22^{defg}	1.38^{jk}
	Mono cropping	SOR	SOR	1.19^{f}	1.26^{fg}	1.28^{fg}	1.29^{fg}	1.27^{gh}	1.32^{ghi}	1.33^{ghij}	1.41^{jk}
	Crop Rotation	CP-SOR	SOR	-	-	-	-	0.94^{ab}	1.01^{abc}	1.05^{abcd}	1.1^{de}
	Crop Rotation	DOL-SOR	SOR	-	-	-	-	1.04^{abcd}	1.12^{def}	1.16^{def}	1.22^{defg}
TR	Intercropping	SOR/CP	SOR	0.86^{a}	0.87^{a}	0.88^{a}	0.94^{ab}	$0.91a^{b}$	0.94^{abc}	0.95^{abc}	0.98^{abc}
	Intercropping	SOR/DOL	SOR	1.01^{abcd}	1.03^{abcd}	1.04^{abcd}	1.06^{abcde}	0.99^{abc}	1^{abc}	1.01^{abc}	1.07^{de}
	Mono cropping	SOR	SOR	1.19^{a}	1.33^{fgh}	1.36^{fghi}	1.38^{fghi}	1.17^{def}	1.29^{ghi}	1.34^{ghij}	1.39^{jk}
	Crop Rotation	CP-SOR	SOR	-	-	-	-	1.01^{abc}	1.1^{de}	1.13^{def}	1.19^{defg}
	Crop Rotation	DOL-SOR	SOR	-	-	-	-	1.34^{ghij}	1.37^{ghij}	1.39^{jk}	1.44^{jk}

Legend: SOR-sorghum, SP-sweet potato, DOL-dolichos, CP-chickpea, TP-tillage practice, TR-tied ridges, FR-furrows and ridges, OP-oxen plough, FYM-farm yard -manure, MRP-minjingu rock phosphate, CTRL-control, LRS-long rain season, SRS-short rain season, CS-cropping system. Dash (-) indicates in Rotation legumes were harvested during SRS of 2012. Means followed by the same letters in the same season are not significantly different at P ≤ 0.05.

Table 16: Effects of tillage practice, cropping systems and organic inputs on crop yield during SRS 2012 and LRS 2013.

			SRS 2012				LRS 2013			
		CROPS				MRP+				MRP+
TP	CS		CTRL	MRP	FYM	FYM	CTRL	MRP	FYM	FYM
FR	intercropping	SP/CP	8.45^{a}	12.17^{bc}	13.42^{bcd}	13.41^{bcd}	13.61^{abcd}	15.04^{defg}	15.52^{gh}	15.62^{gh}
	Intercropping	SP/DOL	9.25^{a}	12.33^{bc}	13.35^{bcd}	13.35^{bcd}	11.62^{a}	12.84^{abc}	13.25^{abc}	13.24^{abc}
	Monocropping	SP	15.2^{bcdef}	15.53^{bcdef}	15.67^{bcdef}	15.77^{bcdef}	16.17^{ghi}	16.53^{ghij}	16.69^{ghij}	16.79^{jk}
	Crop rotation	CP-SP	-	-	-	-	11.87^{a}	13.04^{abc}	13.44^{abcd}	13.43^{abcd}
	Crop rotation	DOL-SP	-	-	-	-	11.97^{a}	13.15^{abc}	13.54^{abcd}	13.54^{abcd}
OP	intercropping	SP/CP	12.56^{bc}	13.89^{bcd}	14.33^{bcde}	14.32^{bcde}	13.61^{abcd}	15.04^{defg}	15.52^{gh}	15.62^{gh}
	Intercropping	SP/DOL	10.72^{b}	11.85b	12.23^{bc}	12.33^{bc}	11.62^{a}	12.84^{abc}	$13.25a^{bc}$	$13.24a^{bc}$
	Monocropping	SP	14.7^{bcde}	15.03^{bcde}	15.17^{bcdef}	15.27^{bcdef}	16.17^{ghi}	16.53^{ghij}	16.69^{ghij}	16.79^{jk}
	Crop rotation	CP-SP	-	-	-	-	11.5^{a}	12.68^{abc}	13.07^{abc}	13.17^{abc}
	Crop rotation	DOL-SP	-	-	-	-	11.75a	12.92^{abc}	$13.32a^{bcd}$	13.31^{abcd}
TR	intercropping	SP/CP	11.17^{b}	12.34^{bc}	12.74^{bc}	13.14^{bcd}	12.1^{ab}	13.37^{abcd}	13.8^{abcd}	14.23^{de}
	Intercropping	SP/DOL	12.9^{bc}	13.53^{bcd}	13.67^{bcd}	13.77bcd	13.98^{de}	14.66^{def}	14.81^{def}	14.81^{def}
	Monocropping	SP	15.7^{bcdef}	16.03^{bcdef}	16.17^{bcdef}	16.27^{bcdef}	17.27^{jk}	17.63^{jkl}	17.79^{jkl}	17.89^{jklm}
	Crop rotation	CP-SP	-	-	-	-	11.95^{a}	13.12^{abc}	13.51^{abcd}	13.61^{abcd}
	Crop rotation	DOL-SP	-	-	-	-	12.08a	13.26^{abc}	13.65^{abcd}	13.75^{abcd}

