Simulation of Soil Moisture, Sorghum (*Sorghum bicolor L.*) and Sweet potato (*Ipomea batatas L.lam*) Yields using CropSyst Model in Matuu Sub-County, Kenya

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DECLARATION

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

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DEDICATION

Dedicated to my parents Christine and Stephen Ndivo, who throughout the years have taught me to live a principled life and for their care, love and tremendous sacrifices.

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LIST OF ABBREVIATIONS AND ACRONYMS

ASALs	Arid and Semi-Arid Lands
IPCC	Intergovernmental Panel for Climate Change
SATs	Semi-Arid Tropics
DSTs	Decision Support Tools
SLA	Specific Leaf Area
VPD	Vapor Pressure Deficit
LAI	Leaf area Index
RUE	Radiation Use Efficiency
RMSE	Root mean square Error
WI	Wilmott Index
PD	Percentage difference
SLP	Stem leaf partition
USDA	United States Department of Agriculture
WRB	World Reference Base for Soil Resources
GDD	Growing degree days
FYM	Farm Yard Manure
RP	Rock Phosphate

GENERAL ABSTRACT

There has been declining crop yields in the ASALs of Kenya due to low soil fertility caused by continuous cropping without addition of external inputs and low soil water availability due to low and unreliable rainfall and poor water harvesting techniques. To increase crop yields, research on better use of available rainfall and interaction between climate, soil and management on crop production is required. CropSyst model was used to study the effect of soils, and management on cropping systems productivity. The aim of the study was to simulate soil moisture, sorghum and sweet potato yields under different tillage practices, cropping systems and organic inputs. The study was conducted in Matuu Sub-county in Kenya. The experiment was laid out in a Randomized Complete Block design with split-split plot arrangement and replicated three times. The main plots were tillage practices; furrows and ridges, oxen plough and tied ridges. Split plots were cropping systems; monocropping, intercropping and crop rotation. Split- split plots were organic inputs; farm yard manure (FYM), rock phosphate (RP) and FYM + RP. A control denoted that no organic input was used. In each plot, soil sampling was done to determine physical and chemical soil characteristics. The test crops were sorghum (*Sorghum bicolor L.*) and sweet potato (*Ipomea batatas L.lam*) rotated and/or intercropped with dolichos (*Lablab purpureus*) and chickpea (*Cicer arietinum*). The CropSyst model was calibrated using the measured soil texture, permanent wilting point, field capacity, bulk density and initial soil moisture at the experimental site. Sorghum and sweet potato growing degree days were used to calibrate the crop phenology in the crop file. Validation of the model was done using Root Mean Square Error (RMSE), percentage differences (PD) and wilmott index (WI) of agreement. CropSyst model was validated for soil moisture due to the low RMSE (0.5 to 1.3) and PD (less than ±15) values that were obtained and the WI index which was close to 1. CropSyst model Validation for the sorghum and sweet potato yield was achieved due to the low RMSE (0.629) and PD (less than ±3) values that were obtained and the WI index which was close to 1. In the sorghum based cropping systems, simulated soil moisture (101.91 mm) was significantly ($P < 0.05$) high in the interactions between tied ridges with sorghum/dolichos intercrop when Rock Phosphate(RP) + Farm Yard Manure (FYM) was applied and least (13.52 mm) in the interactions between oxen plough with sorghum mono cropping when no organic input was applied in the first season. In the second season, simulated soil moisture was significantly high (108.3 mm) in the tied ridges with sorghum/dolichos intercropping when FYM + RP was applied and least (15.4 mm) in the interactions between the oxen plough with sorghum monocropping when no organic input was applied. In the sweet potato based cropping system during the first season, soil moisture was significantly high in tied ridges (95 mm), sweet potato-dolichos rotation (75.32 mm), RP and FYM application (75.03 mm) and least in the oxen plough (32.49 mm), sweet potato monocropping (53.46) and control (52.52 mm). In the second season, soil moisture was significantly high in the tied ridges (100.24 mm) sweet potato-dolichos rotation (79.63 mm), RP + FYM (79.39 mm) and least in the oxen plough (34.36 mm), sweet potato monocropping (55.26 mm) and control (55.39 mm).

In the sorghum based cropping systems during the first season, sorghum yield was significantly high in the tied ridges (1,611 kg/ha), sorghum/dolichos intercrop (1,825 kg/ha), RP +FYM (1,595 kg/ha) and in the interaction between tied ridges and sorghum/dolichos intercrop (1,955.6 kg/ha) and least (1383 kg/ha) in the oxen plough and interaction between oxen plough and sorghum monocropping (981.5 kg/ha). In the second season, simulated sorghum yield was significantly high in the tied ridges (2,072 kg/ha), sorghum-dolichos rotation (2,218 kg/ha) and when RP + FYM was applied, and in the tied ridges interaction with sorghum and dolichos rotation (2,584 kg/ha). Sorghum yield was least (1,779 kg/ha) in the oxen plough, sorghum monocropping (1,191 kg/ha), in the control (1,436 kg/ha and least (1,519 kg/ha) in the oxen plough with sorghum monocropping.

In the first season, sweet potato yield (13,127 kg/ha) was significantly high in the tied ridges, sweet potato-chickpea rotation (14,222 kg/ha), high when RP + FYM (13,247 kg/ha) was applied, in the tied ridges interaction with sweet potato intercrop with dolichos (16,737 kg/ha) and least (10,127 kg/ha) in the oxen plough and least (9,772 kg/ha) in the sweet potato monocropping, control (10,405 kg/ha), oxen plough interaction with sorghum monocrop (8572 kg/ha). In the second season, sweet potato yield (14,768 kg/ha) was significantly high in the tied ridges, sweet potato rotation with dolichos (16,000 kg/ha), RP + FYM (14,034 Kg/ha) and least (11, 699 kg/ha) in the oxen plough, sweet potato monocropping (10,993 kg/ha), control (10,995 Kg/ha): In the second season, sweet potato yield (18,066 kg/ha) was significantly high in the tied ridges interaction with sweet potato rotation with chickpea and least (9643 kg/ha) in the oxen plough interaction with sweet potato monocrop.

Soil moisture was high in the tied ridges, crop rotation and intercropping systems, FYM + RP and least in the oxen plough, monocropping and control. Sorghum and sweet potato yields were significantly high in the plots with high soil moisture. Crop production in ASALs could be increased by improving soil moisture through the use of tied ridges, rotation and intercropping systems and the use of FYM + RP. Tied ridges improved on water infiltration through reduced runoff. Rotation and intercropping cereals and tubers with legumes improved the soil fertility and hence high crop yields. FYM + RP increases on water holding capacity hence increased soil moisture.

Keywords; Cropping Systems; CropSyst; Organic fertilizers; Sorghum; sweet potato; simulation; Tillage practices

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 BACKGROUND INFORMATION

Arid and Semi-Arid Lands (ASALs) of Kenya account for over 84 % of the landmass and support at least 25% of the population (Manyeki et al., 2013). Rainfall is erratic, poorly distributed and insufficient to support rain- fed agriculture. The soil moisture decreases as precipitation decreases and evaporation increases due to increasing temperatures (IPCC, 1996). ASALs experience food and nutritional insecurity due to low agricultural productivity (Sanchez and Swaminathan, (2005). These areas are characterized by low agricultural productivity caused by low soil fertility and drought which have led to frequent crop failure (Macharia. 2004). Traditional crops such as sorghum and sweet potatoes which are adapted to ASALs have long been abandoned by small scale farmers (Mwadalu and Mwangi, 2013). These crops can withstand adverse weather conditions, pests and diseases (GoK, 2009).

Sorghum is Africa's oldest food crop and is often referred to as the continents food for the poor (Fetene, 2011). Sorghum is not only drought resistant but it is also adapted to most of Kenya's climatic zones and soils (Taylor, 2003). Sorghum is the fifth most important cereal crop of the world after rice, wheat, maize and barley (Bantilan et al., 2004; Akram et al., 2007). In Kenya, sorghum is important traditional food crop in the dry areas of Nyanza, Eastern and coastal parts of Kenya. Due to its resistance to drought, diseases, and the notorious striga weed, sorghum regularly out yields maize in these areas (Pursgrove, 1995). Sorghum is one of the most important drought crops and is often referred to as the camel of the plant Kingdom (Fetene et al., 2011). It is one of the main staple food crops for the world's poorest and food insecure people (Timu et al., 2012).

Sweet potato (*Ipomoea batatas* (L.) on the other hand, is grown over a broad range of environments and cultural practices and is commonly grown in low-input agriculture systems (Prakash, 1994). The plant is sensitive to water deficits, particularly during the establishment period including vine development and storage root initiation (Indira and Kabeerathumma, 1988). Sweet potato is considered to be moderately drought tolerant (Valenzuela *et al* 2000). Sweet potatoes are important in economy of resource poor households in the arid and semi-arid lands (ASALs), and are major source of subsistence and cash income to farmers in agro climatically-disadvantaged regions of Kenya (Githunguri, 2004). Farmers in these areas prefer to grow maize since it is less labour intensive and the often ready market even in the rural areas.

The introduction of resource-conserving methods will require insights on how such alternatives will affect present agricultural productivity. However, studying the integrated effects of management, environment and eco-physiological characteristics would require complicated field experiments. Quantitative, system dynamic tools such as crop-soil simulation models can complement single and multi-factor research by accessing the integrated impact of variables on productivity and resource conservation. The crop-soil simulation model CropSyst can serve such purposes.

Crop simulation models are increasingly being used to study the behavior of complex agricultural systems and to understand the interactions between soil and plant under different meteorological conditions (Confalonieri et al. 2006). Crop models are often used to evaluate the impact of management or climatic scenarios, and their reliability is still judged mainly on their accuracy in estimating crop biomass at the end of the growing season and, consequently, the crop production (Parry et al., 2004). The suitability of a crop model is assessed, on one hand, by the authenticity of the basic equations describing the crop processes while, on the other hand, by the quality of its input data (Rivington et al., 2006). They both should be coherent with the level of detail used by the model in order to "reproduce" the real system. Additionally, crop simulation models assist scientists in making more efficient use of resources by providing an insight on potential plant responses to alterations in cropping systems (Staggenborg et al., 2005)

Crop models currently available are often dissimilarly structured, with equations and input parameters of different nature, different organizational levels, as well as different capabilities in representing the actual system. A list of the most widespread models to simulate crop development and growth include; APSIM (Keating *et al.*, 2003), CropSyst (Stöckle *et al.*, 2003), DSSAT (Jones *et al.*, 2003), models from the Wageningen school such as LINTUL, SUCROS, ORYZA, WOFOST, INTERCOM (van Ittersum *et al.*, 2003), STICS (Brisson *et al.*, 2003).

