COMPARATIVE EFFECTS OF MAIZE-SOYBEANS AND MAIZE-DESMODIUM INTERCROPPING SYSTEMS ON YIELD OF COMPONENT CROPS AND RAINFALL USE EFFICIENCY IN WESTERN KENYA

BY

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN AGRONOMY

SCHOOL OF AGRICULTURE, FOOD SECURITY AND ENVIRONMENTAL SCIENCES

MASENO UNIVERSITY

DECLARATION

This thesis is my original work and has not been submitted for the award of a degree or diploma in any other institution of higher learning.

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ACKNOWLEDGEMENT

I am greatly indebted to all the individuals and institutions that in one way or the other facilitated the successful completion of this study. I am especially grateful to my supervisors Professor H. Ogindo and Professor G. Odhiambo for their valuable guidance throughout the study, staff at the School of Agriculture, Food Security and Environmental Sciences and those in Chemistry Department at Maseno University for their assistance during the laboratory work. Thanks also to farmers in Busia and Vihiga counties for providing space and participating in the study activities. This study greatly benefited from partial funding by Humidtropics, a CGIAR research program on integrated systems for the humid tropics _ West Kenya and I therefore say thank you.

DEDICATION

To my daughter, Angela-do more than I have done this day

ABSTRACT

Inadequate soil moisture ensuing from climate change and variability limits the effectiveness of legumes to increase maize production. Soybeans and desmodium are legumes intercropped with maize to control striga weed, improve soil fertility and prevent soil degradation. However, there exists need to determine their comparative effect on yield and rainfall use efficiency when intercropped with maize in rain-fed maize production. The main objective of this study was to compare the effect of maize-soybeans (MS) and maize-desmodium (MD) intercropping systems on yield and rainfall use efficiency in Western Kenya. The specific objectives sought to compare the effect of maize monocrop (M), MS and MD intercrops on soil moisture trends; determine effect of M, MS and MD intercrops on maize energy yield and; determine the effect of M, MS and MD intercrops on rainfall use efficiency. The study was carried in two sites in Busia and Vihiga during the planting seasons in the year 2015. This was experimental research with treatments of MS intercrop; MD intercrop; and M monocrop. Each treatment was replicated three times in RCBD arrangement. Each experimental plot measured 30 m^2. Freshco 425 IR maize, Soybeans HB 19 and Greenleaf desmodium varieties were used. On site rainfall data was collected using rain gauge. Volumetric soil moisture content was measured at 7 days intervals at 5cm, 25cm and 45cm depths using theta probe type ML2X equipment. Crop yields were determined from 15m^2 net plot areas by weight for maize and soybeans, and as dry matter weight for desmodium. Yield energy values were determined in kJ using bomb calorimetry to standardize yield units for maize, soyabeans and desmodium then expressed in kJ ha. $^{-1}$. One-way ANOVA was performed using R software version 3.1.2 to determine whether the cropping systems had effect at 5% level of significance. Tukey Honestly significant difference was used to separate the treatment means that were significantly different. Statistically there were no significant differences in soil moisture trends in the cropping systems in season I and II at both sites. Maize energy yields were also not significantly different in both seasons in the two sites. Statistically significant differences in RUE ($P<0.05$) only existed in Busia site in season II in favour of intercropping. There was no yield advantage of growing maize as a single crop. Maize can be intercropping with soybeans and with desmodium at the current recommended maize population of 44,000 plants ha^{-1}.

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ABBREVIATIONS AND ACRONYMS

ANOVA- Analysis of variance

CAN- Calcium Ammonium Nitrate

DAP- Di Amonium Phosphate

DAS- Days After Sowing

DM- Dry matter

HSD- Honestly Significant Difference

ISFM- Integrated Soil Fertility Management

kJ/ha- kilo Joules per hectare

M- Maize

MD- Maize/Desmodium

MS- Maize/Soybean

RCBD- Randomised Complete Block Design

RUE- Rainfall Use Efficiency

DEFINITION OF TERMS

- Intercropping: Mixed cropping involving cultivation of two or more crops in the same space at the same time

- Integrated soil fertility management: Soil fertility management practices aimed at maximizing agronomic use efficiency of plant resources to improve crop production.

- Additive crop: The intercrop planted in addition to the recommended population in a pure stand crop.

- Replacement crop: The equivalent number of intercrop plants planted to substitute for the reduced population of a pure stand crop.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Drought limits the effectiveness of legumes to increase maize production. Kenya, like the rest of the world, is experiencing climate change and variability and the associated negative impacts (Linne *et al.*, 2013). The incidences result in a number of socioeconomic and environmental challenges that include irregular rainfall and droughts that cause among others reduced soil moisture content leading to reduced crop production and increased food insecurity (Zhao and Running, 2010). Rainfall for crop production has become erratic. Droughts are experienced everywhere, leading to reduced or nil yields in some instances (Linne *et al*., 2013). This situation is detrimental to global food security (Ciais *et al.*, 2005; IPCC, 2007; Zhao and Running, 2010). Stress resulting from drought is therefore a major limiting factor to crop production in the world (Dai *et al.*, 2004; Zou *et al.*, 2005). Droughts account for half of the world's food emergencies each year. In the year 2003 World Food Program spent US $ 565 million to mitigate drought in sub-Saharan Africa. About 20 million metric tons of possible tropical maize production is lost every year as a result of drought (Doering, 2005).

Crop production in Kenya depends mainly on rainfall. Rain-fed crop production accounts for 98% of crop production activities in the country. Banking on rain-fed crop production poses considerable risk to farmers because of high temporal and spatial variations in rainfall (Barron *et al*., 2003). Dependency on rainfall for crop production limits sustainable food production as only about 8.14% of national irrigation potential has so far been established (Adeboye *et al*., 2009). Drought resulting from variability of rainfall has been singled out as the most important climate risk in Western Kenya where it has occurred quite frequently in recent years resulting in food insecurity (Linne *et al*., 2013). Maize production in Western Kenya region is subjected to large fluctuations due to the frequent drought periods. The state of climate change in Kenya as documented in the National Climate Change Response Strategy (GoK, 2010a), the National Climate Change Action Plan (2013-2017) and the State of Environment Outlook (GoK, 2010b) indicates that temperatures have generally risen throughout the country resulting in heightened soil moisture loss. This calls for increased crop production through enhanced management of available soil moisture to gain more crop yield from less rainfall. Crops depend not only on precipitation amounts but also on the ability of the soil to absorb and store moisture. The effectiveness of legumes to increase maize production is affected by their ability to reduce moisture loss and increase moisture use efficiency. There occurs an obvious need for agronomic solutions to close the common and often large gap between actual and attainable yield per unit rainfall (Wani *et al.*, 2009).

Maize (*Zea mays* L.*)* is the main cereal crop in Western Kenya as it is the leading food for over 90% of its population (Illa *et al*., 2010). Majority of agricultural households in Western Kenya plant maize crop (Olwande, 2012). Food security in the region is generally attached to availability of adequate supplies of maize to meet domestic food demands. Small scale production makes up 70% of the total maize produced. On average 80% of the land acreage under maize crop is owned by smallholder farmers. *Striga hermonthica* (Del.) Benth is a parasitic weed that poses momentous constrain in the production of maize in Sub-Saharan Africa (Emechebe *et al*., 2004; Odhiambo and Woomer, 2005; Esilaba, 2006; AATF, 2006; Wambugu *et al*., 2012; MOA, 2013). *Striga* affects livelihood of millions of resource poor farmers (Atera *et al*., 2013). *Desmodium spp.* and soybeans (*Glycine max*) are legumes that have been successfully intercropped with maize crop. Desmodium has been documented to improve soil fertility and prevent soil degradation. Desmodium also fits well with traditional mixed cropping systems (Khan *et al*., 2011). Desmodium has been applauded severally for reducing *striga* weed infestation to substantial levels through suicidal germination (Khan *et al*., 2008, 2009; Odhiambo *et al.,* 2009). Soybeans also improve soil fertility and control *striga* weed in a comparable way (Dugje *et al*., 2009). Much of the nitrogen these two legumes require is produced through fixation of atmospheric nitrogen by bacteria in nodules on their roots. Addition of nitrogen to the soil lessens the effects of *striga* weed and also lowers the amount of *striga* weed supported by the maize crop. Inclusion of desmodium and soybeans in cropping systems plays an important role in maintaining soil fertility and sustaining maize crop even under *striga* weed invasion (Khan *et al.,* 2007). This has resulted in advocating for intercropping of maize crop with desmodium and soybeans in Western Kenya.

Intercropping maize crop with legume crops has shown some relative advantages over sole cropping when all the treatments were of replacement crop type (Natarajan and Willey, 1986). In each instance the total plant population was maintained uniform. Higher total plant populations in intercrops as in the case of additive crop type result in less yield under moisture stress conditions arising from drought. This is due to increased competition for soil moisture among other crop requirements (Hulugalle and Lal, 1986). Planning agricultural systems that use the limited available rainfall efficiently is a requirement for improving rainfall use for crop production. This necessitates good understanding of crop rainfall use efficiency in the context of available rainfall (Mulebeke *et al*, 2010). Soil moisture stress resulting from drought limits capacity of crops to take up nutrients (Okalebo *et al*., 2007). Therefore, the need to effectively use rainfall is of major concern. In spite of recommendations on adoption of cropping systems incorporating fodder and grain legumes, there exists need to determine their effect on maize yield and rainfall use efficiency when used as additive crops. This study therefore aimed at comparing the effect of maize-soybeans and maize-desmodium intercropping systems on yield and rainfall use efficiency in Western Kenya with a view of mitigating the effects of drought to maximize production of maize.

1.2 Problem Statement

Maize production in Western Kenya region is exposed to low yields as a result of frequent droughts. Soil moisture stress during growth period reduces ability of maize crop to take up nutrients resulting in low yields. The need to efficiently utilize available rainfall is of foremost concern. Maize-legume intercropping systems have shown some relative advantages in productivity over sole cropping when the treatments were of replacement crop type. Higher total crop populations in intercrops result in reduced yield under drought instigated soil moisture stress conditions as a result of increased competition for soil moisture. Total soil moisture requirement for intercrops is higher than that for monocrops during stress periods. Planning agricultural systems that efficiently use limited available rainfall is of necessity for improving rainfall use efficiency. This requires good understanding of crop rainfall use efficiency in the context of available rainfall. In spite of recommendations on adoption of maize cropping systems incorporating desmodium and soybeans, there exists need to compare their effect on yield and rainfall use efficiency in intercropping.

1.3 Objectives of the Study

1.3.1 General Objective

To compare the effect of maize-soybeans and maize-desmodium intercropping systems on yield and rainfall use efficiency in Western Kenya.

1.3.2 Specific Objectives

1. To compare the effect of maize monocrop, maize-soybeans and maize-desmodium intercrops on soil moisture trends.
2. To determine the effect of maize monocrop, maize-soybeans and maize-desmodium intercrops on maize energy yield.
3. To determine the effect of maize monocrop, maize-soybeans and maize-desmodium intercrops on rainfall use efficiency.

1.4 Null Hypotheses

1. There is no significant difference in soil moisture trends in maize monocrop, maize-soybeans and maize-desmodium intercrops.
2. There is no significant difference in maize energy yield in maize monocrop, maize-soybeans and maize-desmodium intercrops.
3. There is no significant difference in rainfall use efficiency in maize monocrop, maize-soybeans and maize-desmodium intercrops.

1.5 Justification of the Study

Maize production in Western Kenya is dependent on available rainfall. Droughts have become frequent in the region resulting in low maize yields. Farmers in the region primarily practice intercropping of maize with legumes since maize is a staple food. Understanding the effect of maize-soybeans and maize-desmodium intercropping systems on yield and rainfall use efficiency will alleviate continued low maize yield resulting from soil moisture stress by playing a critical role in the development of informed choices of systems to adopt within the many different cropping systems. This will increase maize production necessary for food security and increased income to improve the living standards of the many smallholder farmers in Western Kenya.

CHAPTER TWO

LITERATURE REVIEW

2.1 Maize Production in Western Kenya

Western Kenya, which is part of the Lake Victoria Basin, is found in an altitude of between 900-1800m above sea level. It is one of the rural areas with the highest human population densities in Kenya with some of the counties in it having densities of over 500 persons per square kilometre (GoK, 2013). The region's annual rainfall ranges from 950 mm to 1500 mm with a bimodal distribution (GoK, 2013). An average rainfall of between 500 mm to 800 mm is recommended for maximum production of a medium maturing maize crop (FAO, 2012). The high population densities have created increasing pressure on land and other natural resources with the consequence being felt in extensive loss of forest cover, land degradation, declining water resources and evolving climate variability (GoK, 2010c). Maize (*Zea mays* L.*)* is the main cereal crop in Western Kenya and the primary food for over 90% of the population (Illa *et al.*, 2010). The average farm size is 0.5 ha per house hold. About 0.2 ha out of the 0.5 ha is used to produce maize whose yields often fall as low as 1 t ha^{-1} over two seasons (Okalebo *et al*.2005). Households require above 1 ton each year for food security. Most households are therefore only producing maize to feed themselves for a few months and must therefore purchase maize from the market during the remaining months or endure hunger periods (Olwande, 2012). The food security in this region is frequently pegged to availability of adequate supplies of maize to meet domestic food demands. Small scale production makes up 70% of the total maize produced. On average 80% of the land acreage under maize is owned by smallholder farmers. Most agricultural households therefore plant maize (Olwande, 2012).

2.2 Effects of Climate Change and Variability on Maize Production

Kenya is facing climate change and variability together with the associated negative impacts just like the rest of the world (Linne *et al*., 2013). These incidences of negative impacts present a number of socio-economic and environmental challenges including unpredictability in rainfall resulting in droughts causing reduced agricultural production and increased food insecurity (Zhao and Running, 2010). While susceptibility to climate change and variability impacts is differentiated and context-specific, it has resulted in major economic loses that can ruin attainment of the country's development goals. Rainfall is becoming unpredictable yet most farmers depend on it for crop production. Droughts are experienced everywhere, leading to reduced or no yields at all in some cases (Linne *et al*., 2013). Drought stress is a major abiotic factor restraining crop productivity in the world (Dai *et al.*, 2004; Zou *et al*., 2005). The severe droughts may lead to global loss in crop yields which can be detrimental to universal food security (Ciais *et al*., 2005; IPCC, 2007; Zhao *et al.*, 2010). Severe drought has been reported in Eastern, West and Southern Africa (Sanginga and Woomer, 2009). Drought accounts for half the world's food emergencies each year. In 2003 the world food program spent US $ 565 million to mitigate drought in Sub Saharan Africa. About 20 million metric tons of potential tropical maize production is lost each year as a result of drought (Doering, 2005).