Legend: SP-sweet potato, DOL-dolichos, CP-chickpea, TP-tillage practice, TR-tied ridges, FR-furrows and ridges, OP-oxen plough, FYM-farm yard -manure, MRP-minjingu rock phosphate, CTRL-contro, LRS-long rain season, SRS-short rain season, CS-cropping system.Dash (-) indicates in *rotation legumes were harvested during the SRS 2012 whereas sweet potatoes and sorghum were harvested during the LRS 2013, Means followed by the same letters in the same season are not significantly different at* $P \leq 0.05$

The increase in the yield following the application of organic inputs FYM and FYM+MRP could be attributed to improved soil nutrients availability and soil moisture for the crop uptake leading to the increase in the yield as a result of their application. The use of organic inputs increases the yield in all the crops this is because organic inputs have an impact on the soil physical and chemical characteristic. Organic inputs improve on soil water holding capacity and enhance the release of other soil nutrient to the crops leading to an increase yield. The improved yield was due to increased nutrient uptake under the use of organic inputs has also been reported by (Muhammad and Khattak 2009; Akande*et al*., 2010). It was also found out by Belay *et al*. (2001) that thenutrients released from the application of FYM and MRP+FYM upon decomposition and activate soil microbial activities. It is also evident that improved yield by addition of organic manures from the study by Boateng*et al*. (2006); Hirzel*et al*. (2007) might be attributed to improved nutrient availability of the soil Marschner (2011). This results in addition confirm to the findings of Shirani*et al*., (2002) and Iqbal*et al*., (2005) who concluded that manure application either alone or in combination with different tillage practices and cropping systems improved crop growth and in turn the crop yield.

There was an increase in the yield of sweet potato and sorghum in dolichos rotation (14.81 tha^{-1} and 1.44tha^{-1}) whereas the lowest was noted in the intercrop (13.61 tha^{-1} and 1.07 tha^{-1}) during LRS 2013. This could be due to higher competition between two plants for light, Nutrients and soil moisture leading to a noticeable low yield under the intercrop whereas higher yield under rotation was due the breaking of diseases and pests cycle as a result of change in crop type (Table 15 and 16). This could also be due to lack of competition of nutrients, water and light with the legume cover crop (Wanderi *et al.,* 2003). In other studies, many justifications have been presented for yield increase in crop rotation Rathke*et al., (*2005) due to pests and diseases control when crops are rotated, increasing soil biological activity Larkin, (2008), and rising water use efficiency Christen and Sieling, (1995) are the important reasons for increasing grain yield in crop rotation. Application of crop rotation along with increasing soil organic matter increases biodiversity and soil biological community Kamkar and Damghani, (2009).

Combined TR, mono cropping sorghum and MRP+FYM had a higher yield during the long rain season (1.38tha^{-1} and 16.27 tha^{-1}) as compared to short rain season (1.39 tha^{-1} and 17.29 tha^{-1}) as noted in (Table 15 and 16). This was attributed to prolonged rainfall during the long rain season, which translated to a higher yield. This also implies that under such prolonged rainfall the crops utilize the nutrients. The higher yields in the LRS 2013 were partly as a result of the elevated available N,P, K and organic carbon content in soil due to residual effect of the amendments FYM, MRP+FYM and MRP (Buresh *et al.*,1997) and its subsequent uptake by sorghum and sweet potatoes.

In Northern Ethiopia, Brhane*et al.* (2006) found sorghum (*Sorghum bicolour*L. Moench) yield to be increased by 62% with tied-ridging compared with flat planting. Adoption of tied-ridging for small-scale sorghum production in Africa was found to increase farm income by 12% (Sanders *et al.*, 1996).

Conclusion

Combined Tied-ridging, rotation of sweet potato and sorghum with dolichos with application of FYM+MRP led to an increase in crop yield. Addition of farm yard manure + minjingu rock phosphate significantly improved the soil properties and crop growth. Improvement in crop growth was principally due to increase in N, P, K and organic carbon availability in soil. Hence integrated use of farm yard manure + minjingu rock phosphate with tied ridges and crop rotation would be a better and practical approach to sustain soil fertility and productivity.

5.0 Conclusion and recommendation

5.1 General Conclusions

Farmers in Yatta Sub County have perceived climate change, which has led to changes in crop production and influenced soil moisture content thus; farmers applied a number of soil moisture conservation techniques to improve on soil moisture contnt. The main indicators of climate change among the farmers in Yatta Sub County are raising temperatures, erratic rainfall, low rainfall and increase drought conditions.The changing climate as perceived by the farmers vis-à-vis the emerging crop production trends calls for better methods of soil moisture conservation and production of adapted crops.Addition of farm yard manure + minjingu rock phosphate significantly improved the soil properties and crop growth. Improvement in crop growth was principally due to increase in N, P, K and organic carbon availability in soil. Hence integrated use of farm yard manure + minjingu rock phosphate with tied ridges and crop rotation would be a better and practical approach to sustain soil fertility and productivity. The soil organic inputs, MPR and FYM are viable alternatives to the expensive inorganic fertilizers for improving the soil nutrient status in Matuu, Yatta sub County. Moreover, the MRP, FYM are locally available, thus making it an ideal source of nutrients for smallholders economically.