CropSyst, a multi-year, multi-crop, daily time step cropping-system simulation model has been applied and used extensively to simulate crop growth and yield for a range of crops such as wheat, maize, soybean, sorghum and forage crops in diverse environments (Confalonieri et al.,2006). The model simulates soil-water budget, soil plant nitrogen budget, crop canopy and root growth, crop phenology, dry matter production, yield, residue production and decomposition and erosion. The main inputs are daily weather data (precipitation, wind speed, maximum and minimum temperature, and solar radiation) with the model allowing the user to specify management options. These include the timing of events such as sowing, organic and inorganic nitrogen fertilizer applications (and rates), tillage, etc. Crop physiology is determined by cultivar specific coefficients controlling canopy and root growth and development. The CropSyst model is intended for crop growth simulation over a single land block fragment with uniform soil, weather, crop rotation and management.

CropSyst has been used to model growth and development of several crops in many parts of the world (Rivington et al., 2006; Moriondo et al., 2007). CropSyst is credited with the capability to simulate the growth of many crops from a uniform structure and a common set of parameters. The model provides for simultaneous modeling of changes in crop environment including plant and soil moisture and nutrients, which constitute constraints of productivity of tropical agricultural systems (Tingem et al., 2008). It has a generic routine to simulate the growth of annual, herbaceous plants and this routine can be adapted to any new crop meeting this criterion (Confalonieri and Bechini, 2004).

Water budget in the model includes precipitation, irrigation, interception, runoff and water infiltration. Water redistribution in the soil is simulated by a simple cascading approach.

CropSyst model was used to simulate soil moisture and yields of sorghum and sweet potato in Matuu Sub-County, in South Eastern Kenya.

1.2 STATEMENT OF THE PROBLEM

Arid and Semi-Arid Lands (ASALs) are characterized by low, poorly distributed, and highly variable rainfall within 100-600 mm per year (Mugwe et al, 1999). The ASAL in Kenya covers over 80 % of the country. These vast lands are generally poor and experience food scarcity. Studies have shown that agriculture in the ASALs of East Africa is mostly rain-fed (Hatibu and Mahoo, 2000; Critchley, et al.1999). Therefore, moisture stress is a major constraint against food production in these areas.

People in ASALs have long experienced water shortages and drought due to unreliable and poorly-distributed rains (Barron et al., 2003). However, the rains have become more unpredictable since the 1980s. The low rainfall together with its unreliability and poor distribution severely limits crop production (KARI, 1996). Climatic conditions with high atmospheric evaporative demand and highly variable rainfall in spatial and temporal scales make farming a risky business (Biamah, 2005) due to crop failures and reduced crop yields. With high evaporative demand of approximately 1.5-10 times the average annual rainfall and low soil water holding capacity, water is considered a major environmental constraint to rainfed cropping systems (Barron, 2004).

Traditional crops such as sorghum, millet and sweet potatoes which are adapted to harsh conditions in ASALs have been neglected for modern crops such as maize and beans (Mwangi et al., 2011). This is because of much attention given to these crops in terms of research and development (Rutto, 1982).

ASALs are also characterized by soils low in nutrients especially nitrogen and phosphorus. This is largely due to continuous cropping without external inputs (Kimiti, 2009).

Traditional experiments are conducted at particular points in time and space, making results site- and season-specific, time consuming and expensive. Costs of research and development, on the other hand, pose a major hindrance to carrying out comprehensive field trials for long term periods to sufficiently evaluate the suitability and profitability of such an alternative farming strategy (Carberry et al., 1989).

1.3 JUSTIFICATION

To guarantee food security in the ASALs where crop production is limited by moisture stress, sound Agricultural Water Management (AWM) is necessary. AWM includes all deliberate human actions designed to optimize the availability and utilization of water for agricultural purposes. AWM include practices such as soil and water conservation, rainwater harvesting and soil fertility management. Sound agricultural management should ensure that available rainwater becomes useful to crops and that it is not used for negative impacts such as soil erosion. Soil and water conservation with water harvesting, is one of the techniques for supporting rain-fed agriculture in the ASALs where crop failure is much evident. On-farm rainwater harvesting using structures such as bunds and ridges preserve soil moisture and result in improved crop yields.

In addition to soil moisture stress, soil fertility limits crop production in the ASALs. Addition of organic materials to the soil improves the chemical, physical and biological properties that enhance the availability of nutrients and their uptake by crops. Manures provide both N and P and other nutrients, but they are present in less soluble forms than in inorganic fertilizers.

In ASALs, Significant improvement in agricultural productivity and subsequently food availability would potentially be realized through the production of selected neglected traditional crops. Growing of traditional crops in the ASALs where rainfall is low and less reliable can improve food production in the ASALs. Reviving and improving the production of traditional crops such as sorghum and sweet potatoes will improve food productivity and food security in drylands.

To determine the effects of these alternatives in the ASALs quantitative, system-dynamic tools such as crop-soil simulation models can complement single and multi-factor research. A more robust analysis of long-term productivity, climatic risk and environmental sustainability of tested management options becomes possible when field experimentation are combined with simulation modeling.

Currently, yield from cropping systems in Kenya is determined only through experimentation, field research or on-farm trials, which are time consuming and are affected by limited resources and climate change. The use of models will counter the above shortcomings.

1.4. OBJECTIVES

1.5.1 General Objective

To simulate soil moisture, sorghum and sweet potato yields under different tillage practices, cropping systems and organic inputs for informed decision making in crop production.

1..2 Specific Objectives

To simulate;

1. Soil moisture under different tillage practices, cropping systems and organic inputs using CropSyst model.

2. Yields of sorghum and sweet potato under different tillage practices, cropping systems and organic inputs using CropSyst model.

1.5.3 Hypothesis

1. Soil moisture will be significantly different under the different tillage practices, cropping systems and organic inputs.

2. Sorghum and sweet potato yields will be significantly different under the tillage practices, cropping systems and organic inputs.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Soil moisture conservation technologies

Inadequate soil moisture is the most limiting constraint to productivity in the semi-arid areas of Kenya (Itabari et al., 2004). Improvements in on-farm water management through water harvesting may prove key to up-grade smallholder farming systems in dry sub-humid and semi-arid Sub-Sahara Africa (SSA) (Barron, 2004). The low yield levels are ascribed to the poor crop water availability due to variable rainfall, losses in on-farm water balance and inherently low soil nutrient levels (Tittonell, 2013). To meet an increased food demand with less use of water and land in the region requires farming systems that provide more yields per water unit and/or land area in the future.

Research conducted in this region over the years has pointed out that rain water harvesting in combination with improved soil fertility has potential to significantly increase crop production (Itabari and Wamuongo, 2003; Gichangi et.al., 2007). The rain water harvesting technologies that have been tested and found suitable for increasing crop productivity are those that retain rain water in situ in the farms for crops. They also allow rain water to be retained on open furrows for longer duration as the water infiltrates the soil through the tied and open ridges. These water harvesting techniques favour prolonged rain water infiltration and retention, thus raising the overall soil moisture and soil water holding capacity like the tied and open ridges (Itabari et al. 2003).

Better on-farm water management through rain water harvesting presents an opportunity to upgrade current farming practices in these climate regions (Rockstrom, 2003). Less risk of crop failure due to crop water deficits may improve farmers' willingness and ability to further invest with fertilizers and other crop management strategies.

Farmers in the drylands of SSA incorporate different technologies to improve *in-situ* water infiltration capacity. Examples are soil conservation technologies such as ridging and zai pits (Hatibu, 2003). Improved strategies incorporating in-situ water harvesting together with fertility management are also suggested (Gicheru et al., 2003; Jensen et al., 2003). Although these structures improve soil infiltration and crop water availability, the efficiency for mitigation of dry spell effects may be limited depending on soils inherent water holding capacity. The concept of conservation tillage, though not new, is gaining popularity in East Africa for sustainable crop production, especially in dry areas (Biamah et al. 2000; Jonsson et al. 2000). More people are beginning to realize that surface runoff is a resource as important as the rain, and that it can be used to improve crop production. Consequently, there has been a major development in a diverse range of technologies in water harvesting and conservation. Rain Water Harvesting (RWH) systems are also applicable over a wide range of conditions in areas where average annual rainfall is insufficient to meet the crop water requirement, with seasonal rainfall being as low as 100 to 350 mm (Oweis et al., 2001; SIWI, 2000).

Tillage practices that increase soil roughness such as tied ridging and ripping can increase soil water storage and availability to crop as they capture rainfall and increase the time for infiltration hence better crop yields Guzha (2004). The challenge faced by farmers when using tied ridging in Kenya is the high labour required because this tillage system is not mechanized (Nyamadzawo, 2013). Tied ridges**;** Small earthen tied contour ridges that break the slope, slow down erosive runoff and store water in the soil. Tied ridges usually have a height of to 20 cm and have an up slope furrow. These upslope furrows accommodate runoff from an uncultivated catchment strip. The catchment strips between the ridges can be used for small-scale production. Tied ridges can be used in arid and semi-arid areas with annual average precipitations between 200-750 mm per year. The soil should be at least 1.5 m deep to ensure adequate tree root development and to store sufficient water. The topography must be even without too many gullies and slopes can be up to 5% (Critchley et al., 1991). Tied ridges increase the capture of runoff water. They also help to increase the soil's capacity to store water and reduce erosion (both regulating ecosystem services). Ridges are built parallel to the contour lines. They enable water to infiltrate the soil more efficiently and add to soil moisture storage. To augment the efficiency of the ridges, ties are built up slope in order to stop lateral water flow. The ties are designed in a way that their height is two thirds of the ridge height, in order to prevent downstream overflow (Hunink et al., 2010).

Rain water harvesting in combination with improved soil tillage and fertility management has potential to significantly increase crop production (Itabari and Wamuongo, 2003; Gichangi et.al.

2007). Water and nitrogen are the most limiting factors in agricultural production in most parts of the world and especially in the arid and semi-arid areas (Cassman, 2001). Water and nitrogen have been overused in agriculture for decades (Gonzalez, 2010). This is no longer sustainable, considering the economic and environmental costs of these practices (Jury and Vaux, 2005). Water scarcity is driving the maximization of water and N use in agriculture, in order to meet current and future water demands while reducing resource requirements (Dugo et al., 2009)

2.2 Systems of Modeling Crop Growth

A system is a limited part of a reality that contains interacting elements, while a model is a simplified representation of such systems (Sterman, 2000). Simulation can be defined as the art of building mathematical models and the study of their properties in regard to those of the systems they represent (Penning de Vries et al., 1989). Attempts to model crop systems by including all that is known to be affecting the system would not be practical. Therefore, in crop simulation it is necessary to divide the system into its constituent parts (Jones and Ritchie, 1990). The values of many parameters are set either as observed in local experiments or extracted from literature sources. Some crop parameters that tend to fluctuate among cultivars are often calibrated to match selected data with model outputs (Makowski et al., 2006). Crop parameters are known to vary temporally but, in spite of this, some models simulate crop processes using single values of crop parameters over entire seasons and multi-year simulations. Models do not always behave intuitively and, since parameterization errors are one of the primary sources of uncertainty with many models (Quinton, 1997), the understanding of model response to the variation of parameter values is needed as one of the pre-requisites for model use. Multiple values of the parameters can be used for the simulations, allowing confidence limits to be assigned to the model output. A model whose outputs differ largely as a consequence of minor changes to its parameter values is of suspect reliability, especially if the sensitive parameters are difficult to estimate accurately.