Rain-fed crop production accounting for 98% of crop production in the country is the backbone of Kenya's economy and is susceptible to droughts. Relying on rain-fed agriculture poses significant risks to farmers because of high temporal and spatial dissimilarities (Barron *et al*., 2003). Kenyan crop production depends almost 100% on natural rain. Only about 8.14% of national irrigation potential has so far been developed. The state of climate change in Kenya is documented in The National Climate Change Response Strategy (GoK., 2010a), The National Climate Change Action Plan 2013-2017 (Gok., 2012) and The State of Environment Outlook (GoK., 2010b) indicating that temperatures have generally risen throughout the country resulting in greater soil moisture lose. Climate change and variability are associated with reduced maize yields and therefore reduced income particularly for the smallholder maize producers. Droughts used to occur about every decade. At the moment dry spells are experienced almost every other year. Variability in rainfall has therefore been singled out as the most important climate risk in Western Kenya where it has occurred more frequently in recent years (Linne *et al.,* 2013). Reliance on rainfall for maize production has become a major limitation for sustainable food production in Western Kenya (Adeboye *et al*., 2009).

2.3 Effects of Drought on Plant Water Relationships

Drought encourages regulation of water loss and uptake in plants to allow maintenance of their leaf relative water content within the limits where the photosynthetic capacity shows non if not little changes. Severe drought induces in plants critical changes resulting in inhibition of photosynthesis and growth (Yordanov *et al*., 2003). The amount of water obtainable to plants is important, since water accounts for 80-90% of the fresh weight of most herbaceous plant structures and over 50% of the fresh weight of woody plants (Kramer and Boyer, 1995). On a global basis, about one-third of potential agricultural land suffers from inadequate water supply, and the crop yields of much of the remainder two-thirds of agricultural land are occasionally reduced by drought (Kramer, 1980). Water is gradually lost from a saturated soil by draining freely under the influence of gravity. The rate of loss slows down gradually until no more water drains away to a point at which the soil is at field capacity. Additional loss of water by evaporation or by absorption by plant roots reduces the moisture content to a point where no further loss happens. This is wilting point. Plants can no longer obtain the water required to meet their needs and they therefore wilt and die from moisture starvation (Akinci and Losel, 2012). Water stress ensuing from drought affects growth and the root-shoot ratio of the entire plant (Passioura *et al.,* 1993). Every plant process is affected directly or indirectly by water supply. When soil dries, the decrease in water content is accompanied by other changes such as rise in salt concentration and increasing mechanical resistance which adversely affect crop productivity. Plant growth is controlled by rates of cell division and expansion as well as supply of organic and inorganic compounds required for the synthesis of new protoplasm and cell wall. Water stress not only affects morphological appearance but also changes bio-mass ratio. Leaf growth is usually diminished to a greater extent than root growth, and partitioning of photosynthate is changed to increase root/shoot ratio (Setter, 1990). Water stress due to drought causes major reductions in height, leaf number, leaf area index, fresh and dry weight in plants (Akinci and Losel, 2010) consequently low crop production. Water conservation is therefore an important factor in increasing crop production to overcome food inadequacies (Akinci and Losel, 2012).

Current methods for reducing the effects of annual and inter-annual drought focus on water conservation for irrigated agriculture (Raman *et al*., 1992; Seckler *et al.*, 1999; Ines *et al*., 2002). A better method is to enhance the use of natural soil moisture in rain-fed agro-ecosystems (Di´ az-herna´ ndez and Salmero'n, 2012). The huge yearly variation in yields creates an obvious need for agronomic solutions to close the common and often large negative gap between actual and achievable yields. This is likely to have positive spin-off effects on additional investments in yield increasing inputs such as fertilizers (Wani *et al.,* 2009). Soil management practices which affect soil structure have major influence on most agricultural soil functions including water entry, water transmission, water storage and consequently crop production (Daraghmeh *et al*., 2008). Intercropping enhances ground cover therefore reducing soil surface evaporation to improve soil moisture retention (Walker and Ogindo., 2003; Olasantan, 2007; Ghanbari *et al*., 2010). Soil moisture stress limits the uptake of nutrients therefore the preservation of water is of importance (Okalebo *et al*., 2007). Water limits the potential for realizing soil fertility and plant nutrition (FiBL, 2012). Therefore, soil moisture warrants to be treated as a valuable plant resource.

2.4 Principles of Integrated Soil Fertility Management

Integrated soil fertility management (ISFM) has been defined as a set of soil fertility management practices that include the use of fertilizer, organic inputs and upgraded germplasm combined with the knowledge on how to adapt these practices to local conditions (Vanlauwe *et al*., 2010). This is aimed at maximizing agronomic use efficiency of the applied nutrients to improve crop productivity. All inputs require to be managed following comprehensive agronomic principles (Vanlauwe *et al*., 2010). Land in small holder farms is cultivated nonstop with insignificant if any nutrient returns due to population pressure and resource constrains (Smaling *et al.,* 1997, Swinkels *et al.,* 1997). This results in reduced soil fertility hence diminishing crop yields, food insecurity and environmental degradation. Continued nutrient removal without adequate replenishment depletes soil nutrient reserves. Soil fertility depletion in small holder farms is an important biophysical root cause for declining crop production in sub-Saharan Africa (Sanchez *et al*., 1997). Soil moisture stress resulting from drought restricts crop nutrient uptake therefore the need to conserve water and soil organic matter is of major importance (Okalebo *et al*., 2007). Africa suffers from innate soil degradation, caused by overgrazing, lack of adoption of modern farming technologies, limitation of the farmers ability to replace nutrients lost in the continuous cultivation, annual bush burning, soil and wind erosion among others (Ugboh and Olebor, 2011). Soil fertility is not a static feature as it changes continuously. Its direction, either accumulation or depletion of soil fertility is determined by interaction among physical, chemical, biological and anthropogenic processes (Smaling *et al*., 1997). Hence the need for an integrated approach in soil fertility management that will allow for a build-up of soil fertility despite the low incomes and the increasing land and labour constraints faced by small scale farmers.

2.5 Benefits of Intercropping

Intercropping is a type of mixed cropping that involves farming of two or more crops in the same space at the same time (Hailu, 2015).). It is commonly practiced by smallholder farmers in sub-Saharan Africa. It is an ISFM technology which has intercropping cereals with legumes as one of its main components (Mucheru-Muna *et al.,* 2010; Sanginga and Woomer, 2009). This practice is an attractive strategy to smallholder farmers for increasing crop production and land labour utilization per unit area of available land as it ensures intensification of land use (Seran and Brintha, 2010). Intercropping cereals with legumes have enormous capacity to replace soil mineral nitrogen through its ability to biologically fix atmospheric nitrogen (Giller, 2001). Legumes are plants that bear their seeds in pods. They include desmodium and soybeans among others. Much of the nitrogen they require is obtained through fixation of atmospheric nitrogen by bacteria in nodules on their roots. Inclusion of legumes in cropping systems therefore plays significant role in sustaining soil fertility and improving crop production (Khan *et al*., 2007).

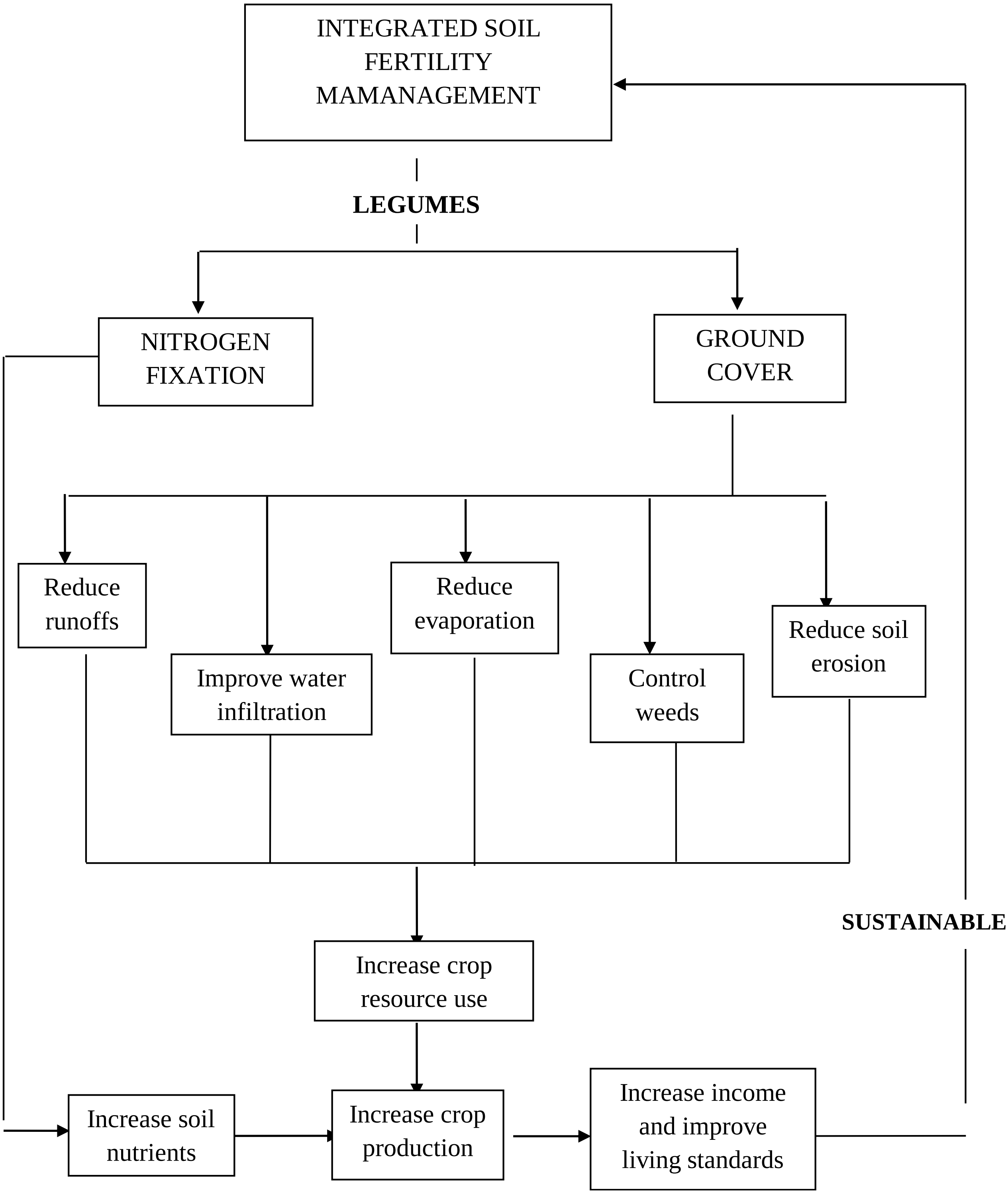


Figure 2.1 Water Dynamics in a Maize/Legume Intercrop

The common crop combinations in intercropping systems in Western Kenya are cereal-legume. Cereal-legume intercropping systems in sub-Saharan Africa have proved effective compared to the monocrops (Okoth and Siameto, 2011). One of the most important reasons for smallholder farmers to intercrop is to avoid total crop failures and to get diverse products for family food and income (Sullivan, 2003). Experiments have shown that intercropping under irrigation improves crop water use efficiency without a significant decline of photosynthetic rate and biomass of the individual crops (Caihong et al., 2015). Intercropping systems use the growth factors more efficiently because they capture more radiation and make better use of the available water and nutrients, reduce pests and diseases, suppress weeds and also improve soil-physical conditions. Specifically, cereal and legume intercrops help in maintaining and improving soil fertility (Sanginga and Woomer, 2009) as well as water use efficiency leading to increase in the use of other plant resources (Hook and Gascho, 1988). Intercropping systems showed some relative benefits over sole cropping when the treatments were of 'replacement' type (Natarajan and Willey, 1986). In this type of intercropping, introduction of a constituent crop is made by replacing another and none of the constituent crops are sown at full population as recommended in their pure stands. Certain percentage of population of one crop constituent is foregone and another constituent is introduced in its place. Competition is therefore relatively reduced between constituent crops as compared to additive types. In an experiment conducted using replacement techniques in different cropping systems of intercropping maize and green grams it was shown that intercropping improved soil moisture (Dahmardeh and Khashayar, 2013).

Soil moisture content was reduced significantly in sole crop of maize in an experiment performed by replacement technique to determine the influence of intercropping maize (*Zea mays* L.) with green gram (*Vigna Radiata* L.) on the changes of soil temperature, moisture and nitrogen (Dahmardeh and Khashayar, 2013). The results indicated that intercropping can increase shading that reduces soil surface evaporation thus conserving soil moisture. Inadequate shading is credited to high soil surface evaporation in sole crop of maize. On the contrary soil moisture content was improved significantly in the sole crop of green gram due to low evaporation as green gram provided better soil cover compared to sole maize. Intercrops use soil water conserved due to shading, reduced wind speed and increased infiltration due to the mulch layers and better soil structure (Dahmardeh and Khashayar 2013; Mobasser *et al*., 2014). Similar observations were made in the study of water budget of rain-fed maize and beans intercrop in which the denser cover with higher leaf area index of the canopy in intercrop was seen to suppress evaporation from the soil surface (Walker and Ogindo, 2003). In a study conducted to compare changes in seasonal water content by rain-fed maize-bean intercrop and component cropping systems in semi-arid region of South Africa it was observed that intercrop did not have significantly dissimilar total soil water extraction, in spite of being additive (Ogindo and Walker., 2005). A study set to determine the effect of maize (*Zea mays* L.)-cowpea (*Vigna unguiculata* L.) intercropping on light distribution, soil temperature and soil moisture in arid environment found that the values of soil water content under sole maize crop were similar to those in cowpea-maize system in a replacement design. The study reported that water intake from soil surface layers increased due to root density in the upper layers, thus reducing water dissipated by evaporation (Ahmad *et al.*, 2010). Maize intercropped with cowpea had a higher land productivity than monocropped cowpea and maize respectively in an experiment that was done to determine the effect of cropping system on soil moisture content, canopy temperature, growth and yield performance of maize and cowpea (Ndiso *et al*., 2017).

When maize was intercropped with Rhizobium inoculated common bean in different planting patterns, maize-legume intercrops had the highest yield advantages with optimum exploitation of the land and environmental resources regardless of the planting patterns (Prosper *et al*., 2017). In the experiment designed to determine optimal sowing date for selected cowpea variety in association with maize in Western Gojam, Ethiopia cowpea intercropped simultaneously with maize had no substantial effect on the yield of maize (Misganaw *et al*., 2015). Similar findings came up in the study conducted to investigate the effects of intercropping on the performance of maize and cowpeas in Botswana in which the number of maize plant cobs and weight of seeds were not affected by intercropping systems (Gabatshele *et al*., 2012). While in the study conducted to monitor soil moisture regime and water use efficiency under maize cowpea cropping system there was no significant difference between the two growing seasons which was attributed to there being similar conditions for growth. However, there were significant differences between the maize-cowpea intercrop and its corresponding sole crops in which intercrops of maize and cowpea had greater water use efficiencies than their component crops (Ofori *et al*., 2014). When two crops are planted together, intra and or inter specific facilitation between plants may occur (Zhang and Li, 2003). When crops differ in the way they utilize environmental resources they can complement each other and make improved resource use when grown together than when grown separately (Ghanbari-Bonjar, 2000). Intercropping enhances crop productivity through more effective plant resource use compared to sole crops (John and Mani, 2005; Eskandari and Ghanbari, 2009).