5.2 General Recommendations

Production of climate resilient crops should be promoted in order to minimize the loss of yields due to climate change.Further research to be done on better ways of soil moisture conservation and availed to the farmers for improved crop production in ASALs.A combination of tied ridges with intercrop of Dolichos with sorghum and sweet potato with the application of MRP+FYM are feasible methods for moisture conservation as well as for improved soil nutrient status for increased crop yield in the semi arid areas of Yatta Sub County.Generally, the adoption of tied-ridging intercropping with the application of combination of farm yard manure and minjingu rock phosphate are worthwhile techniques applied for semi-arid areas as compared to the other tillage practices, cropping syatems and organic inputs evaluated in this study.

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Appendix 1: Questionnaire

Crop production trends, moisture conservation methods and climate change perception

<u>SECTION A: Background Information</u>

1. Name …………………………………...Age ………. Sex; Male [ ] Female [ ]
2. Location ………………………………….. Village …………………………………..
3. How many household members?

(Specify parents, children, relatives)…………………………………………………….

4. What is the highest education level completed by the household members?

HOUSEHOLD MEMBER / EDUCATION LEVEL	CODE	FATHER (HUSBAND)	MOTHER (WIFE)	CHILDREN	OTHERS SPECIFY
Lower primary	1				
Upper primary school	2				
Secondary school	3				
Certificate	4				
Diploma	5				
University	6				
Others specify					

5. What is the size of your farm (in ha)?………………………………………..
6. What proportion of your farm in (ha) is used for:
   (i) Crop production ……………… (iii) Livestock production ……………….
   (ii) Homestead …………………… (iv) Others (Specify) ……………………..
7. a) What do you do for a living, source of income

   Farming [ ]

   Business [ ]

   Formal Employment [ ]Others (specify)

   b) Of the various sources of income what percentage can you attribute to farming?

   0-10% [ ], 11-20% [ ],

21-40% [ ], 41-50% [ ], over 50 %

SECTION B: Crop Production

8. What are the major factors affecting agricultural production and in your locality?

   Low soil fertility [ ]   Low soil moisture [ ]

   Unreliable rainfall [ ]   Wrong crop type [ ]

   Drought [ ]   pests and diseases [ ]

   Others (specify) ……………………………………

9. How are you coping with these problems/challenges

Problem	Coping mechanism	Remarks

10. How do you enhance crop productivity on your farm?

    Fertilizers [ ]   Manures [ ]

    Crop varieties (specify)…………………………………………………………………

    Tillage practices (specify)…………………………………………………………..

    Others (specify) …………………………………………….

11. What problems/challenges do you experience (have you experienced) in crop production?

    Crop pests and diseases [ ]   Unpredictable/inadequate rainfall [ ]

    Lack of rain [ ]   Labour scarcity [ ]

    Low soil fertility [ ]   Lack of inputs [ ]

    Low quality seeds/seedlings [ ]   Others (specify) …………………………………

12. How are you addressing the problems in (11 above) and how would you like to be assisted?

Problem	How addressed	Assistance required	Remarks

13. a) Has there been a change in crop production in the last 15-20 years? Yes ( ) No ( )

    b) If the answer to the above is yes how as the change been like? Some crops:

    Abandoned/neglected/orphaned [ ]   Production intensified [ ]

    Acreage under crop production reduced [ ]

    Others specify [ ]

    c) For the identified changes above explained in your opinion why they happened?

Change	Reasons for change

d) For the abandoned /neglected/orphaned crops what were the agronomic practices applied in their production?

Agronomic practice	How it was done
Land Preparation	
Planting	
Weeding	
Flowering	
Harvesting	
Storage	
Others (specify)	

e) i) Are there any new crops that has been introduced in the area for the last 5 years

Yes [ ] No [ ]

ii) If yes which one and why?

crop	Reason for introduction

14. What is the trend in production of the following crops?(Increasing, decreasing or constant)

CROP	TREND				
	1960-1970	1970-1980	1980-1990	1990-2000	2000- to date
Pigeon pea					
Chickpea					
Green grams					
Maize					
Sweet potato					
Cassava					
Pumpkin					
Sorghum					
Finger millet					
Others specify					

15. a) Give reasons for the observed trend in crop production?

…………………………………………………………………………………………

b) Are there possibilities of having the crops of the 1960-80s being re-introduced and if so, which ones and why?

crop	Reason for re- introduction

16. What are/were the significance of the crops in terms of [Ecological, nutritional, social and economic] between the following years (give examples):

Aspect / Crop	Ecological	Nutritional	Social	Economic

SECTION C: Moisture Conservation

17. What are the methods of land preparation in your locality? Give examples

…………………………………………………………………………………………………

a) Are the methods mentioned (above 17) been consistently used over the years?