Sensitivity analysis (Saltelli et al., 2000) calculates how much the outputs of a model depend to its inputs and is an important step of model evaluation to address parameter uncertainty, indirectly revealing the reliability of model estimates (Martorana and Bellocchi, 1999). Sensitivity analysis is also helpful to identify parameters respect to which an output is rather or entirely insensitive to, so that such redundant parameters may be ignored in subsequent analyses or modeling. One of the main objectives of modeling teams is to develop simulation approaches that require a minimum number of model parameters, using those which are biologically meaningful.

Agricultural systems are by nature complex ecosystems and numerous interacting factors involving soil, plant, climate and management components must be taken into account (Grabisch, 2003). The systems need to consider production, environmental and societal issues for the sustainability of agriculture (Sinclair and Seligman, 1996). Due to the complex nature of agricultural systems, modeling is a key tool that aids in understanding the intricacies of the interactions and delivers a myriad of potential outcomes to users world-wide. As models become more available to explore new management strategies and extend information to larger scales, proper parameterization, calibration and validation are critical for their use.

Agriculture is highly dependent on weather, and therefore, changes in global climate could have major effects on crop yields. Changes in climate will affect productivity in different ways depending on the hybrids and cropping systems in a region. Important direct effects will be through changes in temperature, precipitation, length of growing season, and timing of extreme or critical threshold events relative to crop development (Saarikko and Carter, 1996). According to the IPCC (2000), the effects of climate change will particularly be severe in ASALs since agriculture is rain-fed in most of the areas although irrigation is important in some regions. The absence of irrigation increases the sensitivity of crop yields to climate variations.

Agricultural systems are highly complex and therefore difficult to predict their behavior, however, dynamic of agricultural systems is possible with the use of simulation models. Simulation models are now valuable tools for representing the long term productive and environmental effects of different cropping systems and extrapolating the experimental results in time and space (Grabisch, 2003). Crop simulation models have emerged as a tool for agronomic management strategy evaluation and helped researchers in ascertainment of relationships among environment, management and yield variability (Sinclair and Seligman, 1996).

Research for agricultural development in the semi-arid tropics (SAT) is frustrated by high year-to-year climatic variability. Crop yield-simulation models provide a means of placing crop and environment information collected at a site during a particular season into the context of the variation in seasons for that and similar sites. Farmers make decisions that are surrounded by natural uncertainties, mainly weather. Agricultural research is designed to provide information that will help the farmer in making decisions. Application of a knowledge-based systems approach to agricultural management has been gaining popularity due to the growing knowledge of processes involved in plant growth, and the availability of inexpensive powerful. The systems approach makes use of dynamic simulation models of crop growth and cropping systems. Simulation models that can predict crop yield, plant growth and development and nutrient dynamics offer good opportunities for assisting, not only farm managers, but also regional decision makers in several aspects of decision making.

CropSyst simulation model, serves as an analytical tool to study the effect of climate, soil and management on cropping system productivity and the environment (Stockle et al., 2002). The model simulates the soil water budget, crop phenology, canopy and root growth, biomass production, crop yield, residue production and decomposition, soil erosion by water and salinity. These processes are affected by weather, soil characteristics, crop characteristics and cropping system management options, including crop rotation, cultivar selection, irrigation, nitrogen fertilization, soil and irrigation, water salinity, tillage operation and residue management.

The approach to dry matter partitioning is based on one empirical equation, with two main input parameters, the leaf area/ plant biomass ratio at the early growth stages (LAR, as m^2 leaves kg^{-1}), that the stem/leaf partition coefficient (SLP, as m^2 kg^{-1}), that accounts for the sharp decline of LAR as biomass accumulates overtime (Stockle and Nelson, 2003). On the other hand, dry matter portioning to commercial yield is simulated by multiplying final accumulated biomass by the harvest (HI), eventually corrected by water stress during flowering and fruit ripening. It has been shown that LtBC, BTR, LAR and SLP, together with other phenological parameters, are those that more strongly affect simulation results and thus must be chosen with care (Confalonieri and Bechini, 2004; Donatelli et al., 1997). The simplicity of the dry matter portioning may be regarded as an advantage, because CropSyst is easily parameterized and calibrated. This may contribute to a high level of diffusion, outside research institutions and with very practical aims. The use of CropSyst without an appropriate validation may lead to unreliable conclusion.

2.3 Sorghum and sweet potato yields and biomass simulation

Crop development is simulated based on thermal time required to reach specific growth stages (Baker, 2001). The accumulation of thermal time may be accelerated by water stress. Daily crop growth is expressed as biomass increase per unit ground area. CropSyst model accounts for four limiting factors to crop growth: water, nitrogen, light and temperature. Given the common pathway for carbon and vapor exchange of leaves, there is a conservative relationship between crop transpiration and biomass production. Daily biomass accumulation is calculated as in equation 1

$$BT = K_{BT}\ T/VPD \qquad (1)$$

Where B_T is the transpiration-dependent biomass production (Kg m^{-2} day^{-1}), T is the actual transpiration (Kg m^{-2} day^{-1}), and VPD is the mean daily vapor pressure deficit of the air (kPa). The Tanner-Sinclair relationship has the advantage of capturing the effect of site atmospheric humidity on transpiration use efficiency. However, this relationship becomes unstable at low VPD; indeed it would predict infinite growth at near growth at near zero VPD. To overcome this problem, a second estimate of biomass production is calculated following Monteith (1977) equation 2:

$$B_L = e\ I_{PAR} \qquad (2)$$

Where

B_L is the light-dependent biomass production (Kg m^{-2} day^{-1}), is the light-use efficiency (kg MJ^{-1}) and I_{PAR} is the daily amount of crop-intercepted photo-synthetically active radiation (PAR) (MJ^{-1} m^{-2} day^{-1}). Each simulation day, the minimum of B_T and B_L is taken as the biomass production for the day.

The increase of leaf area during the vegetative period, expressed as leaf area per unit soil area (Leaf area index, LAI), is calculated as a function of biomass accumulation, specific leaf area, and partition coefficient. Leaf area duration, specified in terms of thermal time and modulated by water stress, determines canopy senescence. Root growth is synchronized with canopy growth, and root density by soil layer is a function of root depth penetration. The penetration of yield is based on the determination of harvest index (grain yield/ aboveground biomass). Although an approach based on the prediction of yield components could be used, the harvest index seems more conservative and reliable for a generic crop simulator. The harvest index is determined using the unstressed harvest index and required crop input parameter, modified according to crop stress (water and nitrogen) intensity and sensitivity during flowering and grain filling.

2.4 Organic Inputs

High population density has led to rapid soil fertility decline as a result of continuous cropping and inappropriate cropping systems with very little or no external nutrient input to replenish soil fertility. Yields are generally low in most regions and are likely to continue declining because of the ever increasing population density. In fact, under current farming systems in small holders' fields, soil nutrient balances are negative (Bationo et al. 2006). In ASALs, low soil fertility is the most important yield-limiting factor in most of the bean producing regions. The major soil fertility related problems are found to be low available phosphorus (P) and nitrogen (N), and soil acidity, which is associated aluminum (Al) and manganese (Mn) toxicity.

Organic matter based soil nutrient management is a traditional practice that continues on smallholder farms. Among the organic resources used are animal manure, compost, crop residues for soil incorporation, natural fallowing, improved fallows, relay or intercropping of legumes, and biomass transfer (Place *et al.,* 2003). Organic manure, compost and farmyard manure are the most common inputs used to improve soil fertility by small scale farmers (Musungayi et al. 1990; Kankwatsa et al., 2008). The need for both organic and mineral inputs to sustain soil health and crop production through ISFM has been highlighted due to their positive interactions (Vanlauwe et al. 2010).

2.5 Crop Rotation and Intercropping

Intercropping can be defined as the agricultural practice of growing two or more crops within the same space at the same time (Andrews & Kassam, 1976). The main reason for growing two or more plant species together is the increase in productivity per unit of land. Several authors have shown that over time, average dry matter (DM) yields are higher with intercropping than when each of the plant species in the mixture is grown as a monoculture (Vandermeer, 1989). When legumes are included in a crop mixture, an extra benefit is improved soil fertility due to the legume species' fixation of biological nitrogen (N), and increased protein content of the cereal component (Jensen, 2006). Legumes fix atmospheric nitrogen, which may be utilized by the host plant or may be excreted from the nodules into the soil and be used by other plants growing nearby. The fixed nitrogen may also be released by decomposition of the nodules or leguminous residue after the legume plants die or are incorporated in the soil as residuals. The crop residues left on the surface or incorporated into the soils have an added advantage of reducing surface run-off and subsequent soil losses. The use of crop residues enhances nutrient cycling thereby reducing the need for fertilizer applications (Onyango and Clegg, 1993). Residue removal has been shown to reduce grain yields by amounts equal to 10-30% of the quantity of residue removed (Wilhelm et al., 1986). Legumes are grown as cover crops and serve as short-term fallow species. They have proven to be an effective means of sustaining soil fertility (Cheer et al., 2006). In addition, grain legumes are important as human food source and are rich in protein, while herbaceous and tree legumes are important livestock feeds

CHAPTER THREE

3.0 General Materials and Methods

3.1 Experimental site

The study was conducted in Matuu Sub-County located in Eastern part of Kenya between 1º37’ S and 1º45’ S latitude and 37º15’ E and 37º23’ E longitude (Fig 2). Matuu Division is in agro-climatic zone IV which is classified as semi-arid land (Jaetzold and Schmidt, 2006). Rainfall patterns exhibits distinct bimodal distribution. The first rains fall between mid- March and end of May and are known as the long rains (LR). The second rains, the short rains (SR), are received between mid-October and end of December. Average seasonal rainfall is between 250-400 mm. Inter-seasonal rainfall variation is large with a coefficient of variation ranging between 45-58 per cent, while temperature ranges between 17-24^{0}C. Evapo-transpiration rates are high and exceed the amount of rainfall most of the year except the month of November (Fredrick et al., 2000).