2.6 Disadvantages of Intercropping

Higher total crop populations in intercrops could result in low crop yield under stress conditions resulting from drought due to increased competition for soil moisture (Hulugalle and Lal, 1986). When two crops are planted together, intra and or inter specific competition between plants may occur (Zhang and Li, 2003). In a study set to determine the effect of maize (*Zea mays* L.)-cowpea (*Vigna unguiculata* L.) intercropping on light distribution, soil temperature and soil moisture in arid environment, additive designs had lower soil water content than replacement design as a result of higher combined use of water by the two crops as it gave full exploitation of the soil moisture profile (Ahmad *et al.*, 2010). Intercropping significantly reduced yield and yield components of cowpea and maize, in an experiment that was done to determine the effect of cropping system on soil moisture content, canopy temperature, growth and yield performance of maize and cowpea (Ndiso *et al*., 2017). Competition among intercrops is a major aspect affecting yield as compared with sole cropping (Ndakidemi, 2006). Planning crop production systems that use available rainfall efficiently is a requirement for improving crop production thus requiring good understanding of crop water use in the context of available rainfall (Mulebeke *et al*, 2010).

2.7 Desmodium

Desmodium is a large trailing and scrambling perennial shrub with a strong taproot. Its long trailing stems can root at the nodes when in contact with moist soil. The stems are grooved, hairy and branch freely. They develop narrow segmented pods holding 8–12 seeds. The segments break up when mature and stick to hair or clothing due to their short-hooked hairs (Heuz'e *et.al.,* 2015). Desmodium is used for long-term pastures although it rarely persists permanently. When desmodium is intercropped with maize it produces repellent volatile chemicals that push away the stem borer moths thus reducing maize stalk borer damage. Additional benefits of *desmodium* include effective control of *striga* weed through suicidal germinations, increased availability of soil nitrogen through biological nitrogen fixation, and soil shading which conserves soil moisture and also prevents soil erosion (Khan *et al*., 2011).

Desmodium can be used in irrigated pastures, conserved as hay and silage, in cut-and-carry systems, and as ground cover where the abundant leaf fall and slow decomposition result in a deep layer under the plants. The technology is suitable to smallholder farmers as it successfully addresses the major maize production constraints that include striga weed infestation (Khan *et al.,* 2009). Maize-desmodium intercropping is based on locally available plants without expensive external inputs therefore economical. It also fits well with traditional mixed cropping systems (Khan *et al.,* 2011). *Desmodium spp.* has been commended severally for reducing striga weed infestation to bellow economic injury levels through suicidal germination (Khan *et al.,* 2008, 2009; Odhiambo *et al.,* 2009).

2.8 Soybeans

Soybean is an annual plant with erect stems covered with thick brownish hair. The leaves are alternate, trifoliate with ovate leaflets and short peduncles, the basal ones are simple. The flowers are white or white-violet in 5-6 cm long clusters. The fruits are pods of up to 7 cm long with 1 - 4 seeds inside. Excess water during vegetative period retards growth of soybeans since it requires well-aerated soils to grow vigorously (Geoffrey *et al*., 1998).

Soybean is good for human food as it is rich in nutrients, that is, high in fibre content, high in protein, low in saturated fat, good source of omega-3 fatty acids, a source of antioxidants and high in phytoestrogens (Garima et.al., 2020). It is a source of vegetable oil extraction. Soybean cake is an excellent livestock feed, especially for poultry. The haulms provide feed for livestock. Soybean is among the major industrial and food crops grown effectively using low agricultural inputs (Dugje *et al.,* 2009)**.** Industrial demands for soybean products remain growing. The market for soybean is rising very fast with prospects for improving the income of farmers. Kenya imports huge quantities of soybean hence the need for adequate measures to be taken to promote domestic soybean production to meet the local demand (Woomer and Mulei., 2015). Soybean improves soil fertility and controls striga weed which is a major deterrent to maize production in the region (Dugje *et al*, 2009). Addition of nitrogen to the soil by this legume is considered to lessen the adverse effects of striga weed on maize crop and also lowers the amount of striga weed supported by maize by causing suicidal germination of the weed (Khan *et al*., 2007). This increases maize production and land labour utilization per unit area of available land as it ensures intensification of land use. Smallholder farmers can therefore avert total crop failures and also get diverse products for family food and income to better their living standards.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Characterization of Study Sites

Western Kenya, which is part of the Lake Victoria Basin, is found at altitude of between 900-1800m above sea level. It is one of the rural areas with the highest human population densities in the country with reported human densities of over 500 persons per square kilometre. Annual rainfall ranges from 950 to 1500 mm with a bimodal distribution (GoK, 2013). The project was conducted in two sites – Busia and Vihiga. The study sites were selected because of their distinct soil types and therefore soil conditions, and also distinct weather patterns. This provides reasonable grounds for generalizing the research findings.

Soils in Busia site are friable, brown Ferralsols of sandy clay loamy texture with moderate depth due to underlying hard-pans over petroplinthite (depth of 50-80 cm to murram). Soil fertility is low and water holding capacity moderate (MoA, 1982). The study site was Esirisia village of Bukhayo West Location in Matayos Sub County of Busia County (N00.42745 E034.17609 at Altitude 1216) (GPS readings). Figure 3.1 shows the 30 years average rainfall and temperature for the Busia site.

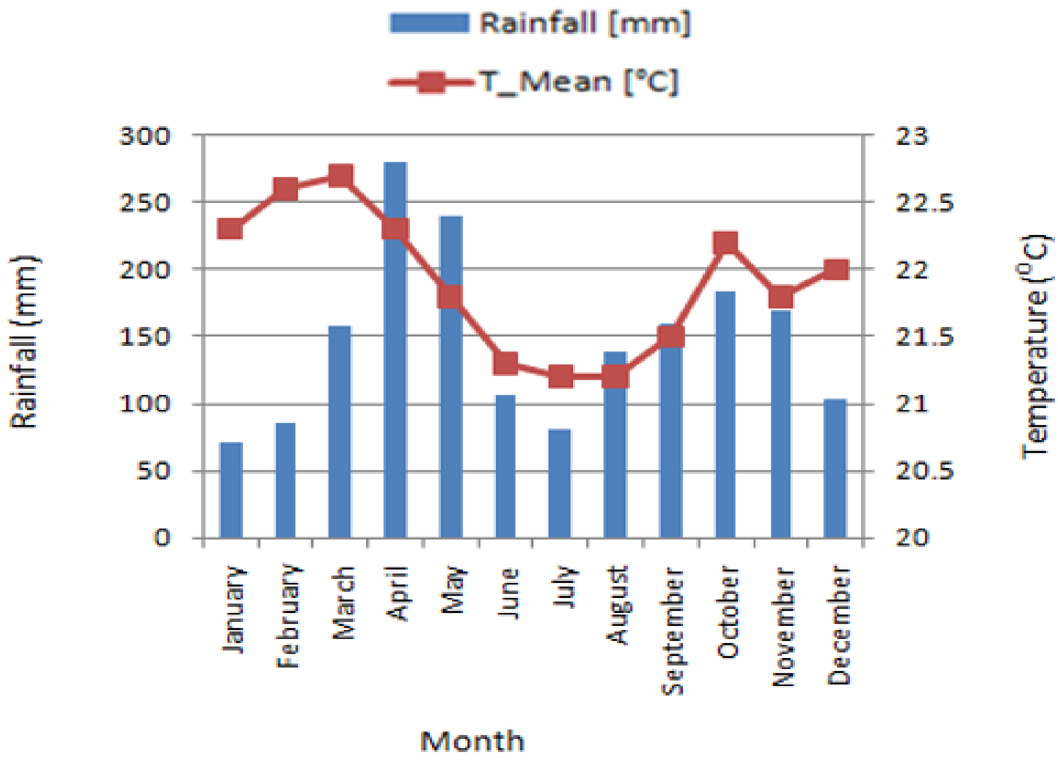


Figure 3.1 Busia site long term (30 years average) rainfall and temperature (FAO, 2002)

The long term thirty years annual average temperature of Busia site is 22° C (MoA, 1982; FAO, 2002). High long-term temperatures are experienced in the months of January to March whereas low long-term temperatures occur in the months of June to August (Figure 3.1). The region's annual rainfall ranges from 950 mm to 1500 mm with a bimodal distribution (GoK, 2013). The peak of the first rainfall season occurs in the months of April/May while the peak for the second season occurs in the months of October/November (Figure 3.1).

Soils at the Vihiga site is deep, well drained, dark red, friable to firm Acrisols of clay texture. The soils have undergone leaching and therefore low in fertility and with moderate water holding capacity (MoA, 1982). The study site was Chamasilihi Village of Lyaduywa Location in Sabatia Sub County of Vihiga County (N00.09945 E034.72079 at Altitude 1543) (GPS readings). Figure 3.2 shows the 30 years average rainfall and temperature for the Vihiga site.

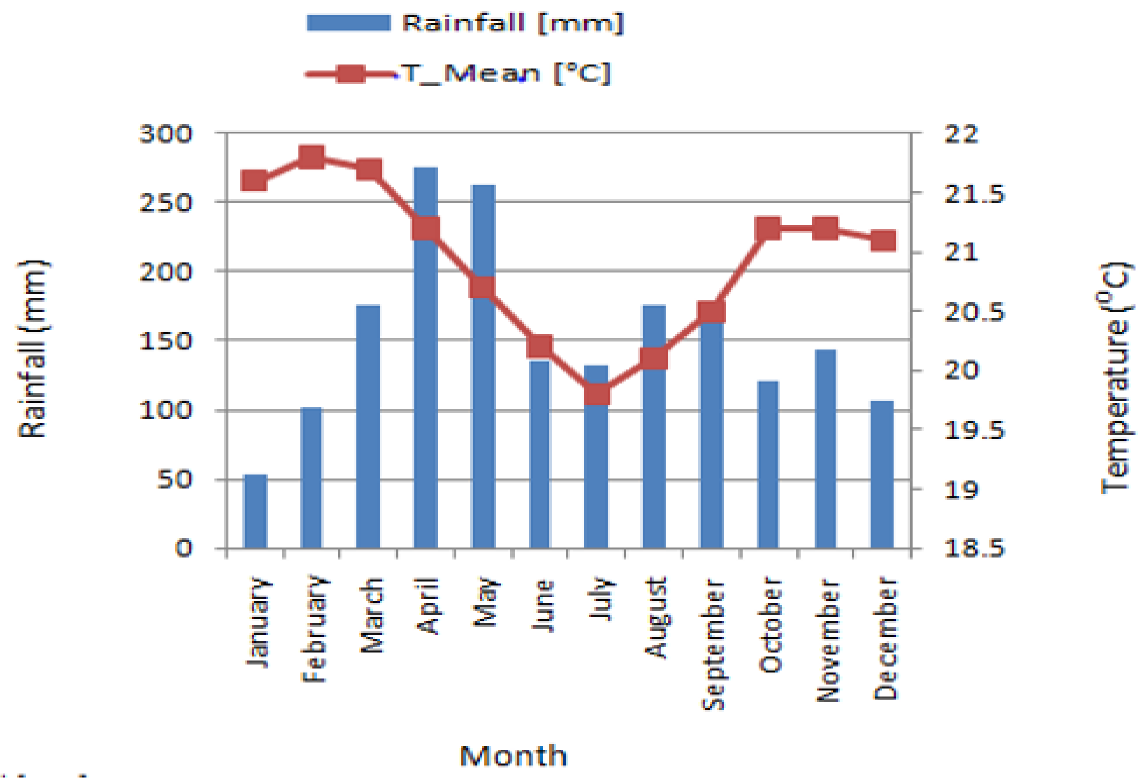


Figure 3.2 Vihiga site long term (30 years average) rainfall and temperature (FAO, 2002)

The annual thirty years long term average temperature of Vihiga site is 19° C (MoA, 1982; FAO, 2002). High average long-term temperatures are experienced in the months of January through to March whereas low average long-term temperatures occur in the month of July (Figure 3.2). The peak of the first rainfall season occurs in the months of April/May while that for the second season occurs in the months of August/September (Figure 3.2).

Soils at both Busia and Vihiga experimental sites were sampled for characterization. Each experimental plot was divided into four parts from which four sub samples were collected randomly. Soils were sampled by taking five soil cores (diameter of 5 cm) to a depth of 0–20 cm using soil auger following a systematic 'W' scheme and bulking them per site. The soils were then sieved through 2 mm and air-dried. Soil pH was determined in a 1:1 (w/v) soil-water suspension using a pH-meter. Phosphorous was determined using the available P (Double Acid Method) where oven-dried samples at 40^0 C were extracted in a 1:5 ratio (w/v) with a mixture of 0.1 N HCl and 0.025 N H_2SO_4. Available P was determined using Atomic Absorption Spectrophotometer (AAS). Total nitrogen was determined by digesting soil samples with concentrated sulphuric acid containing potassium sulphate, selenium and copper sulphate hydrated at approximately 350^0 C. This was then distilled and titrated with H_2SO_4. Exchangeable Ca, Mg, and K were determined by leaching soil samples with 1N ammonium acetate buffered at pH 7. The leachate was analyzed for exchangeable Ca, Mg and K. K was determined with a flame photometer whereas Ca and Mg was determined using Atomic Absorption Spectrophotometer (AAS) (Okalebo *et. al*., 2002).

3.2 Experimental Design and Treatments

A randomized complete block design (RCBD) was adopted in both Busia and Vihiga experimental sites (Figure 3.3). Each experimental plot measured 6m x 5m ($30m^2$) with paths of 1m in between them. The treatments were Maize monocrop (M), Maize - Desmodium intercrop (MD) and Maize - Soybean intercrop (MS) as laid down in Figure 3.3. Intercropping maize with soybeans and with desmodium are new technologies that have shown good control of striga weed.