Yes ( ) No ( )

Method	Yes	No	Reason

b) If no to the above a) why has there been a change

…………………………………………………………………………………………………

18. What are the advantages/disadvantages of the various methods of land preparation?

Method	Advantages	Disadvantages

19. How do you conserve moisture on your farm? Give examples of the methods used?

Method	Examples
Physical/mechanical	

Cultural	
Biological	
Irrigation	

20. Are there any other better innovative soil moisture conservation methods that can be tried? Why these methods

Method	Reasons
Tied ridges	
Ridges and furrow	
Plastic mulch tillage	
Sub-soiling and ripping	

SECTION D: Climate Change

21. a) Have you ever heard of climate change?

    Yes [ ]   No [ ]

    b) If Yes in (1 above), what aspects of climate change have you heard of?

    Rising Temperatures [ ]   Droughts [ ]   Floods [ ]   Erratic Rainfall [ ]

    Low rainfall [ ]   Strong wind [ ]   Cold Spells [ ]

    Others (specify) ………………………

22. a) Have you ever experienced/noticed any changes in climate in your locality?

    Yes [ ]   No [ ]

    b) If Yes in 3 (a) above, what changes have you experienced and since when? Give the year or the range of years

Change	When
Erratic rainfall [ ]	
Low rainfall [ ]	
Flooding due to heavy rains [ ]	
Prolonged droughts [ ]	
Increasing temperatures [ ]	
Others (specify) ………………….	

23. To what extent have the changes identified in 3 (b) above impacted on agricultural activities?

At your farm/local level	At the national/regional level
Reduced crop yield [ ] Change in planting time [ ] Crop failure [ ] Increased pest and disease infestation [ ] Flooding of crop fields [ ] Reduced soil moisture [ ] Others (specify) ……………………….	Insufficient food [ ] High food prices [ ] Human wildlife conflicts [ ] Competition over resources [ ] Others (specify) ………………………..

24. How are you responding to these changes in 23 above?

____

25. Which of the practices listed below are used in your locality in response to climate change?

Strategy	Approximate % of farmers using
Agro forestry [ ]	
Drought tolerant crops [ ]	
Rain water harvesting [ ]	
Irrigation [ ]	
Soil and water conservation [ ]	
Application of fertilizers and organic inputs [ ]	
Planting appropriate crop varieties [ ]	
Use of different cropping systems [ ]	

Others (specify) ………………………………..	

Appendix 2: ANOVA Tables

Potassium sorghum plots short rain season 2012

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
C1 stratum	2	1.0757135	0.5378568	23.59	
C1.TILAGE_PRACTICE stratum					
TILAGE_PRACTICE	2	77.6177015	38.8088508	1702.28	<.001
Residual	4	0.0911928	0.0227982	37.98	
C1.TILAGE_PRACTICE.CROPPING_SYSTEMS stratum					
CROPPING_SYSTEMS	4	1.1974288	0.2993572	498.66	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS	8	7.6568219	0.9571027	1594.32	<.001
Residual	24	0.0144077	0.0006003	0.97	
C1.TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS stratum					
ORGANIC_INPUTS	3	4.3534748	1.4511583	2334.77	<.001
TILAGE_PRACTICE.ORGANIC_INPUTS	6	0.1875806	0.0312634	50.30	<.001
CROPPING_SYSTEMS.ORGANIC_INPUTS	12	0.4487662	0.0373972	60.17	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS	24	0.7650335	0.0318764	51.29	<.001
Residual	90	0.0559388	0.0006215		
Total	179	93.4640602			

Potassium sorghum plots long rain season 2013

Source of variation	d.f. (m.v.)	s.s.	m.s.	v.r.	F pr.
C1 stratum	2	1.0074811	0.5037405	14.77	
C1.TILAGE_PRACTICE stratum					
TILAGE_PRACTICE	2	91.6480134	45.8240067	1343.19	<.001
Residual	4	0.1364632	0.0341158	51.45	

C1.TILAGE_PRACTICE.CROPPING_SYSTEMS stratum						
CROPPING_SYSTEMS	4		3.9804812	0.9951203	1500.81	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS						
	8		4.7599996	0.5949999	897.36	<.001
Residual	24		0.0159133	0.0006631	5.01	
C1.TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS stratum						
ORGANIC_INPUTS	3		10.5409430	3.5136477	26563.55	<.001
TILAGE_PRACTICE.ORGANIC_INPUTS						
	6		3.6761513	0.6126919	4632.02	<.001
CROPPING_SYSTEMS.ORGANIC_INPUTS						
	12		0.3518472	0.0293206	221.67	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS						
	20	(4)	0.8686110	0.0434306	328.34	<.001
Residual	81	(9)	0.0107141	0.0001323		
Total	166	(13)	94.3243304			