The soils are a combination of Luvisols, Lithisols, and Ferralsols according to USDA 1978, WRB, 2006) criteria. The soils are well drained, moderately to very deep, dark reddish brown to dark yellowish brown, friable to firm, sandy clay to clay, with high moisture storage capacity and low nutrient availability (Kibunja et al. 2010).

The majority of the farmers in the district are small-scale mixed farmers with low income investment for agricultural production. The major crops grown in Matuu Sub-Countyinclude maize, beans, cassava, pigeon peasand cowpeas **(**Macharia, 2004)

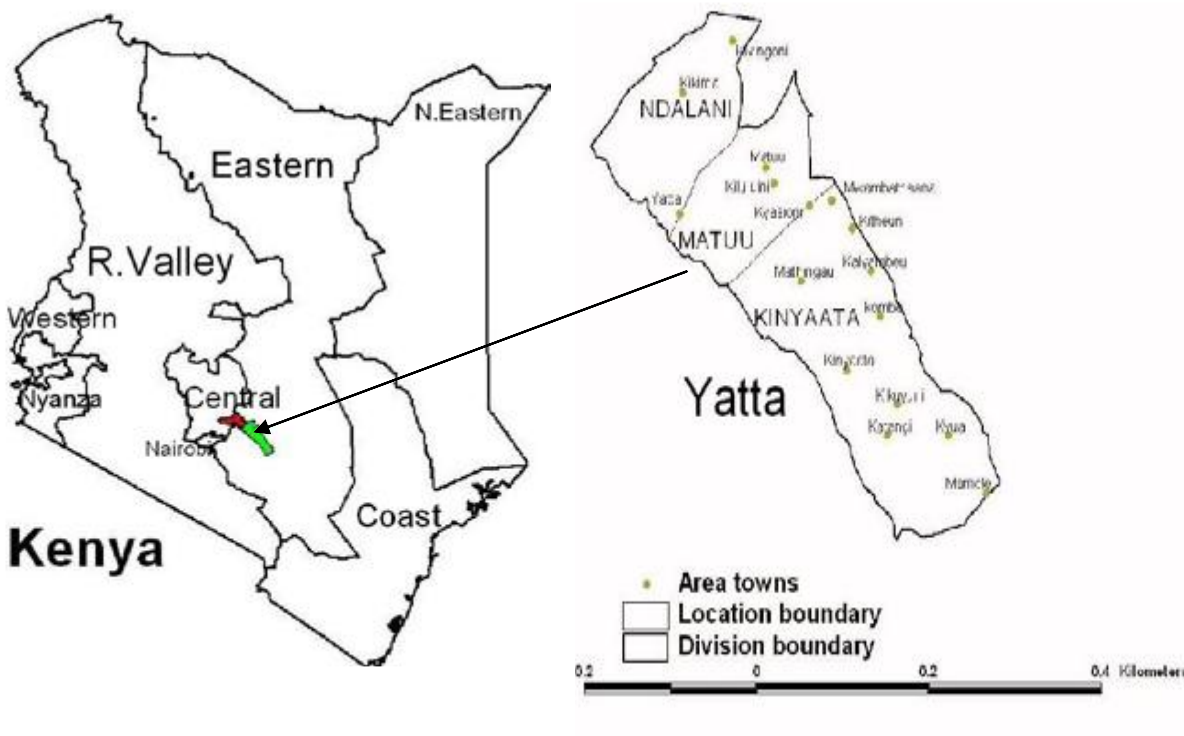


Figure 1: Map of Kenya showing Matuu Sub-County

3.2 Study Approach

The experiment was laid out in a Randomized Complete Block Design with split-split plot arrangement and replicated three times. The main plots were; tillage practices (Oxen plough, tied ridges and furrows, and ridges). Split plots were cropping systems (mono cropping, intercropping and crop rotation) and split-split plots were FYM, RP, FYM+RP and a control (no organic input was applied). The test crops were sorghum and sweet potato intercropped or grown in rotation with legumes; Dolichos and chickpea.

3.3 Agronomic practices

3.3.1 Land preparation and planting

The land was prepared using oxen to plough in late September 2012. Before planting in October, the field was divided into three equal portions in which furrows and ridges, tied ridges and oxen ploughed plots were prepared. The tilled plots were sub-divided into three in which three cropping systems namely monocropping, intercropping and crop rotation were applied. In each cropping system organic inputs such as FYM, RP, FYM+RP and a control were applied. Sorghum and sweet potato were planted in October during the short rains. Sorghum seeds were sown at a spacing of 30 cm by 60cm. Sweet potato cuttings were planted at a spacing of 30cm by 90cm. Weeding was done every 4 weeks after planting. Harvesting sorghum was done by hand after 3 months when it has reached physiological maturity while sweet potato were harvested manually using implements such as hoe after four months to prevent weevil damage.

3.3.2 Soil, plant sampling and analysis

Initial soil sampling was done in zig-zag manner using a soil auger at 0 – 15 cm, 15 – 30 cm and 30 – 45 cm depths and composited into one sample. The particle size analysis was done by the hydrometer method as outlined by Anderson and Ingram (1993). Soil pH was measured in a 1:2.5 ratio soil to water (pH H_2O) and to KCl (pHKCl) using a pH meter (Okalebo et al., 2002). To determine bulk density, soil was oven dried at (105^oC) to constant weight, after Blake and Hartage (1986). Field capacity and permanent wilting point was determined using Initial Drainage Curve described by Klute (1986), mineral nitrogen was determined by Kjeldahl method described by Bremner and Mulvaney (1982).

3.4 CropSyst Model description

The CropSyst model is premised on the assumption that actual biomass/ output growth is a result of interactions involving various independent variables which include weather, soil types, management practices and crop physiology (Fig. 2). The model simulates soil water budget, crop canopy and root growth, dry matter production, yield, residue production and decomposition, and erosion. Management options include: cultivar selection, crop rotation, irrigation, nitrogen fertilization, tillage operations (over 80 options) and residue management.

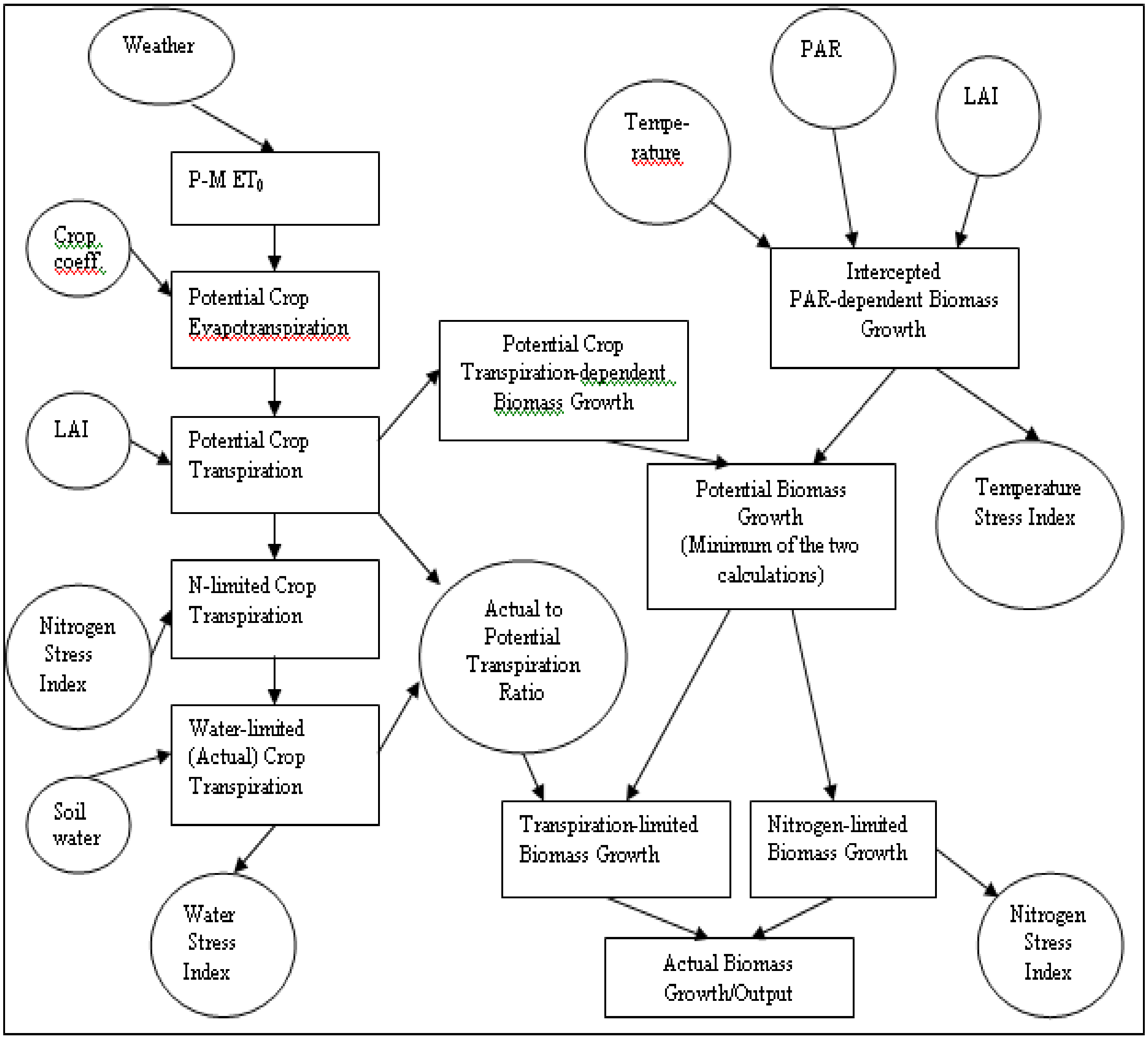


Figure 2: Flowchart of biomass growth calculations in CropSyst

Source: Adopted from Stockle et al., 2003.

3.5 Data sets

Four input data files were required to run CropSyst: Location, Soil, Crop, and Management files. Separation of files allows for an easier link of CropSyst simulations with GIS software. A Simulation Control file combines the input files as desired to produce specific simulation runs. In addition, the Control file determines the start and ending day for the simulation, define the crop rotations to be simulated, and set the values of all parameters requiring initialization.

The Soil file includes surface soil Cation Exchange Capacity and pH, required for ammonia volatilization, parameters for the curve number approach (runoff calculation), surface soil texture (for erosion calculation), and four parameters specified by soil layer: Layer thickness, Field water Capacity, Permanent Wilting Point and Bulk Density.

The Management file includes automatic and scheduled management events. Automatic events (irrigation and nitrogen fertilization) are generally specified to provide optimum management for maximum growth, although irrigation can be also set for deficit irrigation. Management events can be scheduled using actual date, relative date (relative to year of planting), or using synchronization with phonological events (e.g., number of days after flowering). Scheduled events include irrigation (application date, amount, chemical or salinity content), nitrogen fertilization (application date, amount, source- organic and inorganic-, and application mode-broadcast, incorporated, injected), tillage operations (primary and secondary tillage operations, which are basically related to residue fate), and residue management (grazing, burning, chopping, etc.).