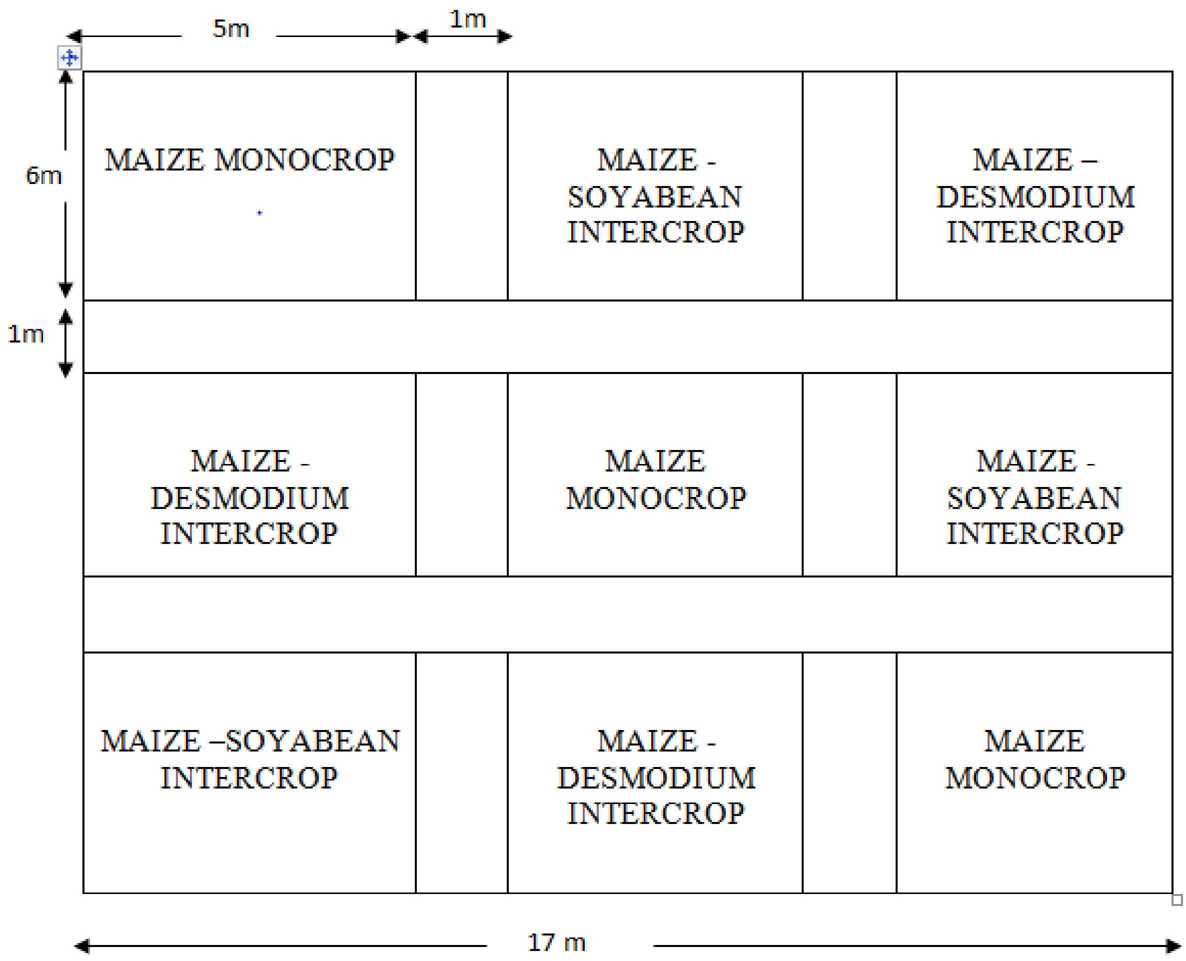


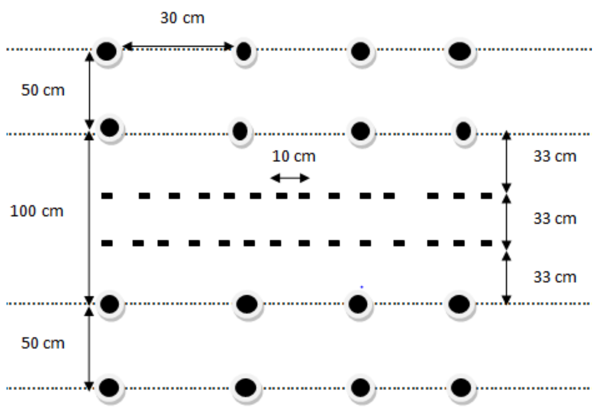
Figure 3.3 Field Experimental layouts

Maize (*Zea mays* L.) variety used was Freshco (FRC 425 IR) produced by Freshco Kenya Ltd. This is herbicide resistant maize seed coated with *imazapyr* herbicide that controls striga weed. The study areas were infested with *striga* weed therefore this was to prevent confounding effects that could have arisen from *striga* weed infestation. Soybeans (*Glycine max* (L.) Merrill) variety HB 19 inoculated with Rhizobium inoculant (Biofix) and Desmodium (*Desmodium intortum* (Mill.) Urb) were planted. Soybean seeds were inoculated at planting time. Inoculation process involved adding 30 g of gum arabic to 300 ml of clean lukewarm water and mixing thoroughly to form sticker. This amount of sticker was then added to 15 kg of soybean seed. The seeds and sticker solution were thoroughly mixed until all the seeds were evenly coated. Rhizobium inoculant was then added onto the mixture of seeds and sticker and mixed thoroughly until all seeds were uniformly covered with the inoculant. Inoculated seed was then protected from direct sunlight by keeping in the shade until planted. The soybean seeds were measured in ratios of 15 kg for purpose of inoculation. Several 15 kg soybean seed units were inoculated to obtain sufficient seed to plant all the intended plots.

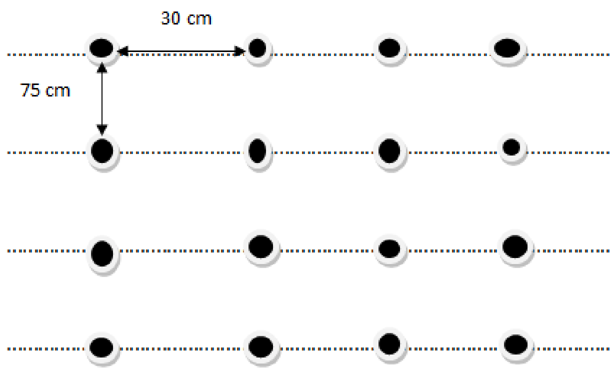
3.3 Land Preparation and Planting

Land was cultivated when dry in each season at both sites to obtain a medium soil tilth. Soil tillage was aimed at weed control, incorporation of residue, reduction of wind and water erosion and improving soil structure. This optimises water infiltration and minimises water evaporation. Hand hoe was used. Season I planting in Busia and Vihiga sites was done on the 7th day and 13th day of May 2015 respectively. While season II planting was done on the 12th day and 17th day of October 2015 for Busia and Vihiga sites respectively. Fertilizer rating of 21 Kg P ha^{-1} was applied at planting time to provide the recommended phosphorous for the maize crop therefore ensuring that fertility was not a factor in the resulting differences. It was applied as DAP (18:46:0) fertilizer. Fertilizer was applied in each plot by distributing it equally in the planting holes and mixing thoroughly with soil to avoid seed scorching.

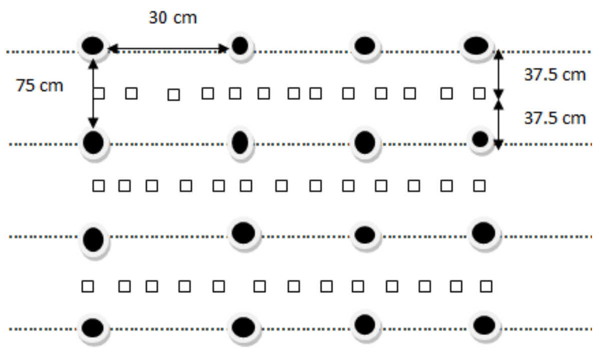
Planting holes in Maize-soybeans intercrop were made using hand hoe at a spacing of 50cm between adjacent maize rows and 30cm within rows. Every set of adjacent two rows of maize were separated by a 100cm space (Figure 3.4a). Marking was done in each experimental plot using a garden line. Two maize grains were sown in each hole and covered slightly with soil. Two rows of open furrows of about 2cm depth spaced at 33cm within the 100cm space (Figure 3.4a) for planting soybeans were made using strong pointed sticks. Inoculated soybean seeds were sown by drilling in these rows.



(a) Spacing in Maize-soybeans



(b) Spacing in Maize monocrop



(c) Spacing in Maize-desmodium

Key

● Maize

□ *Desmodium*

▬ Soybeans

Figure 3.4 Crop spacing in the treatments

In maize monocrop planting holes were also made using hand hoe at a spacing of 75x30cm (Figure 3.4b) marked in each experimental plot using a garden line. Two maize seeds were sown in each hole and covered slightly with soil. While in maize-desmodium intercrop planting holes were made using hand hoe at a spacing of 75x30cm (Figure 3.4c) marked in each experimental plot using a garden line. Two maize grains were sown in each hole and covered slightly with soil. Desmodium seed was drilled at a spacing of 37.5cm in furrows of about 1cm deep made in the middle of the space between the rows of maize (Figure 3.4c) using strong pointed sticks.

3.4 Crop Management

First weeding in both seasons, I and II at Busia and Vihiga sites and thinning of maize plants were carried out on the 25th Days After Sowing (DAS). Second weeding was done on the 35th DAS. Weeding was done by cultivation using hand hoe and thinning done by uprooting the excess maize plants during first weeding to obtain one plant per hill. For hills without a maize plant, thinning was done to leave two plants on each side of the gap. Thinning was done to achieve a maize population of 128 plants in each experimental plot. This translates to the recommended 44,000 maize plants ha^{-1} for pure maize stand. The crop was top-dressed with 60 kg N ha^{-1} using CAN 26% fertilizer. Fertilizer was evenly spread around the maize plants at 40th day after sowing. In the two seasons at both sites there were no disease and pest incidences.

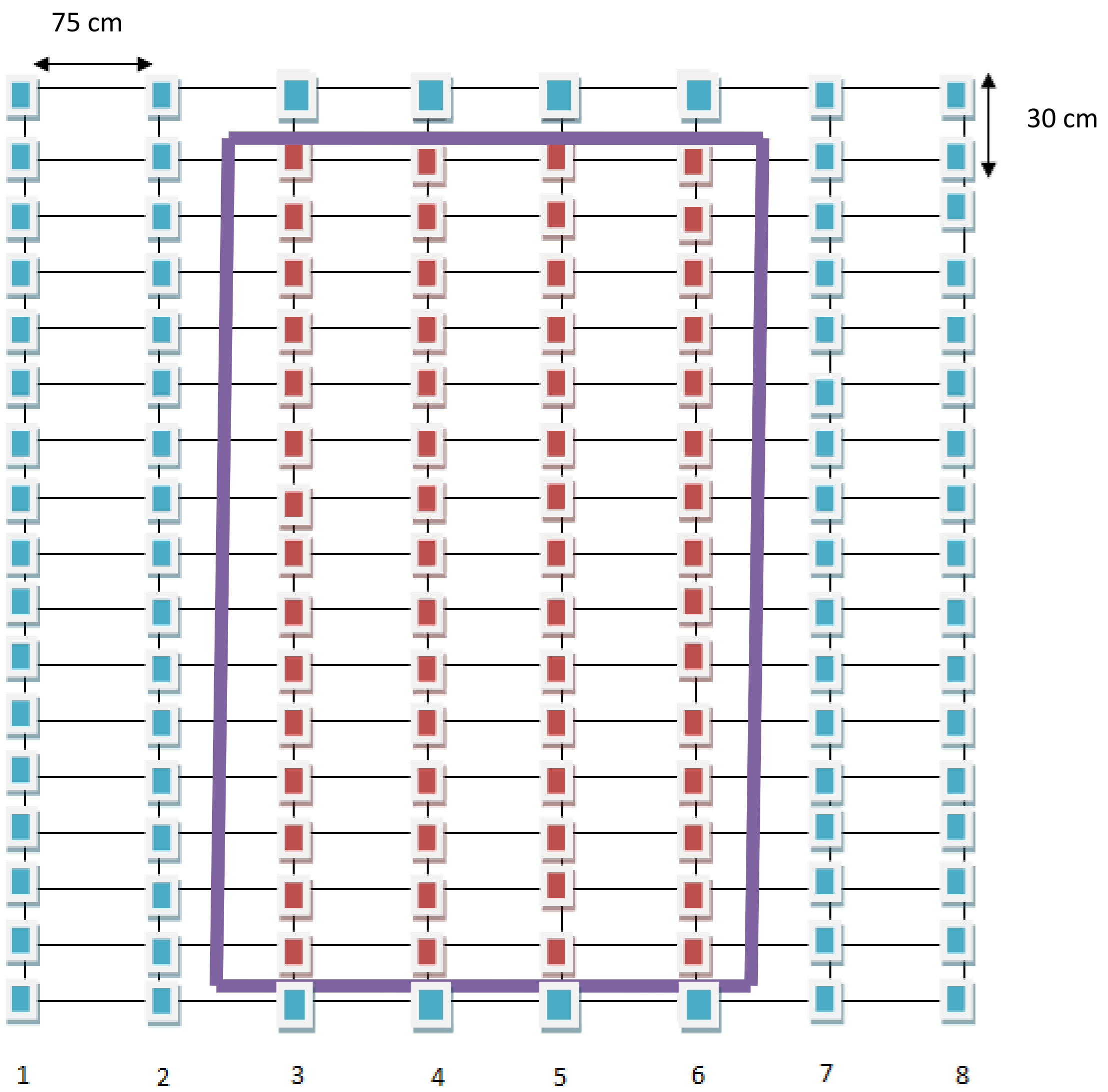
3.5 Collection of Data

3.5.1 Seasonal Rainfall

On-site rainfall data was collected using rain gauges installed at both Busia and Vihiga sites at no more than 200 metres from the experimental plots. Reading and recording was done by the owner of the farm in a template designed for recording purpose. The rainfall data records (Appendices 1 and 2) were checked during site visits.

3.5.2 Soil Moisture Measurement

Collection of data on soil moisture content started after the 40th day after sowing (DAS). This is the point at which maize plant canopy is fully established for enhanced moisture demands (Magwanga, 2014). The leaf area is well developed and the canopy is exposed to high atmospheric evaporative demand. Water requirement of maize crop is low at early growth stages then reaches on peak at reproductive growth stages and during terminal growth stages requirement of water again lowers down (Muhammad *et.al.*, 2015). Data was collected on a 7 days interval including tasselling and silking stages of the maize. It was done on a net plot area of 15 m^2 in each experimental plot (Figure 3.5).



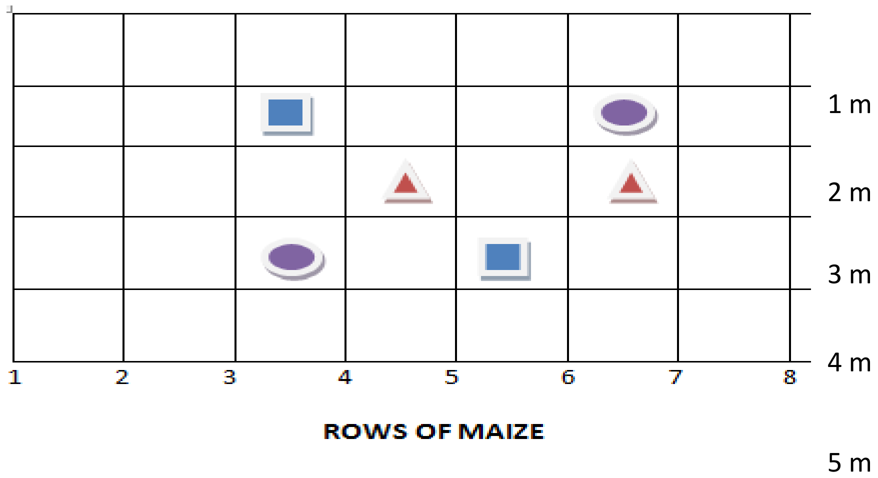
ROWS

Key Guard row plants

Net plot area boundary

Figure 3.5 Net plot areas for data determination

Holes measuring 20cm and 40cm deep with diameters of 11 cm were dug in each experimental plot using soil auger and fitted with plastic containers slit-open at the bottom. The container lids were left on to prevent direct rainfall and runoffs into the holes dug. Two samples of soil moisture measurements were taken at each depth at the indicated points spread in maize monocrop and maize-desmodium intercrop experimental plots (Figure 3.6) and in the maize-soybeans intercrop experimental plots (Figure 3.7). In maize-soybean intercrop experimental plots soil moisture content measurements were taken at maize-maize; maize-soybean; and soybean-soybean interspaces. Soil moisture content measurements were made by inserting the four- 5cm long steel rods of the theta probe equipment into the soil at 5cm depth, 25cm depth and 45cm depth. When taking soil moisture content measurements, the lids of the plastic containers were opened to allow access of the probe equipment to the 25cm depth in the 20cm deep hole and 45cm depth in the 40cm deep hole. The lids were placed back after taking the soil moisture measurements. Theta probe equipment measures volumetric soil moisture content which is a ratio between the volume of water present and the total volume of the sample. Soil moisture content measurement was read on the screen of the theta probe equipment when the rods were inserted into the soil.