Organic carbon sorghum plots short rain season 2012

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
C1 stratum	2	1.243E+00	6.216E-01	106.37	
C1.TILAGE_PRACTICE stratum					
TILAGE_PRACTICE	2	1.280E+01	6.402E+00	1095.58	<.001
Residual	4	2.338E-02	5.844E-03	3.53	
C1.TILAGE_PRACTICE.CROPPING_SYSTEMS stratum					
CROPPING_SYSTEMS	4	1.059E+01	2.648E+00	1597.44	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS					
	8	1.179E+01	1.474E+00	889.46	<.001
Residual	24	3.978E-02	1.657E-03	17.58	
C1.TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS stratum					
ORGANIC_INPUTS	3	4.349E+00	1.450E+00	15376.94	<.001
TILAGE_PRACTICE.ORGANIC_INPUTS					
	6	1.646E-01	2.743E-02	291.00	<.001
CROPPING_SYSTEMS.ORGANIC_INPUTS					
	12	2.400E-01	2.000E-02	212.19	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS					
	24	7.042E-01	2.934E-02	311.24	<.001
Residual	90	8.484E-03	9.427E-05		
Total	179	4.196E+01			

Organic carbon sorghum plots long rain season 2013

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
C1 stratum	2		1.1309395	0.5654697	136.45	
C1.TILAGE_PRACTICE stratum						
TILAGE_PRACTICE	2		10.3412152	5.1706076	1247.68	<.001
Residual	4		0.0165767	0.0041442	2.25	
C1.TILAGE_PRACTICE.CROPPING_SYSTEMS stratum						
CROPPING_SYSTEMS	4		9.8999848	2.4749962	1343.34	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS						
	8		15.1481406	1.8935176	1027.74	<.001
Residual	24		0.0442180	0.0018424	17.94	
C1.TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS stratum						
ORGANIC_INPUTS	3		3.9014353	1.3004784	12662.59	<.001
TILAGE_PRACTICE.ORGANIC_INPUTS						
	6		0.3035026	0.0505838	492.53	<.001
CROPPING_SYSTEMS.ORGANIC_INPUTS						
	12		0.2661390	0.0221782	215.95	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS						
	20	(4)	0.6145756	0.0307288	299.20	<.001
Residual	80	(10)	0.0082162	0.0001027		
Total	165	(14)	38.9917780			

Phosphorous sorghum plots short rain season 2012

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
C1 stratum	2	3.298E+02	1.649E+02	3713.21	
C1.TILAGE_PRACTICE stratum					
TILAGE_PRACTICE	2	1.010E+02	5.050E+01	1137.00	<.001
Residual	4	1.776E-01	4.441E-02	0.04	

C1.TILAGE_PRACTICE.CROPPING_SYSTEMS stratum					
CROPPING_SYSTEMS	4	5.597E+03	1.399E+03	1238.77	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS	8	9.815E+03	1.227E+03	1086.12	<.001
Residual	24	2.711E+01	1.130E+00	38.87	
C1.TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS stratum					
ORGANIC_INPUTS	3	1.360E+03	4.535E+02	15602.25	<.001
TILAGE_PRACTICE.ORGANIC_INPUTS	6	8.410E+00	1.402E+00	48.23	<.001
CROPPING_SYSTEMS.ORGANIC_INPUTS	12	4.525E+01	3.771E+00	129.75	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS	24	7.301E+01	3.042E+00	104.67	<.001
Residual	90	2.616E+00	2.906E-02		
Total	179	1.736E+04			

Phosphorous sorghum plots long rain season 2013

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
C1 stratum	2		327.743	163.871	23.17	
C1.TILAGE_PRACTICE stratum						
TILAGE_PRACTICE	2		668.026	334.013	47.22	0.002
Residual	4		28.292	7.073	6.87	
C1.TILAGE_PRACTICE.CROPPING_SYSTEMS stratum						
CROPPING_SYSTEMS	4		3296.900	824.225	800.39	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS	8		8546.734	1068.342	1037.45	<.001
Residual	24		24.715	1.030	0.29	
C1.TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS stratum						
ORGANIC_INPUTS	3		547.079	182.360	50.84	<.001
TILAGE_PRACTICE.ORGANIC_INPUTS	5	(1)	5.108	1.022	0.28	0.920
CROPPING_SYSTEMS.ORGANIC_INPUTS						

	12		26.415	2.201	0.61	0.825
TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS	20	(4)	48.830	2.441	0.68	0.834
Residual	80	(10)	286.944	3.587		
Total	164	(15)	12046.573			

Soil moisture content sorghum plots short rain season 2012

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
C1 stratum	2	3.997006	1.998503	14.07	
C1.TILAGE_PRACTICE stratum					
TILAGE_PRACTICE	2	499.585360	249.792680	1758.04	<.001
Residual	4	0.568345	0.142086	17.55	
C1.TILAGE_PRACTICE.CROPPING_SYSTEMS stratum					
CROPPING_SYSTEMS	4	122.785710	30.696427	3791.81	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS	8	29.556133	3.694517	456.37	<.001
Residual	24	0.194291	0.008095	1.73	
C1.TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS stratum					
ORGANIC_INPUTS	3	60.946864	20.315621	4350.12	<.001
TILAGE_PRACTICE.ORGANIC_INPUTS	6	14.805382	2.467564	528.37	<.001
CROPPING_SYSTEMS.ORGANIC_INPUTS	12	2.032589	0.169382	36.27	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS	24	1.311956	0.054665	11.71	<.001
Residual	90	0.420312	0.004670		
Total	179	736.203948			