The Crop file allows users to select parameters to represent different crops and crop cultivars using a common set of parameters. This file is structured in the following sections: Phenology (thermal time requirements to reach specific growth stages, modulated by photoperiod and vernalization requirements if needed), Morphology (Maximum LAI, root depth, specific leaf area and other parameters defining canopy and root characteristics), Growth (transpiration-use efficiency normalized by VPD, light-use efficiency, stress response parameters, etc.), Residue (decomposition and shading parameters for crop residues), Nitrogen Parameters (defining crop N demand and root uptake), Harvest Index (unstressed harvest index and stress sensitivity parameters), and Salinity Tolerance.

The Location file includes information such as latitude, weather file code name and directories, rainfall intensity parameters (for erosion prediction), freezing climate parameters (for locations where soil might freeze), and local parameters to generate daily solar radiation and vapor pressure deficit values. Meteorological data collected from Katumani which is the nearest weather station, daily values of temperatures (minimum and maximum), rainfall and global radiation, wind speed and relative humidity (minimum and maximum) were used for the CropSyst model.

3.6 CropSyst calibration

Input files required by CropSyst model for Matuu Division, Sorghum and sweet potato crops, different tillage practices, cropping systems and organic inputs were prepared and used to run the model. Measured soil properties such as soil texture, soil pH, bulk density, permanent wilting point, field capacity and cation exchange capacity were used to prepare the soil file. Each tillage practice was used to prepare the management files. The date of each phonological stage was used to calculate the growing degree days (Table 1). The values of the crop input parameters were either taken from the CropSyst manual (Stockle and Nelson, 1994) or set to the values observed (GDD) in the experiments. The measure soil properties were adjusted until biomass and yield values were close to the measured values.

Table 1: Crop parameters for CropSyst model calibration of sorghum and sweet potato based cropping systems

Parameter	Sorghum	Sweet potatoes
Growing degree days emergence (°C-day)	100	300
Growing degree days peak leaf area index (LAI) (°C-day)	1867	22
Growing degree days flowering (°C-day)	1165	1440
Growing degree days maxi mum grain-filling (°C-day)	1209	1875
Growing degree days maturity (°C-day)	1846	2674
Maximum harvest index	1.47	0.49
Maximum expected LAI	7.0	9.0
Base temperature (°C)	8	3
Cut-off temperature (°C)	30	25
Optimum mean daily temperature (°C)	25	23
Maximum root depth (m)	1.2	0.6

3.7 Validation

Validation is the process of determining the degree to which a model is an accurate representation of a real world from the perspective of the intended use or simulation. Validation was done using percentage difference (PD), Root mean square error (RMSE) and Wilmott Index of Agreement (WI). PD is the percentage difference between measured and observed values.

RMSE: This is frequently used measure of the difference between values predicted by a model and those actually observed from the experiment that is being modeled. The RMSE values can be used to distinguish model performance in a calibration period with that of a validation period as well as to compare the individual model performance to that of other predictive models Equation 4

$$\text{RMSE} = [n^{-1} \sum(\text{Yield}_{meas} - \text{Yieldpred})^2] \quad (4)$$

Furthermore, (WI) of agreement was calculated, which take a value between 0.0 and 1.0; where 1.0 means perfect fit (Willmott, 1981)

3.8 Simulations

The input files required by the CropSyst model for Matuu Division, sorghum and sweet potato crops were used to run the model. Planting dates were set as 10th October, 2012 for both crops. Simulations were run from 10th September, 2012 a month before planting and ended in 31st March, 2013 for sorghum and 31st May, 2013 for sweet potato. The experiment was repeated for the second season in 2013. The starting and ending dates indicated the simulation period. Sweet potato required more time to mature compared to sorghum and hence the difference in the ending simulation date. Sorghum and sweet potato was simulated by specifying the soil, location, crop and management practices.

3.9 Statistical test

Effect of the different treatments on simulated soil moisture and crop yields were statistically evaluated by analysis of variance (ANOVA) as a split split plot design with three replicates (Genstat 15.0 for Windows). Least Significant Differences (LSD) at the 5% level were used to detect differences among means.

CHAPTER FOUR

4.0 Results and discussions

Simulating Soil Moisture under different Tillage Practices, Cropping Systems and Organic Inputs Using CropSyst Model

Abstract

Soil moisture stress in the arid and semi-arid lands (ASALs) is a limiting factor in crop production as it affects many physiological and biochemical processes of plants. Research on moisture conservation measures is thus imperative. The current study used CropSyst model to simulate soil moisture under different tillage practices(oxen plough, tied ridges and furrows and ridges), cropping systems (monocropping, intercropping and crop-rotation) and organic inputs (farm yard manure (FYM), rock phosphate (RP) and mixed Farmyard manure and rock phosphate (RP+FYM) in 2012-13 and 2013. The study was conducted in Matuu Division, Kenya. The experiment was laid out in a Randomized Complete Block design with a split-split plot arrangement and replicated three times. The main plots were tillage practices, split plots were cropping systems and split-split plots were organic inputs.

The test crops were sorghum (*Sorghum bicolor L.*) and sweet potato (*Ipomea batatas L.lam*) rotated and/or intercropped with dolichos (*Lablab purpureus*) and chickpea (*Cicer arietinum*). The CropSyst model was calibrated using the Observed soil texture, permanent wilting point, field capacity, bulk density and initial soil moisture. Validation of the model was done using Root Mean Square Error (RMSE), percentage differences (PD) and willmott index (WI) of agreement. CropSyst model was accurately validated due to the low RMSE (0.5 to 1.3) and PD (less than ±15) values that were obtained and the WI index which was close to 1.

In the sorghum based cropping systems, simulated soil moisture (101.91 mm) was significantly ($P < 0.05$) high in the interactions between tied ridges with sorghum/dolichos intercrop when RP + FYM were applied and least (13.52 mm) in the interactions between oxen plough with sorghum mono cropping when no organic input was applied in the first season.

In the second season, simulated soil moisture was significantly high (108.3 mm) in the tied ridges with sorghum/dolichos intercropping when FYM + RP were applied. Least soil moisture

(15.4m m) was observed in the interactions between the oxen plough with sorghum monocropping when no organic input was applied.

In the sweet potato based cropping system, soil moisture (95 mm) was significantly high in tied ridges, sweet potato- dolichos rotation (75.32 mm), when RP and FYM was applied (75.03 mm) and least in the oxen plough (32.49 mm), sweet potato monocropping (53.46) and control (52.52 mm). In the second season, soil moisture was significantly high in the tied ridges (100.24 mm), sweet potato-dolichos rotation (79.63 mm) with application of RP + FYM (79.39 mm) and least in the oxen plough (34.36 mm), sweet potato monocropping (55.26 mm) and control (55.39 mm).

In sorghum and sweet potato based cropping systems, soil moisture was highest in the tied ridges, intercropping and rotation systems with application of FYM + RP and least in the oxen plough, monocropping when no organic input was applied. In sorghum based cropping system, soil moisture was high in the interactions involving tied ridges with sorghum intercropped with dolichos when FYM + RP were applied. In the sweet potato based cropping system high soil moisture was observed in the interactions involving tied ridges with sweet potato intercropped with dolichos when FYM +RP with application.

Soil moisture in the ASALs could be improved by the use of tied ridges, FYM+RP, intercropping and crop rotation systems. Tied Ridges hold water for long time hence increasing infiltration. FYM+RP improved on soil organic carbon hence increasing water retention in the soil.

Keywords; Arid and semi-arid lands; Cropping systems; CropSyst model;, soil moisture; Sorghum; Sweet potato

4.1 Introduction

In arid and semi lands, plant production is limited by soil moisture availability and actual evapotranspiration (Biamah, 2005). The two parameters influence the occurrence of water stress in rainfed agricultural systems. Fluctuations in soil moisture often have negative effects on crop productivity (Purcell et al., 2007). In these lands soil moisture deficits, soil fertility depletion and soil erosion are major constraints to agricultural crop production (Biamah et al., 1998). Moisture loss from the soil through evaporation and presence of erratic rainfall in the middle of the cropping season leads to crop failure.

Introduction of soil moisture conservation methods would require insights on how such a method would impact on present crop production. To study the effects of different moisture conservation methods would require complicated field experiments. Crop-soil simulation models could complement field experiments. The crop-soil simulation model CropSyst can serve such purposes.

CropSyst is a multi-year, multi-crop, daily time step cropping systems simulation model developed to serve as an analytical tool to study the effect of climate, soils and management on cropping systems productivity and the environment (Stockle et al., 1994). CropSyst simulates the soil water and nitrogen budgets, crop growth and development, crop yield, residue production and decomposition, soil erosion by water and salinity (Donatelli et al., 1999). The model was used to simulate soil moisture under different tillage practices, cropping systems and organic inputs in a sorghum and sweet potato based cropping systems using CropSyst model.

4.2 Materials and Methods

4.2.1 Experimental site

The study was conducted in Matuu Sub-County of South-eastern Kenya between 1º37’ S and 1º45’ S latitude and 37º15’ E and 37º23’ E longitude and an altitude of 700-800 meters above sea level. Matuu Division is in agro-climatic zone IV which is classified as semi-arid land (Jaetzold and Schmidt, 2006). Rainfall patterns exhibits distinct bimodal distribution. The first rains fall between mid- March and end of May and are locally known as the long rains (LR). The second rains, the short rains (SR), are received between mid-October and end of December. Average seasonal rainfall is between 250-400 mm. Inter-seasonal rainfall variation is large with a coefficient of variation ranging between 45-58 per cent, while temperature ranges between 17-24^{0}C (Fredrick et al., 2000).

Soils in the area are well drained, dark-reddish brown to dark yellowish brown, friable to firm, sandy clay to clay and low nutrient availability (Kibunja et al., 2010). The soils are a combination of Luvisols, Lithisols, and Ferralsols according to USDA (1978) and WRB (2006) criteria.

The majority of the farmers in the district are small-scale mixed farmers with low income investment for agricultural production. The major crops grown in the area include maize, beans, cassava, pigeon peas, sweet potatoes and cowpeas **(**Macharia, 2004) Crop performance and yield are significantly influenced by the amount of rainfall and distribution throughout the rainy season.

4.2.2 Treatments and Experimental design

To obtain data for CropSyst model calibration, field experiments were conducted for two seasons; short rain season in 2012 and long rain season in 2013. Data for season one was used to calibrate the model while season two data was used for model validation. The experimental layout was a Randomized Complete Block Design with split-split plot arrangement and replicated three times. The main plots were tillage practices (Oxen plough, tied ridges and furrows, and ridges), split plots were cropping systems (mono cropping, intercropping and crop rotation) while split-split plots were organic inputs (FYM, RP and FYM + RP). A control denoted that no organic input was applied. The test crops were sorghum and sweet potato intercropped or grown in rotation with legumes; Dolichos and chickpea.