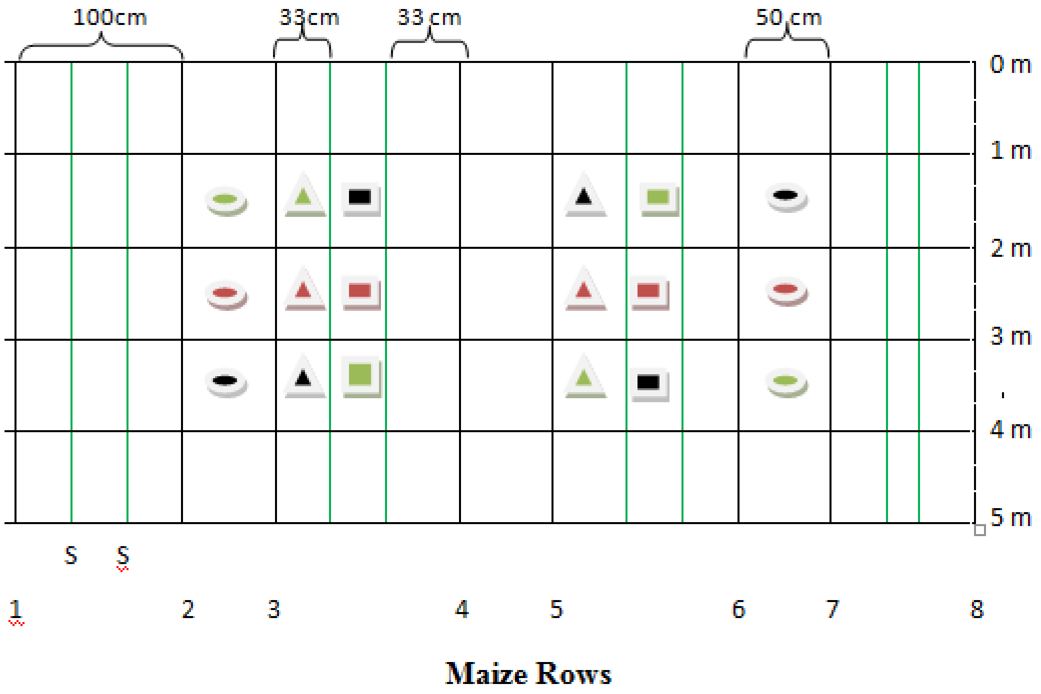
Key

5cm depth

25cm depth

45cm depth

Figure 3.6 Layout for soil moisture data collection points in maize monocrop and maize-desmodium intercrop



Key

Maize-maize 5cm depth

Maize-maize 25cm depth

Maize-maize 45cm depth

Maize-soya 5cm depth

Maize-soya 25cm depth

Maize-soya 45cm depth

Soya-soya 5cm depth

Soya-soya 25cm depth

Soya-soya 45m depth

S Soya row

Figure 3.7 Layout for soil moisture data collection points in maize-soya intercrop

3.5.3 Crop Yield

At physiological maturity, maize and soyabeans were harvested and their individual yields per plot established by weight (Table 3.1). This was done on net plot areas of 15m^2 for all treatments and replications.

Table 3.1: Yield in Kg ha^{-1} for Busia and Vihiga sites seasons I and II

SEASON	TREATMENT	AVERAGE YIELD IN KG/HA.		
		MAIZE	SOYBEANS	DESMODIUM
BUSIA I	Maize monocrop (M)	4332		
	Maize-Soybeans (MS)	4231	314	
	Maize-Desmodium (MD)	4684		273
BUSIA II	Maize monocrop (M)	1169		
	Maize-Soybeans (MS)	1300	38	
	Maize-Desmodium (MD)	1055		3255
VIHIGA I	Maize monocrop (M)	6222		
	Maize-Soybeans (MS)	4733	382	
	Maize-Desmodium (MD)	5840		697
VIHIGA II	Maize monocrop (M)	2650		
	Maize-Soybeans (MS)	3156	519	
	Maize-Desmodium (MD)	564		3136

The weight of maize ears harvested at physiological maturity from the net plot area was measured and samples collected randomly from it. The sampled ears were shelled and their moisture content measured using a grain moisture tester. Grain weight was then standardized by adjusting to 15.5% moisture content and expressed in t/ha (Lauer, 2002).

$$\text{Ton/Ha} = \left\{ (\text{Wt of ears in Kg} \div \text{Factor from table}) \div (\text{Net plot area m}^2 \text{ x } 0.00025) \right\} \div 14.87$$

Soybeans were also harvested at physiological maturity by uprooting entire plants. These were then threshed and the grains weighed. Grain moisture content was measured using the grain moisture tester and the yield standardized at 13% moisture content and expressed in t/ha (Lauer, 2002).

$$\text{Ton/Ha} = \left\{ \text{Grains Kg} \div \left[\left\{ 27.21552 \text{ x } (1 - 0.13) \right\} \div \left\{ \text{Net plot area m}^2 \text{ x } 0.00025 \right\} \right] \right\} \div 14.87$$

Desmodium was harvested by cutting down at 10cm above the ground using hand sickle at late flowering stage from net plot areas of $15m^2$ and weighed. Samples were taken from the harvest and DM content determined after oven drying at 80 ^{0}C for 24 hours. The resultant DM (Table 3.1) was then used to calculate the desmodium yield in t/ha.

$$\text{DM} \quad \text{Ton/Ha} = \left(666.7 \times \left(\frac{k}{x}\right) h\right) \div 1000$$

Where x = Fresh weight of sampled harvest (kg)

h = Dry weight of sampled harvest (kg)

k = Fresh weight of harvest in $15m^2$ (kg)

The study adopted the use of crop energy yield values as a means of standardising the yields of maize, desmodium and soybeans into a common unit for comparison purpose (Tsubo *et al*., 2004). Bomb Calorimetry was used to determine energy yields of maize, soybean and desmodium (Parr, 2007). Sample crop energy yields were then converted into energy yields per hectare.

Sample materials from the field (Maize and soya grains, and desmodium foliage) were dried before picking test samples using standard sampling, grinding, mixing and subdividing procedures to obtain working samples. Three independent measurements of the benzoic acid standard were carried out using 1.20g of benzoic acid made into pellets embedded in a 10cm firing cotton thread.

Ground samples of maize, soybeans and desmodium measuring 0.5g were weighed out using analytical balance. The samples were then made into pellets with a 10cm firing cotton thread embedded using a pellet press. The pellets were then carefully placed in the sample cup with tweezers for the individual firings. Nickel chromium fuse wire measuring 10cm was weighed. The bomb head was then set in the support stand and the length of the fuse wire attached. The wire was inserted through each eyelet and the caps slid downward to complete the connection. The sample cup (with the sample sitting in the centre of the cup) was then placed in the cup holder and the cotton tied to the firing wire without the wire touching the cup. The bomb assembly was closed by sliding the head assembly into the bomb cylinder, screwing open the vent cap on the head assembly to allow air to be expelled, and pushing the head down into the cylinder. The vent cap was then closed tightly to prevent oxygen leaks.

The bomb was carefully secured in the bench clamp and the oxygen tank connection hose slipped on to the pin on the head assembly. The oxygen tank valve was opened followed by the regulator valve slowly to raise the bomb pressure to 25 bars. Thereafter the control valve followed by the tank valve was closed. The quick-release valve was then used to quickly remove the oxygen tank connection to minimize oxygen escape. Operation of the calorimeter involved removal of the lid and placing it on the ring stand with the bucket resting in the jacket. The bucket was then filled with water to a total weight of 2600g. The charged bomb was placed in the bucket by resting it on the raised circular area on the bottom of the bucket. The ignition wire was then connected to the terminal socket on the bomb head and the stirrer turned by hand to be sure that it runs freely, and then the drive belt slipped onto the pulley. Thermometer sensor probes were inserted into the calorimeter top so that the end of the sensors touched the water. The two lead wires on the ignition unit were connected to the calorimeter and the calorimeter, ignition unit and timer plugged in. The stirrer was left to run until the temperatures of the jacket and calorimeter vessel stabilised and became constant. This was the initial temperature reading. The bomb was then fired by pressing the ignition button and holding it down for about 5 seconds (until the light went out). Satisfactory firing was checked by the TEST switch which was no longer lighting. The apparatus was then left for 8 to 10 minutes to obtain its final equilibrium temperature which was recorded. After the last temperature reading, all the electrical connections were turned off, the drive belt removed, and the cover placed in the support ring. The ignition wire was then removed from the bomb, and the bomb lifted out of the bucket. Excess water was then wiped off. The valve cap was opened and the bomb in the hood discharged. The cap was then unscrewed, the head lifted out of the cylinder, and placed on the support stand. Unburned fuse wire still attached to the electrodes and pieces of molten wire was weighed.

Energy equivalent value (kJ) of the bomb calorimeter was established by standardization using benzoic acid. The bomb calorimeter energy equivalent value was then used to determine the gross heat of combustion (kJ) for the maize, soybeans and desmodium. Corrections for acids and fuse were omitted to obtain relative energy values.

$$W = \frac{\mathrm{S\ X\ H}}{\mathrm{T}}$$

Where

W = Energy equivalent of the calorimeter (kJ)

S = Weight of standard benzoic acid (g)

H = Heat of combustion of benzoic acid= 6318 cal/g

T = Temperature rise (^{o}C)

$$Hg = \frac{\mathrm{R\ X\ W}}{\mathrm{D}}$$

Hg = Gross heat of combustion (kJ)

R= Rise in temperature of burnt sample (^{o}C)

D= Weight of sample burnt (g)

The total maize, soybeans and desmodium energy yields per hectare was then used to calculate rainfall use efficiencies (RUE) for each of the treatments (Zahoor *et al*., 2015).

Maize monocrop $\Longrightarrow RUE\ (\frac{kJ}{ha}.mm) = \frac{\text{Total maize energy yield } (\frac{\text{kJ}}{\text{ha}})}{\text{Total rainfall (mm)}}$

MD intercrop $\Longrightarrow RUE\ (\frac{kJ}{ha}.mm) = \frac{\text{Total maize and desmodium energy yield } (\frac{\text{kJ}}{\text{ha}})}{\text{Total rainfall (mm)}}$

MS intercrop $\Longrightarrow RUE\ (\frac{kJ}{ha}.mm) = \frac{\text{Total maize and soybean energy yield } (\frac{\text{kJ}}{\text{ha}})}{\text{Total rainfall (mm)}}$

3.6 Statistical Analysis of Data

One way Analysis of variance (ANOVA) was used to determine whether the treatments had effect on soil moisture trends, maize energy yield and rainfall use efficiency at 5% level of significance. R software version 3.1.2 was used for data analysis. Further Tukey honestly significant difference (HSD) at 5% was used to separate the treatment means that were statistically different.

CHAPTER FOUR

RESULTS

4.1 Site Soil Characterization

The soils at the two sites were generally low in total Nitrogen %, total Organic Carbon % and in Phosphorus which are vital for crop production (Table 4.1) therefore the need to apply fertilizers and prevent soil fertility from becoming a factor in result differences.

Table 4.1 Nutrient status of Busia and Vihiga sites

Soil Analytical Data		
	Busia Site	**Vihiga Site**
Parameter	**Value**	**Value**
Soil pH	5.26	5.57
Total Nitrogen %	0.05	0.07
Total Org. Carbon %	0.47	0.64
Phosphorus ppm	10	20
Potassium me %	0.40	0.42
Calcium me %	2.0	2.0
Magnesium me %	0.74	1.00
Manganese me %	0.45	1.12
Copper ppm	3.31	11.3
Iron ppm	46.2	49.8
Zinc ppm	1.05	10.0
Sodium me %	0.16	0.18

4.2 Rainfall Amounts in Busia and Vihiga Sites

Total monthly rainfall recorded for the period of the study (May 2015-January 2016) in Busia site and the historical long term monthly average rainfall (FAO, 2002) is as shown in Figure 4.1. Rainfall amount recorded in season I production period was 402 mm and in season II it was 768 mm. More rainfall was realised during season II (September 2015-January 2016) as compared to season I (May-August 2015) at this site during the study period. Recorded rainfall in the study period was relatively lower during season I and higher in season II as compared to the historical monthly rainfall averages for the same periods. Figure 4.2 shows monthly rainfall amounts recorded for the period of the study in Vihiga site and the historical long term average monthly rainfall (FAO, 2002). Rainfall amount recorded in season I production period was 421 mm while in season II it was 1352.5 mm. More monthly rainfall was realised during season II (September 2015-January 2016) than in season I (May-August 2015) at this site. Monthly rainfall recorded during the study period was relatively lower during season I than in season II as compared to the historical monthly rainfall averages for the same period. Peak monthly recorded rainfall for November and December was almost four times that of long-term monthly rainfall average at this site (Figure 4.2).