Soil moisture content sorghum plots long rain season 2013

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
C1 stratum	2	4.7570	2.3785	7.92	
C1.TILAGE_PRACTICE stratum					

TILAGE_PRACTICE	2	455.7048	227.8524	758.58	<.001
Residual	4	1.2015	0.3004	2.03	

C1.TILAGE_PRACTICE.CROPPING_SYSTEMS stratum

CROPPING_SYSTEMS	4	132.4182	33.1046	224.15	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS					
	8	37.8300	4.7287	32.02	<.001
Residual	24	3.5446	0.1477	1.05	
C1.TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS stratum					
ORGANIC_INPUTS	3	59.7775	19.9258	141.47	<.001
TILAGE_PRACTICE.ORGANIC_INPUTS					
	6	16.4252	2.7375	19.44	<.001
CROPPING_SYSTEMS.ORGANIC_INPUTS					
	12	3.4853	0.2904	2.06	0.027
TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS					
	24	3.5458	0.1477	1.05	0.417
Residual	90	12.6764	0.1408		
Total	179	731.3662			

Total Nitrogen sorghum plots short rain season 2012

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
C1 stratum	2	0.00610428	0.00305214	53.63	
C1.TILAGE_PRACTICE stratum					
TILAGE_PRACTICE	2	0.04484151	0.02242075	393.93	<.001
Residual	4	0.00022766	0.00005692	0.42	
C1.TILAGE_PRACTICE.CROPPING_SYSTEMS stratum					
CROPPING_SYSTEMS	4	0.05125470	0.01281367	94.47	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS					
	8	0.05955839	0.00744480	54.88	<.001
Residual	24	0.00325547	0.00013564	4.10	
C1.TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS stratum					

ORGANIC_INPUTS	3	0.05518427	0.01839476	556.13	<.001
TILAGE_PRACTICE.ORGANIC_INPUTS					
	6	0.00247977	0.00041329	12.50	<.001
CROPPING_SYSTEMS.ORGANIC_INPUTS					
	12	0.00027807	0.00002317	0.70	0.747
TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS					
	24	0.00179235	0.00007468	2.26	0.003
Residual	90	0.00297686	0.00003308		
Total	179	0.22795333			

Total Nitrogen sorghum plots long rain season 2013

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
C1 stratum	2		0.00443919	0.00221960	40.39	
C1.TILAGE_PRACTICE stratum						
TILAGE_PRACTICE	2		0.03936069	0.01968034	358.16	<.001
Residual	4		0.00021979	0.00005495	0.25	
C1.TILAGE_PRACTICE.CROPPING_SYSTEMS stratum						
CROPPING_SYSTEMS	4		0.04405175	0.01101294	51.04	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS						
	8		0.05875114	0.00734389	34.03	<.001
Residual	24		0.00517897	0.00021579	2.60	
C1.TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS stratum						
ORGANIC_INPUTS	3		0.05138435	0.01712812	206.60	<.001
TILAGE_PRACTICE.ORGANIC_INPUTS						
	6		0.00258843	0.00043141	5.20	<.001
CROPPING_SYSTEMS.ORGANIC_INPUTS						
	12		0.00093920	0.00007827	0.94	0.508
TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS						
	24		0.00284535	0.00011856	1.43	0.116
Residual	89	(1)	0.00737851	0.00008290		
Total	178	(1)	0.21696016			

Potassium sweet potato plots short rain season 2012

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.7636922	0.3818461	91.74	
REP.TILAGE_PRACTICE stratum					
TILAGE_PRACTICE	2	15.2339955	7.6169977	1830.04	<.001
Residual	4	0.0166488	0.0041622	2.21	
REP.TILAGE_PRACTICE.CROPPING_SYSTEMS stratum					
CROPPING_SYSTEMS	4	18.8428322	4.7107080	2498.63	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS					
	8	12.2737822	1.5342228	813.77	<.001
Residual	24	0.0452476	0.0018853	4.32	
REP.TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS stratum					
ORGANIC_INPUTS	3	3.1610115	1.0536705	2417.11	<.001
TILAGE_PRACTICE.ORGANIC_INPUTS					
	6	0.0625315	0.0104219	23.91	<.001
CROPPING_SYSTEMS.ORGANIC_INPUTS					
	12	0.3876905	0.0323075	74.11	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS					
	24	0.4188243	0.0174510	40.03	<.001
Residual	90	0.0392329	0.0004359		
Total	179	51.2454893			