4.3 Agronomic practices

4.3.1 Land preparation and planting

The land was prepared using oxen to plough in late September 2012. Sorghum and sweet potato were planted in October during the short rains. Sorghum seeds were sown at a spacing of 30 cm by 60cm. Sweet potato cuttings were planted at a spacing of 30cm by 90cm. Weeding was done every 4 weeks after planting. Harvesting sorghum was done by hand after 3 months when it had reached physiological maturity while sweet potato was harvested manually using hand hoe after four months.

4.3.2 Soil Sampling and analysis

Soil sampling was done before planting, during flowering stage and at harvest in a zig-zag manner using a soil auger at 0-15 cm, 15-30 cm and 30-45 cm depths and composited in to one sample per depth for physical and chemical analysis before application of treatments. Thereafter soil samples were collected from the top soil during flowering and harvesting stages of sorghum and sweet potato from each treatment. Soil was analyzed for chemical (pH, and mineral nitrogen) and physical (soil texture, bulk density, field capacity and permanent wilting point) properties. The observed soil properties were used for initial soil characterization and to prepare the soil file to be used in calibrating CropSyst model. Soil moisture content was determined by the gravimetric method for each plot before sowing, during flowering and at harvest. Soil moisture observed by gravimetric method (weight basis) was converted into volumetric proportion by multiplying with bulk density (Eqn 1) and converted to volumetric water (mm) by multiplying with soil depth divided by 10 (Eqn 2)

$$\textbf{Volumetric water \% = gravimetric water (\%) x Bulk Density (g/cm}^3\textbf{)} \qquad \textbf{(Eqn 1)}$$

$$\textbf{Volumetric water mm = volumetric \% x } \frac{\textbf{soil test depth (cm)}}{\textbf{10}} \qquad \textbf{(Eqn 2)}$$

The particle size analysis was done by the hydrometer method as outlined by Anderson and Ingram (1993). Soil pH was observed in a 1:2.5 ratio soil to water (pH H_2O) and to KCl (pHKCl) using a pH meter (Okalebo et al., 2002). Bulk density was determined according to Blake and Hartage (1986). Field capacity and permanent wilting point was determined using Initial Drainage Curve as described by Klute (1986), mineral nitrogen was determined by Kjeldahl method (Bremner and Mulvaney, 1982).

4.4 CropSyst Model description

The CropSyst model is premised on the assumption that actual biomass/output growth is a result of interactions involving various independent variables which include weather, soil types, management practices and crop physiology. The model simulates the soil water budget, crop canopy and root growth, dry matter production, yield, residue production and decomposition, and erosion. Management options include: cultivar selection, crop rotation, irrigation, nitrogen fertilization, tillage operations (over 80 options) and residue management.

4.5 Data sets required to run CropSyst model

Four input data files are required to run CropSyst: Location, Soil, Crop, and Management files. The data files used to run the model are given in Table 2. The dates for the phenological stages; emergence, flowering stage, grain filling and physiological maturity were used to calculate growing degree days (GDD= T_{mean}-T_{base} ; where Tmean =(T_{max} + T_{min})/2). Location file was also prepared using the actually observed weather data from the nearest weather station. For each tillage practices, management files were prepared to represent each cropping systems and organic inputs. Soil moisture measurements were used for model calibration. The values of crop input parameters (maximum harvest index, maximum expected LAI, base temperature, cut-off temperature and maximum root depth were taken from the CropSyst manual.

Table 2: Data sets required to run CropSyst model

File/	Parameters Required by the Model	Parameters used in the model
Location	Latitude, Longitude, Altitude	Latitude: 37º15' E and 37º23' E Longitude: 1º37' S and 1º45' S Altitude: 700-800m a.s.l
Soil	pH, Permanent wilting point, Field capacity, Bulk density, Soil texture	Table 2 (observed in the field)
Crop,	Growing degree days (GDD) to emergence, GDD to peak leaf area index, GDD to flowering, GDD to maximum grain filling, GDD to maturity,Base temperatures, Cut-off temperatures, maximum root depth.	(GDD were observed in the experimental site) Other crop input parameters were taken as default values.
Management	**Nitrogen fertilization** (application date, amount, source- organic and inorganic-, and application mode- broadcast, incorporated, injected), **Tillage operations** (primary and secondary tillage operations),	**Organic inputs;** FYM, RP, FYM + RP **,** calibration was done for RP which is not currently in the model **Tillage practices**; Tillage operations were calibrated for oxen plough, tied ridges, furrows and ridges

GDD; growing degree days, FYM; farm yard manure, RP; rock phosphate

Stockle et al., 2003

4.6 CropSyst model Calibration

The calibrated values (Table 3) were permanent wilting point, field capacity and mineral nitrogen. CropSyst calibration was informed by nitrogen and water stress in the soil profiles. This led to adjustment of initial soil moisture in the soil profile to counter for water stress. Permanent wilting point and field capacity were adjusted from 0.17 m3/m^3 to 0.29 m3/m^3 and 0.23 m3/m^3 to 0.38 m3/m^3 respectively (Table 3). Permanent wilting point and field capacity determine the available soil moisture hence raising the values also led to increased soil moisture. Mineral nitrogen was also adjusted from 24 kg N ha^{-1} to 58.91 kg N ha^{-}1 (Table 3). Increasing the amount of soil moisture and nitrogen in the soil resulted in increased simulated above ground biomass and yield to reflect the observed. Bulk density, soil texture and soil pH were not adjusted since they didn't have an impact on the simulated soil moisture (Table 3). The values were adjusted by comparing the observed soil water content with the model output. Calibrated values ensured closeness between the observed soil water values and the simulated values. Crop growth was majorly affected by the soil moisture and nitrogen content and adjustment to the required amount was done. Soil texture and bulk density were not calibrated since they were within the required range and their calibration.

Table 3: Observed and calibrated physioc-chemical soil properties

Soil properties	**Observed soil properties/Depth (cm**			**Calibrated soil properties Depth (cm)**		
	0-10	**10-20**	**20-30**	**0-10**	**10-20**	**20-30**
Sand(%)	49.32	49.30	49.36	49.32	49.30	49.36
Silt (%)	**38.88**	**38.97**	38.77	38.88	38.97	38.77
Clay(%	11.8	11.71	11.78	11.8	11.71	11.78
Textural class	Sand Clay	Sand Clay	Sand Clay	Sand Clay	Sand Clay	Sand Clay
pH (H_20)	6.5	6.7	6.8	6.5	6.7	6.8
Permanent wilting point (m^3/m^3)	0.17	0.18	0.20	0.27	0.28	0.29
Field capacity (m^3/m^3)	0.23	0.25	0.27	0.34	0.36	0.38
Bulk density (g $cm^{-3)}$	1.503	1.508	1.67	1.503	1.508	1.67
NH_4-N (Kg N ha^{-1})	28.54	27.02	34.76	58.91	57.39	55.46
NO_3--N (Kg N ha^{-1})	24.87	29.34	25.72	52.67	51.83	50.44

4.7. Model Validation

CropSyst was validated by comparing model outputs with the Observed soil moisture in different tillage practices cropping systems and organic inputs. The agreement between model and reality was verified by means of percentage differences (PD) and root mean square error (RMSE): This is frequently used measure of the difference between values simulated by a model and those actually observed from the experiment that is being modeled (Eqn 3).

$$RMSE = [n^{-1} \sum(Yield_{meas} - Yieldpred)^2] \qquad 3$$

Furthermore, Willmott index (WI) of agreement was calculated, which take a value between 0.0 and 1.0; where 1.0 means perfect fit (Willmott, 1981)

4.8 Simulations

Simulations were run by creating project scenarios in CropSyst. Each tillage practice represented a scenario in which the weather data, soil file, crop file, management and format were selected. Each scenario was run separately and the consequent output produced.

Planting dates were set as 10^{th} October, 2012 for both crops. Simulations were run from 10^{th}, September, 2012 a month before planting and ended in 31^{st}, March 2013 for sorghum and 31^{st} May for sweet potato. The experiment was repeated for the second season in 2013. The starting and ending dates indicated the simulation period. Sweet potato required more time to mature compared to sorghum and hence the difference in the ending simulation date. Soil moisture was simulated by specifying the soil, location, crop and management practices (Table 1)

4.9 Statistical test

Measured and simulated soil moisture values were statistically evaluated by analysis of variance (ANOVA) as a split- split plot design with three replicates (Genstat 14.0 for Windows). Least Significant Differences (LSD) at the 5% level were used to detect differences among means.

Validation of CropSyst model for soil moisture (mm) in sorghum and sweet potato based cropping systems.

Sorghum based cropping systems: the simulation of soil moisture showed low values of RMSE and percentage differences between observed and simulated values of soil moisture in the sorghum based cropping system (Table 3). The percentage differences (PD) between the observed and simulated values in all cropping systems, oxen plough and FYM ranged from -3.43 to +7.04, the RMSE was 0.582 and a wilmott index of agreement (WI) of 0.989. The PD in all the cropping systems under furrows and ridges with combined FYM and RP ranged from -3.128 to +6.203, the RMSE was 0.512 and a WI of 0.974. In RP, the PD ranged from -2.002 to + 4.661 while the RMSE was 0.487 and a WI of 0.999. In the control, the PD ranged from -0.184 to + 6.123 with RMSE of 0.884 and WI of 0.907 (Table 3)

The PD in the furrows and ridges, cropping systems and FYM ranged from -3.73 to +2.57 while the RMSE was 0.682 and a WI of 0.995. When FYM was combined with RP, the PD ranged from -3.73 to + 2.57 with RMSE of 0.872 and WI of 0.993. In RP, the PD ranged from -1.51 to + 4.994 with a RMSE of 0.685 and WI of 0.957. In the control, the PD ranged from -2.96 to + 8.67 with a RMSE of 0.895 and WI of 0.987 (Table 3)

Under tied ridges, all cropping systems and FYM, the PD between observed and simulated values ranged from -1.39 to 3.58 while the RMSE was 0.8286 and WI of 0.955 (Table 4). In the combined FYM and RP the PD ranged from -1.633 to + 3.078 with RMSE of 0.885 and WI of 0.952. In RP, the PD ranged from -1.66 to +0.244 with a RMSE of 0.624 and WI of 0.925. In the control, the PD ranged from -1.05 to +1.55 with a RMSE of 0.687 and WI of 0.972 (Table 3)

The percentage differences between observed and simulated values are less than 9% hence implying closeness between observed and simulated values. Stockle et al (2003) noted that simulation models can over-or under-estimate observed values by ±27 percent, without necessarily undermining reasonability of estimates obtained. All the simulated yields therefore are within what can be termed as reasonable estimates of the actual soil moisture.