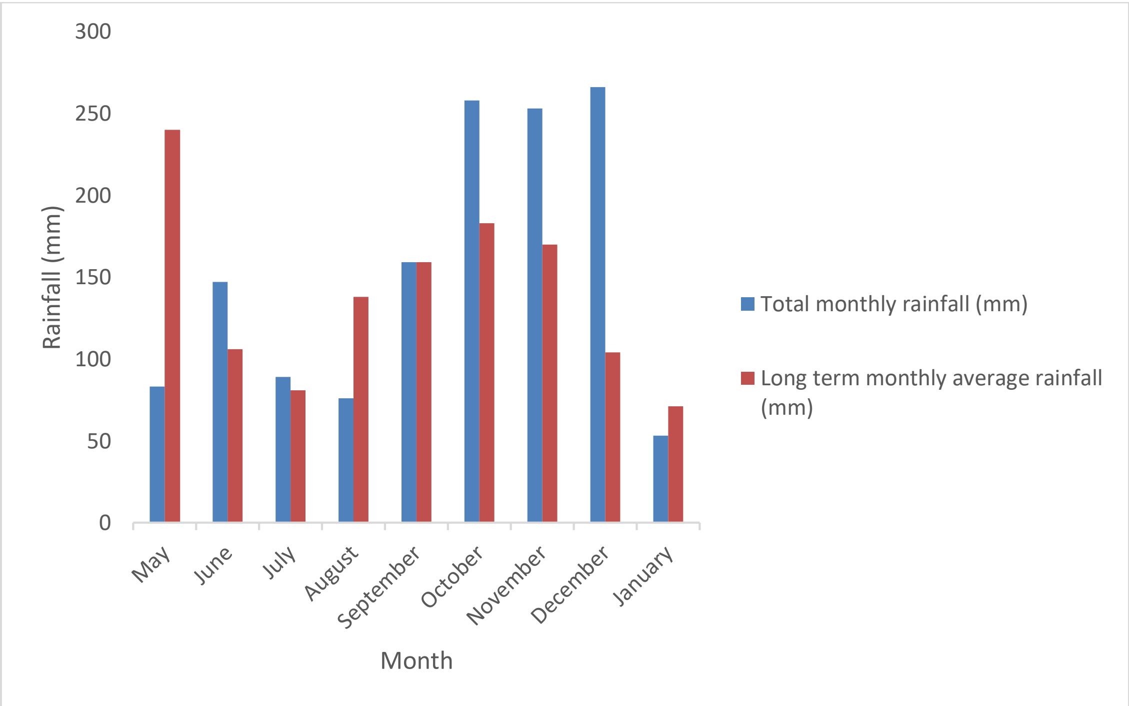


Figure 4.1: Total monthly rainfall for Busia site (May 2015-January 2016) compared to long term monthly rainfall averages

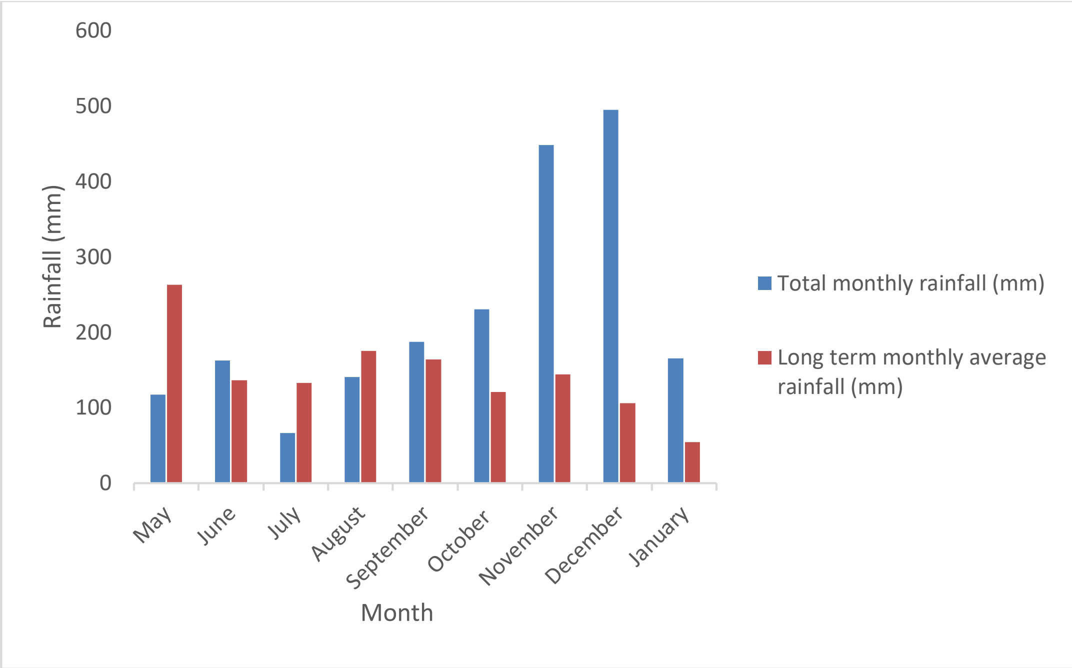


Figure 4.2: Total monthly rainfall for Vihiga site (May 2015-January 2016) compared to long term monthly rainfall averages

4.3 Soil Moisture Content Trends in Busia Site

4.3.1 Season I (May-August 2015)

Soil moisture content differences seen in the cropping systems in Busia site in season I (Figure 4.3) were not significant.

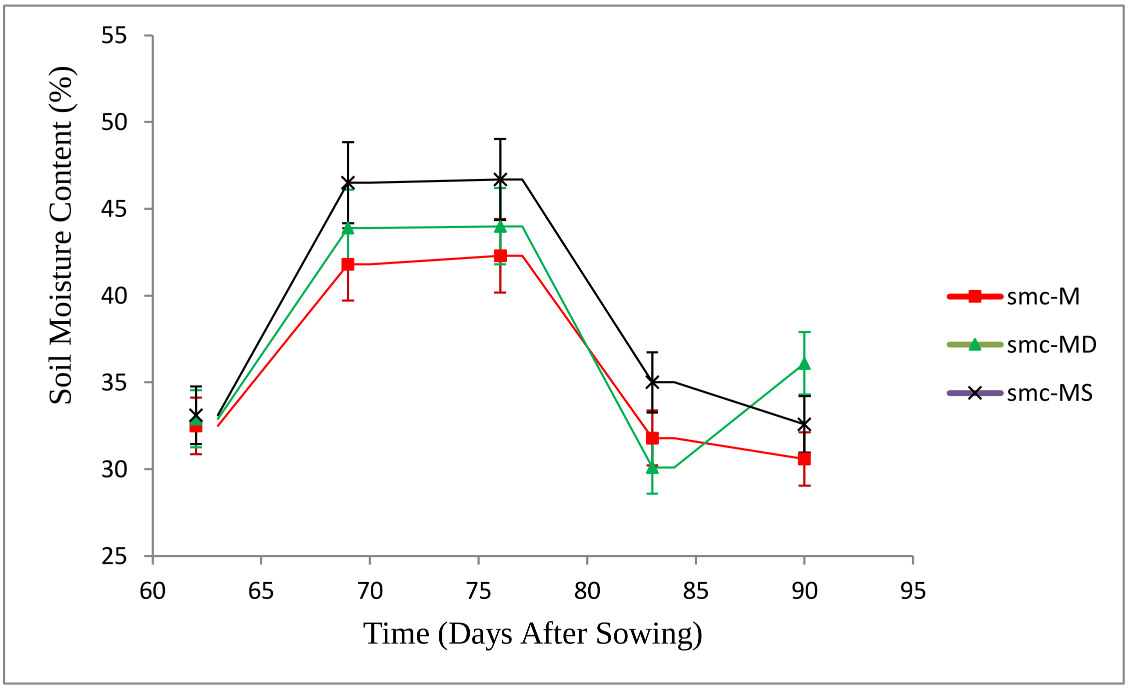


Figure 4.3 Graph of soil moisture content against time in Busia season I

4.3.2 Season II (September 2015-January 2016)

During season II in Busia site the differences in soil moisture content (Figure 4.4) were only significant on the 72nd DAS. This was observed between M and MD; and MS and MD. In MD a moisture content of 41.4% was recorded, while in M and MS 31.7% and 31.3% moisture content was recorded respectively. MD intercropping recorded significantly higher soil moisture content than the other two cropping systems.

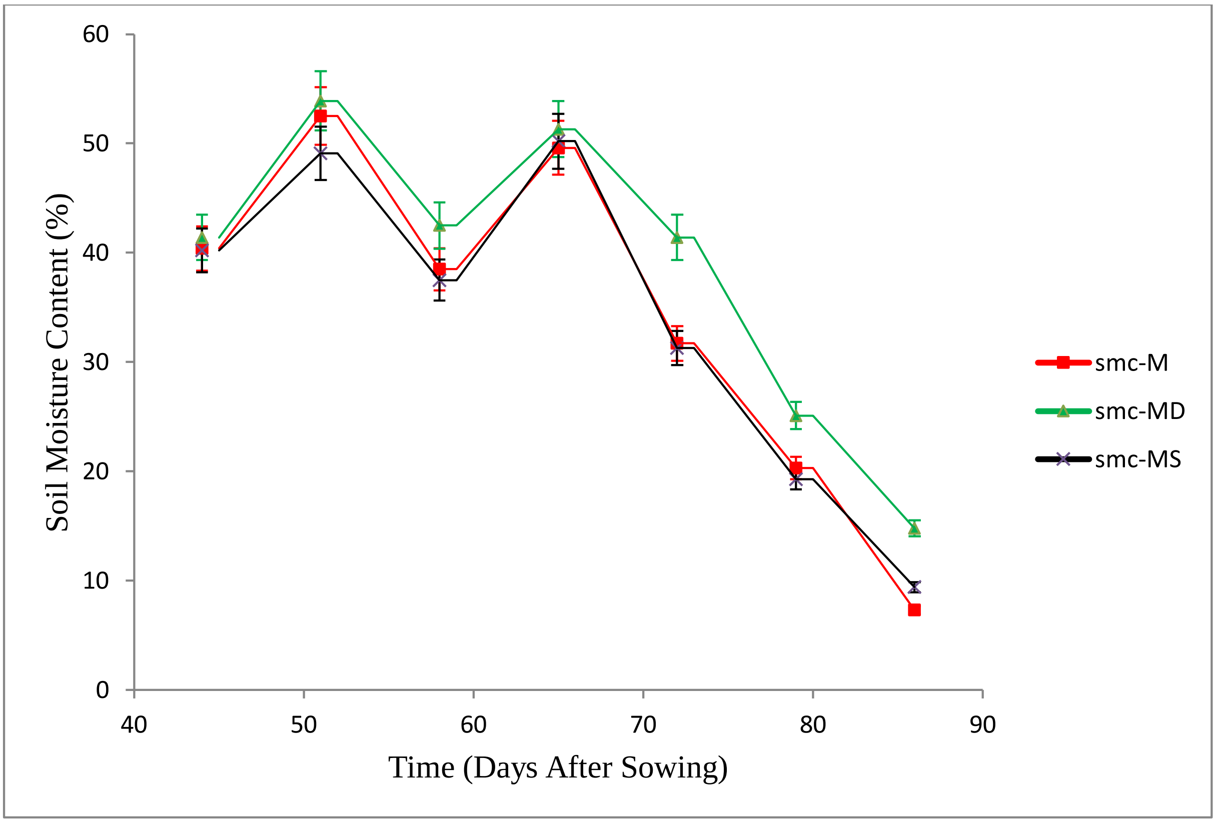


Figure 4.4 Graph of soil moisture content against time in Busia season II

4.4 Soil Moisture Content Trends in Vihiga Site

4.4.1 Season I (May-August 2015)

The differences in soil moisture content recorded in the cropping systems in Vihiga season I (Figure 4.5) were not significant.

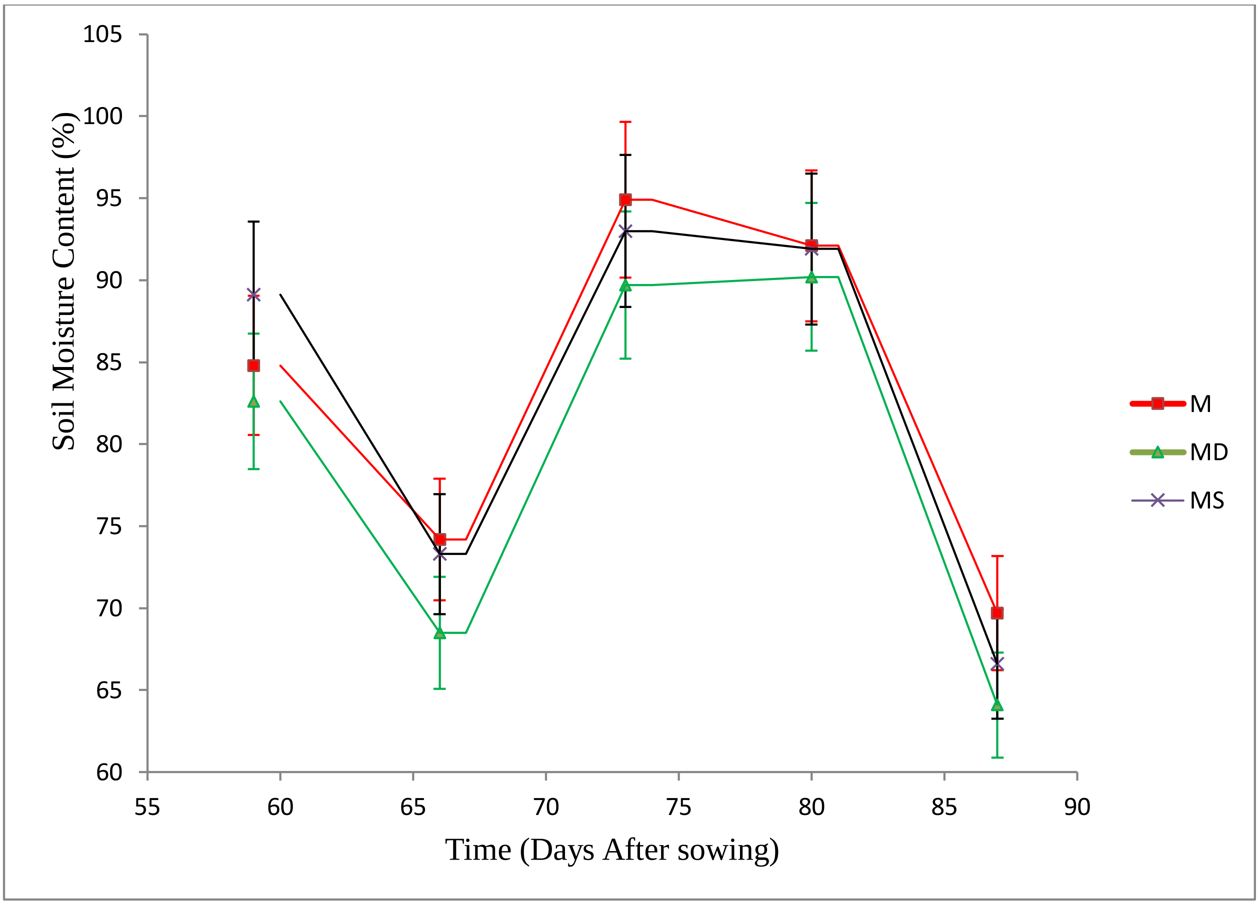


Figure 4.5 Graph of soil moisture content against time in Vihiga season I

4.4.2 Season II (September 2015-January 2016)

During season II in Vihiga site the soil moisture content recorded in the three cropping systems (Figure 4.6) were not significantly different.