Potassium sweet potato plots long rain season 2013

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	1.0011709	0.5005854	38.13	
REP.TILAGE_PRACTICE stratum					
TILAGE_PRACTICE	2	29.8520745	14.9260373	1137.00	<.001
Residual	4	0.0525101	0.0131275	6.49	
REP.TILAGE_PRACTICE.CROPPING_SYSTEMS stratum					

CROPPING_SYSTEMS	4	3.9967383	0.9991846	494.35	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS					
	8	23.5808072	2.9476009	1458.33	<.001
Residual	24	0.0485092	0.0020212	18.07	
REP.TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS stratum					
ORGANIC_INPUTS	3	4.5243923	1.5081308	13480.92	<.001
TILAGE_PRACTICE.ORGANIC_INPUTS					
	6	0.1485309	0.0247551	221.28	<.001
CROPPING_SYSTEMS.ORGANIC_INPUTS					
	12	0.3358522	0.0279877	250.18	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS					
	24	0.7151486	0.0297979	266.36	<.001
Residual	90	0.0100684	0.0001119		
Total	179	64.2658025			

Organic carbon sweet potato plots short rain season 2013

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	8.573E-01	4.287E-01	322.47	
REP.TILAGE_PRACTICE stratum					
TILAGE_PRACTICE	2	2.785E+00	1.392E+00	1047.50	<.001
Residual	4	5.317E-03	1.329E-03	0.53	
REP.TILAGE_PRACTICE.CROPPING_SYSTEMS stratum					
CROPPING_SYSTEMS	4	2.325E+01	5.812E+00	2303.26	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS					
	8	1.082E+01	1.352E+00	535.84	<.001
Residual	24	6.057E-02	2.524E-03	37.87	
REP.TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS stratum					
ORGANIC_INPUTS	3	3.115E+00	1.038E+00	15582.54	<.001
TILAGE_PRACTICE.ORGANIC_INPUTS					
	6	9.607E-02	1.601E-02	240.28	<.001
CROPPING_SYSTEMS.ORGANIC_INPUTS					
	12	3.631E-01	3.026E-02	454.08	<.001

TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS					
	24	2.803E-01	1.168E-02	175.27	<.001
Residual	90	5.998E-03	6.664E-05		
Total	179	4.164E+01			

Organic carbon sweet potato plots long rain season 2013

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	9.575E-01	4.787E-01	203.21	
REP.TILAGE_PRACTICE stratum					
TILAGE_PRACTICE	2	5.357E+00	2.679E+00	1137.00	<.001
Residual	4	9.423E-03	2.356E-03	1.05	
REP.TILAGE_PRACTICE.CROPPING_SYSTEMS stratum					
CROPPING_SYSTEMS	4	1.122E+01	2.805E+00	1253.45	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS					
	8	1.931E+01	2.414E+00	1078.78	<.001
Residual	24	5.371E-02	2.238E-03	23.26	
REP.TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS stratum					
ORGANIC_INPUTS	3	4.032E+00	1.344E+00	13970.90	<.001
TILAGE_PRACTICE.ORGANIC_INPUTS					
	6	8.536E-02	1.423E-02	147.89	<.001
CROPPING_SYSTEMS.ORGANIC_INPUTS					
	12	2.847E-01	2.373E-02	246.64	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS					
	24	5.200E-01	2.167E-02	225.23	<.001
Residual	90	8.658E-03	9.620E-05		
Total	179	4.184E+01			

Phosphorous sweet potato plots short rain season 2012

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	4.055E+02	2.027E+02	124.29	
REP.TILAGE_PRACTICE stratum					
TILAGE_PRACTICE	2	3.709E+03	1.855E+03	1137.00	<.001
Residual	4	6.525E+00	1.631E+00	1.45	

REP.TILAGE_PRACTICE.CROPPING_SYSTEMS stratum					
CROPPING_SYSTEMS	4	5.486E+03	1.371E+03	1217.60	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS					
	8	9.882E+03	1.235E+03	1096.70	<.001
Residual	24	2.703E+01	1.126E+00	31.49	
REP.TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS stratum					
ORGANIC_INPUTS	3	1.538E+03	5.127E+02	14333.20	<.001
TILAGE_PRACTICE.ORGANIC_INPUTS					
	6	7.580E+01	1.263E+01	353.15	<.001
CROPPING_SYSTEMS.ORGANIC_INPUTS					
	12	9.646E+01	8.038E+00	224.71	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS					
	24	1.198E+02	4.993E+00	139.59	<.001
Residual	90	3.219E+00	3.577E-02		
Total	179	2.135E+04			

Phosphorous sweet potato plots long rain season 2013

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	438.521	219.261	22.85	
REP.TILAGE_PRACTICE stratum					
TILAGE_PRACTICE	2	2127.325	1063.663	110.83	<.001
Residual	4	38.388	9.597	6.09	
REP.TILAGE_PRACTICE.CROPPING_SYSTEMS stratum					
CROPPING_SYSTEMS	4	8748.176	2187.044	1388.54	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS					
	8	9068.162	1133.520	719.66	<.001
Residual	24	37.802	1.575	0.38	
REP.TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS stratum					
ORGANIC_INPUTS	3	984.868	328.289	78.68	<.001
TILAGE_PRACTICE.ORGANIC_INPUTS					
	6	107.618	17.936	4.30	<.001
CROPPING_SYSTEMS.ORGANIC_INPUTS					