The low values of RMSE indicate that CropSyst model reasonably simulated soil moisture for different cropping systems, tillage practices and organic inputs. The higher Wilmot index values for the soil moisture indicate that the model simulates soil moisture reasonably.

CropSyst model has also been reported to simulate soil moisture to a reasonable range as stated by Baroudy et al., (2012) who found an RMSE of 2.5mm and 2.23 mm and a WI of 0.98 and 0.96 while determining soil water for two growing seasons. Similarly Benli et al., (2007) obtained a high Wilmott index of agreement with a value of 0.98 and attributed this to the agreement between observed and simulated soil moisture values.

Table 4: Statistical comparisons of observed and simulated soil moisture (mm) under different tillage practices, cropping systems and organic input during sorghum growing season

Treatments	FYM			FYM+RP			RP			CONTROL		
Oxen plough	**Obs**	**Sim**	**PD (%)**	**Obs**	**Sim**	**PD (%)**	**Obs**	**Sim**	**PD (%)**	**Obs**	**Sim**	**PD (%)**
SOR- MONO	21.913	20.82	+0.049	19.5	20.11	-3.128	18.1	17.92	+0.994	14.203	16.816	- 0.184
SOR/ DOL	49.35	49.00	+0.717	56.9	57.38	-0.844	60.9	59.32	+ 2.59	46.886	44.887	+ 4.24
SOR/CP	46.97	46.41	+ 7.04	57.13	56.48	+1.138	60.88	61.22	-0.558	37.558	43.41	+4.947
SOR-DOL	40.64	40.88	+ 3.83	17.41	16.33	+6.203	25.31	24.31	+4.661	32.515	33.367	+1.88
SOR-CP	33.845	35.68	- 3.43	44.43	45.75	-2.566	38.97	39.57	-2.002	28.317	25.583	+6.123
RMSE	**0.582**			**0.512**			**0.487**			**0.884**		
WI	**0.989**			**0.974**			**0.999**			**0.907**		
Furrows and ridges												
SOR- MONO	36.53	35.59	+ 2.57	43.05	40.9	+4.994	38.75	36.84	+4.929	29.224	26.69	+ 8.67
SOR/ DOL	79.89	80.84	- 1.19	94.16	94.87	-0.754	84.47	86.02	-1.510	63.914	63.34	+ 0.9
SOR/CP	60.126	62.37	- 3.73	70.68	69.62	+1.749	63.87	64.83	-0.941	48.101	47.25	+1.77
SOR-DOL	84.755	84.51	+ 0.29	78.47	77.52	+1.549	89.09	88.80	+1.224	67.804	69.19	-2.96
SOR-CP	66.817	66.51	+ 0.524	93.04	94.85	-1.9454	70.82	71.31	-0.607	53.454	51.83	+3.03
RMSE	**0.682**			**0.872**			**0.685**			**0.895**		
WI	**0.995**			**0.993**			**0.957**			**0.987**		
Tied Ridges												
SOR- MONO	76.94	78.00	- 1.39	87.17	85.01	+3.078	84.31	85.71	-1.66	72.8	70.72	+ 1.03
SOR/ DOL	93.77	93.62	+ 0.16	90.21	89.27	+1.072	93.02	94.12	-1.279	89.90	88.51	+ 1.55
SOR/CP	75.83	73.11	+ 3.56	86.32	87.03	-0.787	89.12	90.21	-1.369	72.75	73.00	- 0.35
SOR-DOL	83.72	83.10	+ 0.749	85.01	86.42	-1.633	90.05	89.83	+0.244	80.55	81.39	- 1.05
SOR-CP	88.38	87.21	+ 1.319	93.7	92.56	+1.235	96.08	97.05	-0.109	87.45	87.21	+ 0.48
RMSE	**0.82860.955**			**0.885**			**0.624**			**0.687**		
WI				**0.952**			**0.925**			**0.972**		

Obs-Observed, Sim-Simulated; SOR-MONO; Sorghum monocropping, SOR/DOL; Sorghum dolichos intercrop, SOR/CP; Sorghum chickpea intercrop, SOR-DOL; Sorghum dolichos rotation, SOR-CP; Sorghum chickpea rotation, RP; Rock phosphate, FYM; farm yard manure, PD; Percentage differences, RMSE; root mean square error, WI; wilmott index

Sweet potato based cropping systems:

CropSyst model showed good agreement between observed and simulated values of soil moisture in the sweet potato based cropping systems (Table 4). In oxen plough and all cropping systems where FYM was applied, PD ranged from - 7.2 to +12.09 with RMSE of 1.323 and WI of 0.906. In FYM + RP, PD ranged from -5.003 to +7.539 with RMSE of 1.012 and WI of 0.966. In RP, PD ranged from -4.538 to +8.1 with RMSE of 0.973 and WI of 0.953 while in control, PD was -6.7 to + 6.3 with an RMSE of 0.753 and WI of 0.946 (Table 4)

Under furrows and ridges and in all cropping systems, when FYM was used, PD ranged from (-) 4.3 to (+) 2.8 with RMSE of 0.687 and WI of 0.996, in RP, the PD ranged from -3.548 to + 4.217 with RMSE of 1.155 and WI of 0.986 while in control PD ranged from -5.8 to 2.6 with RMSE of 0.699 and WI of 0.997 (Table 4)

In tied ridges and all cropping systems when FYM was used the PD ranged from - 3.4 to + 3.6 with RMSE of 1.249 and WI of 0.739, in the FYM combined with RP, the PD ranged from -1.902 to + 1.788 with RMSE of 0.878 and WI of 0.832, in RP, the PD ranged from -0.815 to + 1.888 with RMSE of 0.693 and WI of 0.831while in control the PD ranged from -3.7 to +3.9 with RMSE of 1.083 and WI of 0.889 (Table 4).

The percentage differences between observed and simulated values for soil moisture in the different tillage practices, cropping system and organic inputs were less than ± 13% indicating closeness between measured and simulated values. Low percentage differences between observed and simulated values shows good agreement. According to brassard and singh (2007), a difference between observed and simulated values of up to ±15% was judged acceptable since there is closeness between the two values

Tingem et al., (2008) also found a percentage difference between observed and simulated values ranging from 0.6 to -4.5 which are similar to the above results. Singh et al.,(2008) found CropSyst to predict soil moisture well with low RMSE values.

Table 5: Statistical comparisons of observed and simulated soil moisture (mm) under different tillage practices, cropping systems and organic input during sweet potato growing season

Treatments	FYM			FYM+RP			RP			CONTROL		
Oxen plough	Obs	Sim	PC (%)	Obs	Sim	PC (%)	Obs	Sim	PC (%)	Obs	Sim	PC (%)
SP-MONO	31.13	27.37	+ 12.1	28.68	27.41	+4.428	26.44	25.31	+4.274	20.75	21.72	- 5.6
SP/ DOL	30.98	30.39	+2.0	37.90	35.98	+5.066	34.11	32.88	+3.606	24.79	26.24	- 6.0
SP/CP	25.01	26.46	- 6.0	30.58	32.11	-5.003	27.53	25.30	+8.100	20.00	18.73	+ 6.3
SP-DOL	42.43	45.48	- 7.2	49.46	50.76	-2.628	44.51	46.53	-4.538	32.68	34.32	- 5.0
SP-CP	20.17	20.76	- 2.9	24.67	22.81	+7.539	22.20	20.66	+6.937	16.13	17.21	- 6.7
RMSE	**1.323**			**1.012**			**0.973**			**0.753**		
WI	**0.906**			**0.966**			**0.953**			**0.946**		
Furrows and ridges												
SP- MONO	41.16	42.93	- 4.3	48.86	50.13	-2.599	43.97	45.53	-3.548	32.93	34.85	- 5.8
SP/ DOL	58.64	57.03	+ 2.8	69.62	67.87	+2.514	62.66	64.64	-3.548	46.91	46.02	+ 1.9
SP/CP	43.49	43.81	- 0.7	51.63	50.20	+3.769	46.47	44.51	+4.217	34.79	33.88	+ 2.6
SP-DOL	94.42	75.54	- 1.3	82.53	80.35	+2.642	81.22	83.79	-3.164	95.66	74.57	+ 1.3
SP-CP	84.97	84.98	- 2.4	87.55	89.52	-2.250	85.79	84.03	+2.052	67.97	68.88	-1.3
RMSE	**0.687**			**1.011**			**1.153**			**0.699**		
WI	**0.996**			**0.987**			**0.986**			**0.997**		
Tied Ridges												
SP-MONO	84.19	87.18	- 1.1	90.10	91.76	-1.842	88.38	86.89	+1.685	82.07	80.98	- 3.7
SP/ DOL	87.51	87.97	- 3.4	91.17	89.91	+1.382	84.90	83.76	+1.343	83.95	85.71	- 3.3
SP/CP	82.93	79.92	+ 3.6	90.04	88.43	+1.788	87.38	85.73	+1.888	71.68	74.47	+ 3.9
SP-DOL	86.85	85.71	+ 1.6	94.11	95.90	-1.902	84.70	85.39	-0.815	69.48	70.33	- 1.2
SP-CP	95.10	93.12	+ 2.1	96.41	95.23	+1.223	92.75	93.45	-0.755	76.08	78.27	- 2.9
RMSE	**1.249**			**0.878**			**0.693**			**1.083**		
WI	**0.739**			**0.832**			**0.831**			**0.889**		

Obs; Observed, Sim; Simulated, SP-MONO; Sweet potato monocropping, SP/DOL; Sweet potato dolichos intercrop, SP/CP; Sweet potato chickpea intercrop, SP-DOL; Sweet potato dolichos rotation, SOR-CP; Sweet potato chickpea rotation, RP; Rock phosphate, FYM; Farm yard manure, PD; Percentage differences, RMSE; root mean square error, WI; wilmott index of agreement

Simulated soil moisture in the sorghum and sweet potato based cropping systems

Sorghum based cropping system: There were significant (P < 0.05) differences in soil moisture in the tillage practices, cropping systems and organic inputs in the two seasons. The were also significant interactions (P<0.05) in the tillage practices with cropping systems , tillage practice with organic input and tillage practice with cropping systems and organic inputs.