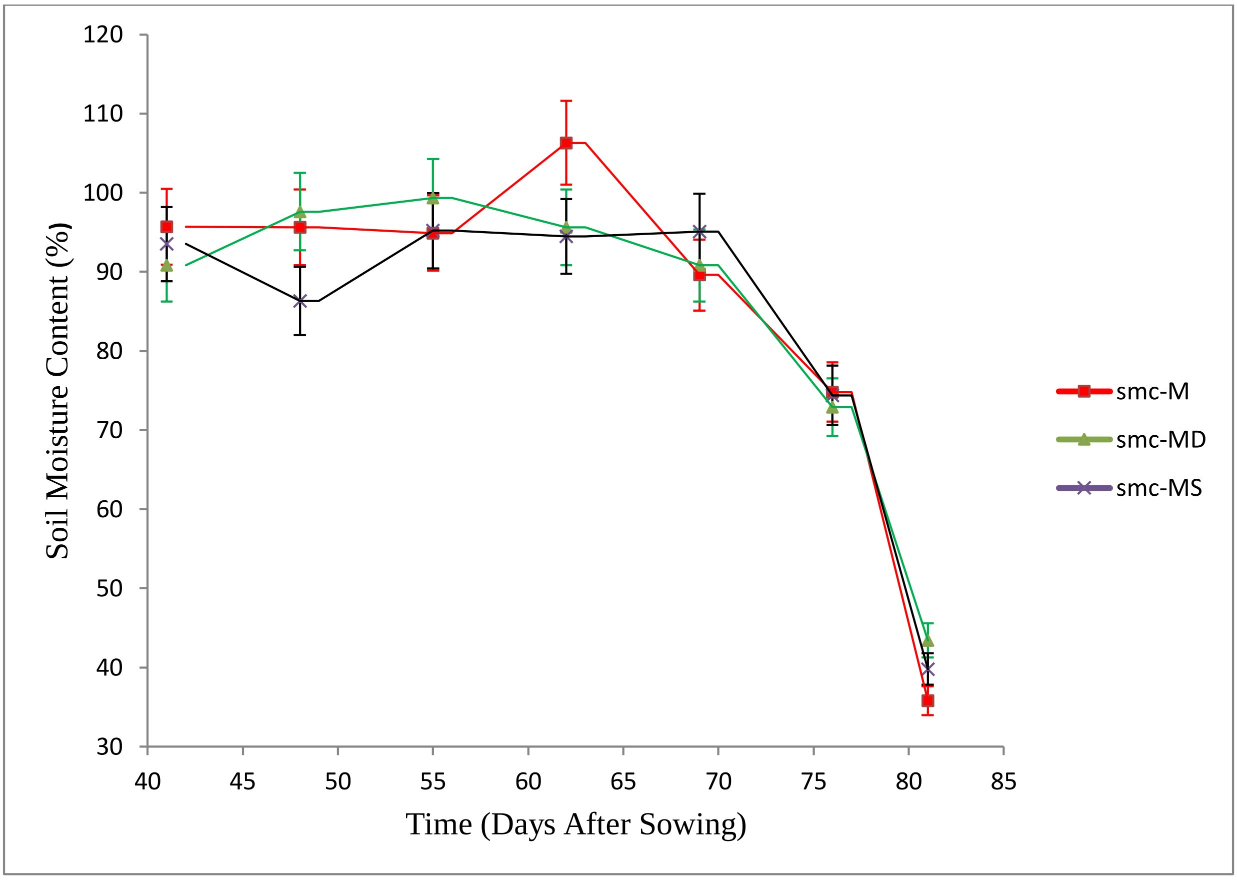


Figure 4.6 Graph of soil moisture content against time in Vihiga season II

4.5 Effect of Intercropping on Maize Energy Yield

4.5.1 Busia and Vihiga Season I

The differences in the results obtained for maize energy yield (Table 4.2) were not significant in both Busia and Vihiga sites during season I.

4.5.2 Busia and Vihiga Season II

Maize energy yield results for Busia and Vihiga sites during season II were as presented in Table 4.2. There were no significant differences in maize energy yield in the cropping systems in both Busia and Vihiga sites during this season.

4.5.3 Comparisons for Seasons I and II Maize Energy Yield

The Maize energy yield results for Busia seasons I and season II (Table 4.2) were significantly different. Similarly, the maize energy yield results for Vihiga season I and season II (Table 4.2) were significantly different. However, in both cases interactions between the seasons and cropping systems were not significant.

Table 4.2: Maize energy yields in kJ/ha for Busia and Vihiga Sites Seasons I and II

		Cropping System Mean maize energy (kJ/ha)		
		Maize	**Maize/ Desmodium**	**Maize/ Soybeans**
Busia	Season I	75,846.86±6,621.57*a*	79,332.10±9,760.36*a*	71,441.75±28,340.51*a*
	Season II	24,567.49±3,918.49*b*	20,074.57±5,753.64*b*	27,446.14±13,108.00*b*
Vihiga	Season I	111,237.95±45,624.33*a*	89,109.09±12,963.61*a*	80,417.76±48,753.66*a*
	Season II	44,577.63±40,679.76*b*	40,087.69±8,110.09*b*	54,648.76±41,962.76*b*

Means with same letters in each row (season) are not significantly different from each other while different letters in seasons at same site denote significant differences ±SD

4.6 Rainfall Use Efficiency (RUE)

4.6.1 RUE for Busia and Vihiga Season I

The RUE of the cropping systems in both Busia and Vihiga sites for season I (Table 4.3) were not significantly different.

4.6.2 RUE for Busia and Vihiga Season II

Differences in the RUE results for Busia season II (Table 4.3) were significant. Tukey honestly significant difference (HSD) test showed cropping system means of MD and M; and those of MS and MD to be different at 5% level of significance. The RUE for MS and M cropping systems was not significantly different. In Vihiga season II (Table 4.3) the differences in RUE observed for the cropping systems were however not significant.

Table 4.3: RUE for the different cropping systems in Busia and Vihiga Seasons I and II

		Cropping System RUE mean energy (kJ/ha/mm)		
		Maize	**Maize/ Desmodium**	**Maize/ Soybeans**
Busia	Season I	177,627.31±15,507.18*a*	196,824.80±23,107.8*a*	183,408.17±72,965.10*a*
	Season II	34,360.13±5,480.40*b*	112,222.63±19,113.26*c*	38,386.21±18,332.87*b*
Vihiga	Season I	190,475.94±78,123.86*a*	173,675.03±26,294.07*a*	151,644.42±90,196.96*a*
	Season II	35,169.73±32,094.49*b*	52,071.44±10,877.61*b*	51,451.08±37,546.63*b*

Means with same letters in each row (season) are not significantly different from each other while different letters in seasons at same site denote significant differences ±SD

4.6.3 Comparisons for Season I and Season II RUE in Busia and Vihiga sites

The RUE results for Busia were significantly different ($P<0.05$) between seasons I and II. Interaction between the cropping systems and seasons were however not significant. In Vihiga significant differences in RUE occurred between seasons I and II ($P<0.05$) whereas interaction between the cropping systems and seasons was not significant.

CHAPTER FIVE

DISCUSSION

5.1 Soil Moisture Content Trends for Busia and Vihiga Sites

During season I (May-August 2015) at both Busia and Vihiga experiment sites the establishment of soybeans in MS cropping systems was faster compared to that of desmodium in MD cropping systems. Growth of desmodium was slowed down by the shading of the maize crop (observation as no data was collected). MS cropping system achieved better soil cover much earlier in the season due to its high canopy density. This protected the soil from excessive soil moisture loss through soil surface evaporation. Similar observations are documented in Walker and Ogindo, (2003) and in Olasantan, (2007). On the 90th DAS in season I in Busia site desmodium in MD cropping system had adequately established a good soil cover therefore posting the highest amount of soil moisture content (Figure 4.3) at the time due to reduced soil surface moisture evaporation loses. Intercropping increases shading compared to pure maize stand. During season II (September 2015-January 2016) Busia site experienced high monthly rainfall amounts (Figure 4.1). This resulted in the soil moisture content measurements taken on the 44th, 51st, 58th and 66th DAS almost having similar values (Figure 4.4). Rainfall was not limiting during season II at both experiment sites. In the same season II on the 72nd DAS there was reduced rainfall at Busia site which resulted in a significant difference in soil moisture content at the time. Desmodium in MD cropping system had already been well established during season I. Desmodium is a perennial crop and therefore provided a good soil surface cover early in season II. This ensured the soil had a better protection against soil surface moisture loss which resulted in MD cropping system having comparatively higher recorded soil moisture content than both M and MS cropping systems (Figure 4.4). Comparatively higher soil moisture content in MD cropping systems was observed on the 79th and 86th DAS though not significantly different in Busia site during season II. The high leaf biomass generated from soybeans leaf fall in MS cropping system facilitated soil moisture conservation resulting in MS cropping system recording higher soil moisture content than M cropping system in the 86th DAS (Figure 4.4).

Soil moisture content in Vihiga season I showed insignificant differences in M, MD and MS cropping systems in the 59th, 66th, 74th, 80th and 87th DAS. During season II at Vihiga site soil moisture content recorded in M, MD and MS cropping systems remained near similar in amounts on the 41st, 53rd, 62nd, 67th and 74th DAS (Figure 4.6) including during the period of reduced rainfall. MD cropping system had comparatively higher soil moisture content in the 67th and 81st DAS (Figure 4.6) although this was not significantly different. High rainfall amounts during the early parts of season II (September 2015-January 2016) resulted in increased soil moisture content. Rainfall was not limiting during the initial DAS at Vihiga site in season II. Intercropping enhances ground cover thereby reducing soil moisture evaporation which improves soil moisture retention and conservation. In this study, M cropping system did not provide adequate soil cover leading to reduced protection against soil surface moisture loss hence the insignificant soil moisture content in spite of it being a single cropping system.

Intercropping did not have a significantly different total soil water extraction, in spite of it involving an additive crop. The dense crop cover with higher leaf area index of the canopy in intercrops impedes evaporation of soil moisture from soil surface (Walker and Ogindo, 2003). This decreases water lost by evaporation (Ahmad *et al*., 2010). Intercrops use soil water preserved by shading, reduced wind speed and increased infiltration due to leaf fall and better soil structure (Dahmardeh and Khashayar., 2013; Mobasser *et al*., 2014). This finding is contrary to the expected increased combined water use by intercrops.

5.2 Effect of Intercropping on Maize Energy Yield

Maize energy yield in Busia site during season I showed insignificant differences although maize energy yield was highest in MD cropping system, followed by M and MS cropping systems (Table 4.2) in that order. In Vihiga site during season I M cropping system had the highest observed maize energy yield (Table 4.2) though not significantly different from that in MD and MS cropping systems. Maize energy yield in Busia site in season II was highest in MS cropping system. M cropping system was second while MD cropping system was third (Table 4.2). These differences were also insignificant. In season II at Vihiga site MS cropping system had highest observed maize energy yield compared to M and MD cropping systems (Table 4.2). The least observed maize energy yield at this site in the season was in MD cropping system. These differences were however not significant. Desmodium in MD cropping systems was adequately established at the start of season II at both Busia and Vihiga sites since it is a perennial crop. MD had reduced maize energy yield as compared to that in MS and M cropping systems due to the poor maize growth. In this study fertilizers used only catered for the nutrient requirements of maize crop which was the main crop. When two crops are planted together inter specific competition occurs between them (Zhang and Li, 2003). Competition between maize crop and desmodium (Ndakidemi, 2006) is a major aspect that affected the maize energy yield during season II. The higher recorded maize energy yield in M cropping system in Vihiga site during season I could be attributed to lack of competition for resources especially nutrients and not necessarily soil moisture stress given that differences in soil moisture content were insignificant. MD cropping system had slightly higher observed maize energy yield than MS cropping system.

Intercropping maize with desmodium (MD) and maize with soybeans (MS) as additive crops did not have significant effect on maize energy yield. The results in both Busia and Vihiga sites were therefore in agreement with that documented in Misganaw *et al*., (2015) and Gabatshele *et al*., (2012). This research finding thus disagreed with the suggestion that higher total crop populations in intercrops could result in low yield under moisture stress resulting from drought conditions due to increased competition for soil moisture as documented in Hulugalle *et al*., (1986). Intercrops use soil water conserved from shading, reduced wind speed and improved infiltration due to leaf fall and better soil structure (Dahmardeh and Khashayar, 2013; Mobasser *et al*., 2014).

5.3 Rainfall Use Efficiency (RUE) for Busia and Vihiga Sites

MD cropping system resulted in the highest observed RUE value in Busia site in both season I and II followed by MS and M cropping systems respectively (Table 4.3). In Busia site season I the differences were not significant whereas the differences in Busia site season II were significant. The highest observed RUE value in Vihiga site during season I was made in M cropping system and least in MS cropping system (Table 4.3). MD cropping system had the highest observed RUE in Vihiga season II but only slightly different from MS cropping system. M cropping system had the least RUE in season II (Table 4.3). These differences in observed RUE in Vihiga site season II were not significant. Intercropping reduces yield and yield components of the specific crops (Ndiso *et al*., 2017) resulting in insignificant differences. Busia site season II result was similar to the findings of the studies done with cereal-legume intercropping systems documented in Okoth and Siameto, (2011) and Prosper *et al*., (2017) in which intercrops performed better equated to the monocrops. Tukey honestly significant difference (HSD) test done on the results of Busia site season II showed significant differences in the cropping system means of MD and M; and those of MS and MD. Intercropping enhances crop production through more effective resource use compared to pure stand crops (John and Mani, 2005; Eskandari and Ghanbari, 2009). When crops vary in the way they utilize environmental resources they complement each other and make better collective resource use when grown together than when grown separately (Ghanbari-Bonjar, 2000).

The significant differences in Busia site season II were attributed to the enhanced monthly rainfall (Figure 4.1) which adversely affected growth of the crops. Busia site has shallow soils due to the underlying murrum (MoA, 1982). Shallow soils are prone to nutrient losses through erosion in enhanced rainfall. Desmodium in MD cropping system provided increased protection of the soil nutrients from erosion losses through reduced runoffs and binding of soil particles by their roots (Khan *et al*., 2011). Desmodium production in MD cropping system benefited from the higher monthly rainfall amounts in season II. Moisture aids nutrient uptake (Okalebo *et al*., 2007). This led to the observed higher RUE recorded in MD cropping system than those in MS and M cropping systems. Growth of soybean**s** in MS cropping system was adversely affected by the higher monthly rainfall amounts received in season II (Figure 4.1). Excess water during vegetative period retards growing of soybeans as it requires well-aerated soils to grow vigorously (Geoffrey *et al*., 1998). Conditions for growth in season I and those of season II were different.

In Vihiga site during season II Desmodium and soybeans in MD and MS cropping systems provided good cover for the soil surface which protected soil from nutrient losses due to leaching and erosion (John and Mani, 2005; Eskandari and Ghanbari, 2009). Crop production can probably be further increased by improved soil management practices which include optimum fertilizer application (Natarajan and Willey, 1986). There were significant differences in the RUE between the results for Vihiga site season I and season II. The enhanced monthly rainfall amounts in season II affected crop production. Desmodium production in MD cropping system benefited from the higher monthly rainfall amounts. The conditions for growth in season I and season II were dissimilar.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion and Recommendations

This research was aimed at comparing the effect of maize-soybeans and maize-desmodium intercropping systems on yield and rainfall use efficiency in Western Kenya. Two study sites, one in Busia and the other in Vihiga were used. The study was done in two seasons. Season I between May – August 2015 and season II September 2015 – January 2016. On site recorded rainfall was relatively lower during season I than in season II as compared to long-term averages for the region for the same period in both Busia and Vihiga experiment sites. The differences in results arising from compared soil moisture trends, determined maize energy yield and rainfall use efficiency in maize monocrop, maize-soybeans and maize-desmodium intercrops were all statistically insignificant. Intercropping maize with soybean and with desmodium does not pose a significant strain on soil moisture content as seen in soil moisture trends in the cropping systems. The crops can be intercropped without fear of adverse competition for soil moisture. Soybean and desmodium intercrops did not have a significant reduction in maize energy yield. Therefore, there is no energy yield advantage of growing maize as a single crop. Similarly intercropping maize with soybeans and with desmodium does not result in significant reduction in rainfall use efficiency in the cropping systems. There exists no need to reduce the maize crop population from the current 44,000 maize plants ha^{-1} so as to accommodate desmodium and soybeans as intercrops.

6.3 Recommendations for Further Research

This research work having adopted intercrops as ‘additive crops’ maintained the field population of maize. Further study to include planting of pure stands of soybeans and desmodium and also include replacement experiments.