	12	63.641	5.303	1.27	0.250
TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS					
	24	71.151	2.965	0.71	0.829
Residual	90	375.517	4.172		
Total	179	22061.171			

Soil moisture content sweet potato plots short rain season 2012

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	3.523E+00	1.761E+00	12.39	
REP.TILAGE_PRACTICE stratum					
TILAGE_PRACTICE	2	4.840E+02	2.420E+02	1702.73	<.001
Residual	4	5.686E-01	1.421E-01	18.43	
REP.TILAGE_PRACTICE.CROPPING_SYSTEMS stratum					
CROPPING_SYSTEMS	4	4.533E+01	1.133E+01	1469.36	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS					
	8	1.123E+02	1.403E+01	1819.41	<.001
Residual	24	1.851E-01	7.713E-03	7.97	
REP.TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS stratum					
ORGANIC_INPUTS	3	5.987E+01	1.996E+01	20611.62	<.001
TILAGE_PRACTICE.ORGANIC_INPUTS					
	6	1.060E+01	1.767E+00	1825.05	<.001
CROPPING_SYSTEMS.ORGANIC_INPUTS					
	12	1.197E+00	9.973E-02	103.01	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS					
	24	2.519E+00	1.049E-01	108.40	<.001
Residual	90	8.714E-02	9.682E-04		
Total	179	7.202E+02			

Soil moisture content sweet potato plots long rain season 2013

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	4.424787	2.212394	12.39	
REP.TILAGE_PRACTICE stratum					

TILAGE_PRACTICE	2	608.029245	304.014623	1702.73	<.001
Residual	4	0.714182	0.178545	18.43	
REP.TILAGE_PRACTICE.CROPPING_SYSTEMS stratum					
CROPPING_SYSTEMS	4	56.944935	14.236234	1469.36	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS					
	8	141.022345	17.627793	1819.41	<.001
Residual	24	0.232529	0.009689	7.97	
REP.TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS stratum					
ORGANIC_INPUTS	3	75.200690	25.066897	20611.62	<.001
TILAGE_PRACTICE.ORGANIC_INPUTS					
	6	13.317257	2.219543	1825.05	<.001
CROPPING_SYSTEMS.ORGANIC_INPUTS					
	12	1.503338	0.125278	103.01	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS					
	24	3.163858	0.131827	108.40	<.001
Residual	90	0.109454	0.001216		
Total	179	904.662621			

Total Nitrogen sweet potato plots short rain season 2012

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.00610428	0.00305214	53.63	
REP.TILAGE_PRACTICE stratum					
TILAGE_PRACTICE	2	0.04484151	0.02242075	393.93	<.001
Residual	4	0.00022766	0.00005692	0.42	
REP.TILAGE_PRACTICE.CROPPING_SYSTEMS stratum					
CROPPING_SYSTEMS	4	0.05125470	0.01281367	94.47	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS					
	8	0.05955839	0.00744480	54.88	<.001
Residual	24	0.00325547	0.00013564	4.10	
REP.TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS stratum					
ORGANIC_INPUTS	3	0.05518427	0.01839476	556.13	<.001
TILAGE_PRACTICE.ORGANIC_INPUTS					

	6	0.00247977	0.00041329	12.50	<.001
CROPPING_SYSTEMS.ORGANIC_INPUTS					
	12	0.00027807	0.00002317	0.70	0.747
TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS					
	24	0.00179235	0.00007468	2.26	0.003
Residual	90	0.00297686	0.00003308		
Total	179	0.22795333			

Total Nitrogen sweet potato plots long rain season 2013

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	6.357E-03	3.179E-03	224.71	
REP.TILAGE_PRACTICE stratum					
TILAGE_PRACTICE	2	3.217E-02	1.608E-02	1137.00	<.001
Residual	4	5.658E-05	1.415E-05	2.33	
REP.TILAGE_PRACTICE.CROPPING_SYSTEMS stratum					
CROPPING_SYSTEMS	4	1.556E-02	3.890E-03	641.09	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS					
	8	6.723E-02	8.404E-03	1384.96	<.001
Residual	24	1.456E-04	6.068E-06	9.12	
REP.TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS stratum					
ORGANIC_INPUTS	3	2.949E-02	9.829E-03	14779.23	<.001
TILAGE_PRACTICE.ORGANIC_INPUTS					
	6	3.016E-04	5.027E-05	75.59	<.001
CROPPING_SYSTEMS.ORGANIC_INPUTS					
	12	1.679E-03	1.399E-04	210.39	<.001
TILAGE_PRACTICE.CROPPING_SYSTEMS.ORGANIC_INPUTS					
	24	2.560E-03	1.067E-04	160.39	<.001
Residual	90	5.985E-05	6.650E-07		
Total	179	1.556E-01			