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APPENDICES

Appendix 1: Busia site rainfall data seasons I and II

Date	2015								2016		
	May	June	July	August	Sept	Oct	Nov	Dec	Jan	Feb	March
1	4	**0**	**17**	**0**	0	0	**5**	**35**	**0**	0	0
2	12	**3**	**0**	**0**	0	0	**0**	**20**	**0**	16	2
3	0	**6**	**0**	**11**	0	0	**10**	**3**	**0**	0	0
4	10	**0**	**0**	**6**	53	0	**33**	**0**	**0**	0	0
5	5	**0**	**0**	**2**	8	0	**0**	**22**	**0**	0	0
6	8	**0**	**7**	**0**	8	0	**25**	**37**	**0**	0	0
7	**0**	**0**	**12**	**34**	0	0	**0**	**0**	**0**	0	0
8	**9**	**0**	**0**	**0**	0	0	**5**	**0**	**0**	0	8
9	**0**	**0**	**0**	**0**	5	0	**2**	**0**	**0**	0	0
10	**0**	**0**	**15**	**0**	13	15	**19**	**22**	**0**	0	0
11	**2**	**2**	**3**	**0**	0	47	**0**	**16**	**8**	0	0
12	**0**	**0**	**0**	**0**	5	**0**	**5**	**0**	**12**	0	0
13	**1**	**0**	**0**	**0**	0	**8**	**9**	**29**	**0**	0	3
14	**0**	**0**	**0**	**0**	0	**8**	**23**	**0**	**0**	5	0
15	**5**	**0**	**15**	**0**	25	**26**	**0**	**0**	**0**	0	0
16	**3**	**0**	**0**	0	0	**4**	**0**	**28**	**0**	6	0
17	**1**	**0**	**0**	0	0	**7**	**23**	**0**	**0**	0	0
18	**10**	**0**	**9**	4	0	**4**	**0**	**0**	**8**	0	0
19	**0**	**0**	**5**	0	0	**13**	**3**	**15**	**25**	0	0
20	**14**	**30**	**0**	4	0	**4**	**0**	**23**	**0**	0	0
21	**4**	**0**	**6**	0	0	**6**	**3**	**3**	0	0	0
22	**5**	**6**	**11**	0	4	**37**	**13**	**0**	0	0	0
23	**2**	**3**	**4**	0	23	**7**	**0**	**0**	0	0	0
24	**0**	**0**	**8**	0	0	**4**	**16**	**0**	0	0	0
25	**2**	**0**	**5**	0	0	**31**	**11**	**0**	0	0	33
26	**0**	**0**	**9**	0	0	**2**	**9**	**0**	0	0	0
27	**8**	**22**	**16**	0	0	**9**	**6**	**13**	0	0	0
28	**3**	**0**	**0**	5	15	**0**	**0**	**0**	0	8	3
29	**0**	**51**	**0**	0	0	**0**	**22**	**0**	0	0	3
30	**0**	**3**	**5**	0	0	**26**	**11**	**0**	0		5
31	**0**	**7**		10		**0**		**0**	0		8

Appendix 2: Vihiga site rainfall data seasons I and II

Date	2015								2016		
	May	June	July	August	Sept	Oct	Nov	Dec	Jan	Feb	March
1	0	**1.5**	**0**	**24**	2	0	**10**	**25**	**0**	2.5	0.5
2	0	**15**	**3**	**1.5**	3	0	**5**	**24**	**0**	0	0
3	0	**3.5**	**6**	**0**	32	0	**25**	**33**	**0**	0	15
4	40	**0**	**0**	**0**	35	0	**5**	**15**	**0**	0	0
5	5	**0**	**0**	**0**	34	0	**10**	**35**	**0**	0	0
6	8	**5.5**	**0**	**7**	0	0	**35**	**19**	**0**	0	0
7	0	**10.5**	**0**	**1.5**	0	2	**0**	**20**	**0**	0	0
8	0	**0.5**	**0**	**0.5**	3	1	**20**	**35**	**0**	0	0
9	5	**0**	**0**	**3**	2	0	**5**	**32**	**0.5**	0	0
10	13	**10**	**0**	**11**	3	11	**15**	**30**	**0**	0	0
11	0	**0**	**2**	**0**	0	5	**28**	**25**	**0**	0	0
12	5	**0**	**0**	**0**	0	0	**17**	**20**	**25**	0	0
13	**0**	**0**	**0**	**0**	11	0	**2**	**28**	**20**	0	0
14	**23**	**4**	**0**	**0**	12	0	**0**	**27**	**0**	0	0
15	**2**	**4**	**0**	**0**	6	2	**5**	**20**	**35**	0	0.5
16	**3**	**0**	**0**	**1**	0	5	**25**	**17**	**8**	0	0
17	**0**	**0.5**	**0**	**0**	0	**2**	**20**	**15**	**13**	0	0
18	**18**	**0**	**0**	**0**	0	**1**	**35**	**23**	**0**	0	35
19	**2**	**35**	**0**	**12**	0	**10**	**19**	**25**	**0**	0	0
20	**0**	**2**	**30**	**15**	0	**35**	**2**	**26**	**35**	0	0
21	**0**	**3**	**0**	**2**	1	**15**	**5**	**0**	**2**	0	0
22	**4**	**1**	**6**	**0**	32	**10**	**11**	**0**	**0**	0	13
23	**20**	**21**	**3**	2	0	**16**	**12**	**0**	**26**	0	
24	**6**	**0**	**0**	0	0	**19**	**15**	**0**	**1**	0	
25	**1**	**0.5**	**0**	0	0	**8**	**26**	**0.5**	**0**	0	
26	**0**	**0**	**0**	0	5	**35**	**17**	**0.5**	0	0	
27	**0**	**14**	**13**	15	6	**10**	**35**	**0**	0	0	
28	**15**	**0**	**0**	18	0	**3**	**32**	**0**	0	0	
29	**20**	**31**	**0**	2	0	**5**	**17**	**0**	0	0	
30	**0**	**0**	**0**	3	0	**4**	**35**	**0**	0	0	
31			**3**	22		**31**		**0**	0		

Appendix 3: ANOVA showing effect of cropping systems on soil moisture content for Busia site season I

DAS		DF	SS	MS	F	P
62	Treatment	2	0.140	0.070	0.029	0.972
	REP	2	9.487	4.743	1.941	0.257
	Residuals	4	9.773	2.443	-	-
69	Treatment	2	0.420	0.210	0.106	0.902
	REP	2	11.227	5.613	2.837	0.171
	Residuals	4	7.913	1.978	-	-
76	Treatment	2	0.336	0.168	0.124	0.8865
	REP	2	11.869	5.934	4.392	0.0979
	Residuals	4	5.404	1.351	-	-
83	Treatment	2	0.149	0.074	0.066	0.9372
	REP	2	16.682	8.341	7.385	0.0454
	Residuals	4	4.518	1.129	-	-
90	Treatment	2	1.820	0.910	1.521	0.3227
	REP	2	11.727	5.863	9.799	0.0287
	Residuals	4			-	-

Appendix 4: ANOVA showing effect of cropping systems on soil moisture content for Busia site season II

DAS		DF	SS	MS	F	P
44	Treatment	2	0.107	0.053	0.156	0.8604
	REP	2	6.407	3.203	9.376	0.0309
	Residuals	4	1.367	0.342	-	-
51	Treatment	2	1.109	0.5544	0.962	0.456
	REP	2	4.869	2.4344	4.226	0.103
	Residuals	4	2.304	0.5761	-	-
58	Treatment	2	1.696	0.848	2.114	0.23639
	REP	2	20.969	10.484	26.139	0.00505
	Residuals	4	1.604	0.401	-	-
66	Treatment	2	0.229	0.1144	0.589	0.5970
	REP	2	3.976	1.9878	10.223	0.0268
	Residuals	4	0.778	0.1944	-	-
72	Treatment	2	6.249	3.124	11.25	0.0228
	REP	2	6.349	3.174	11.43	0.0222
	Residuals	4	1.111	0.278	-	-
79	Treatment	2	2.8689	1.4344	3.764	0.120
	REP	2	0.5756	0.2878	0.755	0.527
	Residuals	4	1.5244	0.3811	-	-
86	Treatment	2	1.6689	0.8344	3.891	0.115
	REP	2	0.0689	0.0344	0.161	0.857
	Residuals	4	0.8578	0.2144	-	-

Appendix 5: ANOVA showing comparison of soil moisture content for Busia site seasons I and II

	DF	SS	MS	F	P
Treatment	2	6.6	3.28	0.600	0.55101
Season	1	1.7	1.74	0.317	0.57452
REP	2	70.6	35.31	6.454	0.00231
Treatment:Season	2	2.4	1.18	0.215	0.80680
Residuals	100	547.1	5.47	-	-

Appendix 6: ANOVA showing effect of cropping systems on soil moisture content for Vihiga site season I

DAS		DF	SS	MS	F	P
59	Treatment	2	2.660	1.330	0.830	0.500
	REP	2	8.327	4.163	2.597	0.189
	Residuals	4	6.413	1.603	-	-
66	Treatment	2	1.847	0.923	0.791	0.513
	REP	2	9.947	4.973	4.263	0.102
	Residuals	4			-	-
74	Treatment	2	1.26	0.63	0.270	0.776
	REP	2	2.42	1.21	0.519	0.630
	Residuals	4	9.32	2.33	-	-
80	Treatment	2	0.18	0.090	0.086	0.919
	REP	2	1.34	0.670	0.641	0.573
	Residuals	4	4.18	1.045	-	-
87	Treatment	2	1.607	0.8033	0.378	0.708
	REP	2	3.227	1.6133	0.759	0.526
	Residuals	4	8.507	2.1267	-	-

Appendix 7: ANOVA showing effect of cropping systems on soil moisture content for Vihiga site season II

DAS		DF	SS	MS	F	P
41	Treatment	2	1.309	0.6544	0.420	0.683
	REP	2	4.002	2.0011	1.285	0.371
	Residuals	4	6.231	1.5578	-	-
46	Treatment	2	7.209	3.604	0.729	0.537
	REP	2	7.109	3.554	0.719	0.541
	Residuals	4	19.771	4.943	-	-
53	Treatment	2	1.182	0.591	0.112	0.897
	REP	2	2.276	1.138	0.216	0.814
	Residuals	4	21.058	5.264	-	-
62	Treatment	2	0.062	0.031	0.009	0.991
	REP	2	8.602	4.301	1.212	0.388
	Residuals	4	14.191	3.548	-	-
67	Treatment	2	0.096	0.048	0.011	0.989
	REP	2	15.056	7.528	1.710	0.291
	Residuals	4	17.611	4.403	-	-
74	Treatment	2	0.187	0.093	0.017	0.983
	REP	2	1.047	0.523	0.097	0.909
	Residuals	4	21.487	5.372	-	-
81	Treatment	2	2.816	1.4078	0.722	0.540
	REP	2	0.296	0.1478	0.076	0.928
	Residuals	4	7.804	1.9511	-	-

Appendix 8: ANOVA showing comparison of soil moisture content for Vihiga site seasons I and II

	DF	SS	MS	F	P
Treatment	2	0.5	0.230	0.021	0.980
Season	1	2.0	1.961	0.176	0.676
REP	2	14.0	6.989	0.627	0.536
Treatment:Season	2	6.4	3.180	0.285	0.753
Residuals	100	1115.1	11.151	-	-

Appendix 9: ANOVA showing maize energy yield in Busia and Vihiga sites seasons I and II and that of seasonal comparisons

Site	Season		DF	SS	MS	F	P
Busia	1	Treatment	2	9.381e+13	4.690e+13	0.222	0.81
		REP	2	1.041e+15	5.205e+14	2.468	0.20
		Residuals	4	8.436e+14	2.109e+14	-	-
	2	Treatment	2	8.281e+13	4.141e+13	0.461	0.660
		REP	2	8.129e+13	4.065e+13	0.453	0.665
		Residuals	4	3.593e+14	8.982e+13	-	-
	1&2	Treatment	2	1.807e+12	9.037e+11	0.006	0.994
		Season	1	1.194e+16	1.194e+16	80.481	4.26e-6
		REP	2	8.416e+14	4.208e+14	2.836	0.106
		Treatment:Season	2	1.748e+14	8.741e+13	0.589	0.573
		Residuals	10	1.484e+15	1.484e+14	-	-
Vihiga	1	Treatment	2	1.515e+15	7.576e+14	0.489	0.646
		REP	2	3.051e+15	1.525e+15	0.984	0.449
		Residuals	4	6.202e+15	1.551e+15	-	-
	2	Treatment	2	3.277e+15	1.638e+15	2.057	0.243
		REP	2	3.776e+15	1.888e+15	2.370	0.209
		Residuals	4	3.187e+15	7.967e+14	-	-
	1&2	Treatment	2	2.461e+15	1.231e+15	1.302	0.31447
		Season	1	1.470e+16	1.470e+16	15.545	0.00276
		REP	2	6.761e+15	3.380e+15	3.575	0.06739
		Treatment:Season	2	2.330e+15	1.165e+15	1.232	0.33235
		Residuals	10	9.455e+15	9.455e+14	-	-

Appendix 10: ANOVA showing Rainfall Use Efficiency in Busia and Vihiga sites seasons I and II and that of seasonal comparison

Site	Season		DF	SS	MS	F	P
Busia	1	Treatment	2	5.820e+08	2.910e+08	0.210	0.819
		REP	2	6.646e+09	3.323e+09	2.395	0.207
		Residuals	4	5.551e+09	1.388e+09	-	-
	2	Treatment	2	1.153e+10	5.765e+09	16.00	0.0123
		REP	2	2.148e+07	1.074e+07	0.03	0.9708
		Residuals	4	1.441e+09	3.604e+08	-	-
	1&2	Treatment	2	8.565e+09	4.282e+09	4.248	0.0462
		Season	1	6.952e+10	6.952e+10	68.965	8.48e-06
		REP	2	3.579e+09	1.789e+09	1.775	0.2190
		Treatment:Season	2	3.548e+09	1.774e+09	1.760	0.2214
		Residuals	10	1.008e+10	1.008e+09	-	-
Vihiga	1	Treatment	2	2.276e+09	1.138e+09	0.247	0.792
		REP	2	1.141e+10	5.706e+09	1.237	0.382
		Residuals	4	1.845e+10	4.612e+09	-	-
	2	Treatment	2	5.511e+08	2.756e+08	0.451	0.666
		REP	2	2.672e+09	1.336e+09	2.186	0.228
		Residuals	4	2.445e+09	6.112e+08	-	-
	1&2	Treatment	2	5.108e+08	2.554e+08	0.114	0.893622
		Season	1	7.110e+10	7.110e+10	31.668	0.000219
		REP	2	1.252e+10	6.262e+09	2.789	0.109016
		Treatment:Season	2	2.316e+09	1.158e+09	0.516	0.612130
		Residuals	10	2.245e+10	2.245e+09	-	-

Appendix 11: HSD test results for mean differences in RUE for cropping Systems for Busia season II

Cropping System	Mean difference	95% CI on the mean difference		P
		Lower	Upper	
MD – M	77862.503	38744.29	116980.7	0.0021311
MS – M	4026.087	-35092.13	43144.3	0.9469891
MS – MD	-73836.417	-112954.63	-34718.2	0.0028062