In the first season, simulated soil moisture (101.91 mm) was significantly (P < 0.05) high in the interactions between tied ridges with sorghum/dolichos intercrop when RP and FYM were applied (Fig. 3). Simulated soil moisture (13.52 mm) was lowest in the interactions between oxen plough with sorghum mono cropping when no organic input was applied (Fig. 3)

In the second season, simulated soil moisture was significantly high (108.3 mm) in tied ridges with sorghum/dolichos intercropping when FYM+RP were applied (Fig. 4). Lowest simulated soil moisture (15.4 mm) was observed in the interactions between oxen plough with sorghum monocropping when no organic input was applied. (Fig. 4)

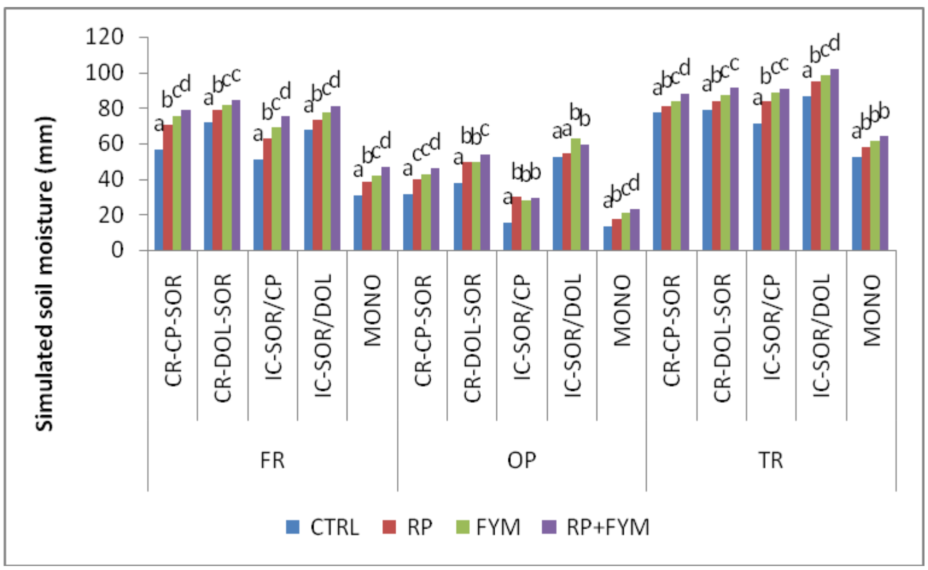


Figure 3: Simulated soil moisture (mm) in the tillage practices, cropping systems and organic inputs interactions in season 1.

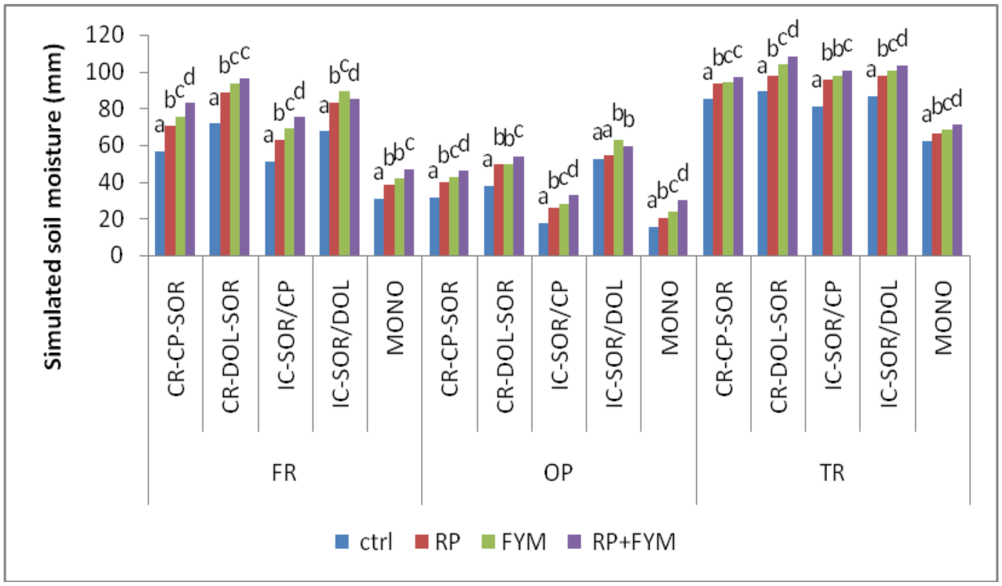


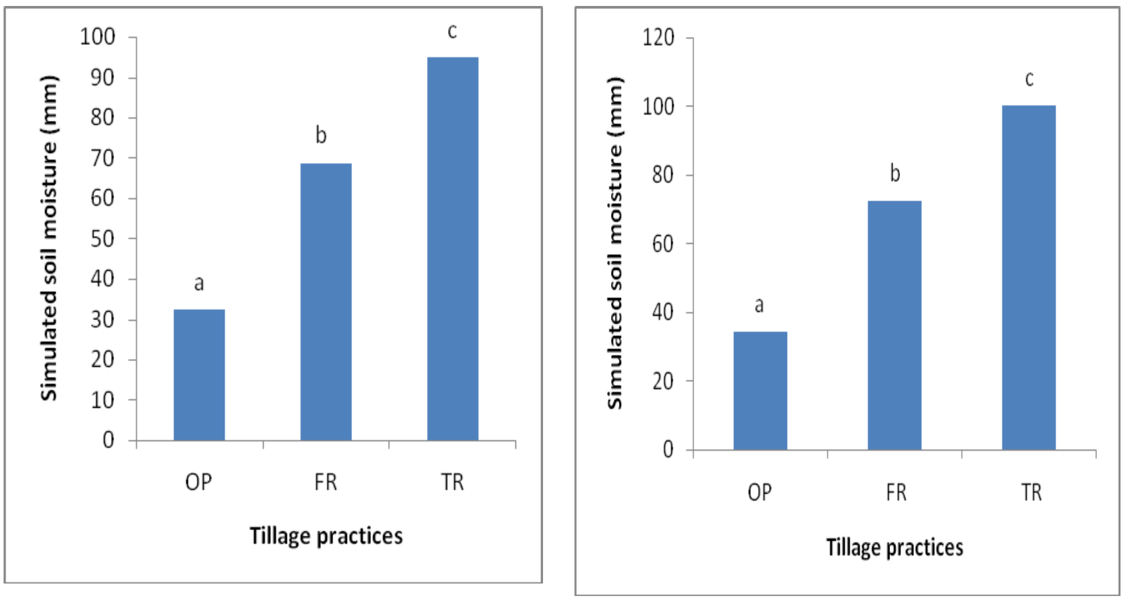
Figure 4: Simulated soil moisture (mm) in the tillage practices, cropping systems and organic inputs interactions in season 2

The combined effect of tied ridges, sorghum and dolichos rotation and combined FYM + RP on soil moisture could be attributed to reduced run-off and increased infiltration due to micro-catchment formed by the tied ridges. Sorghum intercropped with dolichos had significant high soil moisture which could be attributed to the reduced evaporation due to dense soil cover provided by the two crops.

According to Guzha (2004), tillage practices that increase soil roughness such as tied ridging and ripping can increase soil water storage and availability to crop because they are able to capture rainfall and increase the time for infiltration to take place. Rockstrom, 2013 stated that intercropping increases canopy cover and thus reducing evaporation from the soil surface. Combined FYM and RP improved on soil physical properties such as infiltration and soil moisture retention (Palm et al, 1997).

Sweet potato based cropping systems; There were significant (P < 0.05) difference in soil moisture in the different tillage practices, cropping systems and organic inputs. Interactions between tillage practice and cropping systems, tillage practice and organic inputs also had significant (P < 0.05) differences.

Tillage practices; In the first season, simulated soil moisture (95 mm) was significantly high in tied ridges followed by furrows and ridges (68.44 mm) and least(32.49 mm) in the oxen plough (Fig 3). In the second season, simulated soil moisture (100.24 mm) was significantly high in tied ridges followed by furrows and ridges (72.4 mm) and least(34.36 mm) in the oxen plough(Fig. 5)



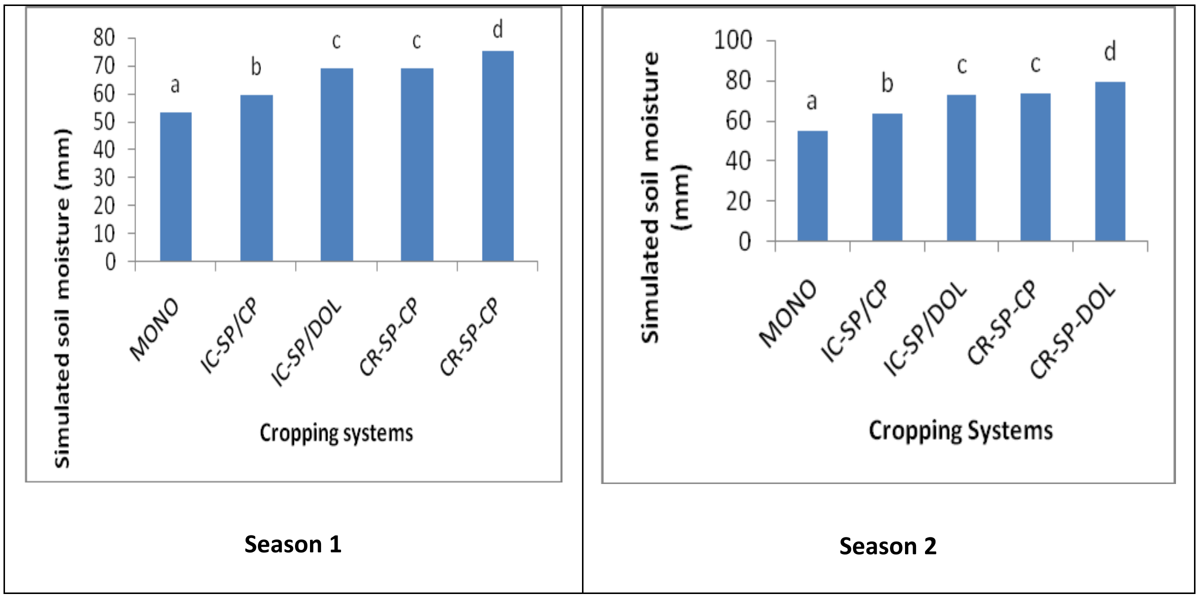
Season 1 Season 2

OP; oxen plough, FR; furrows and ridges, TR; tied ridges

Figure 5: Simulated soil moisture in the different tillage practices

Tied ridges are able to capture more water compared to oxen ploughed plots and furrows and ridges. The more water collected in tied ridges could be attributed to reduced runoff. According to Taye and Abera (2010) in tied ridges, furrows are blocked with earth ties creating basins that catch and hold rainwater, minimizing surface runoff and improving downward infiltration of water. Tillage can improve the physical and hydro-physical properties of the soil and consequently increase rain water harvesting and crop yields (Gachene and Kimaru, 2003; Strudley et al., 2008).

Cropping systems; in the first season, simulated soil moisture (75.32 mm) was significantly ($P < 0.05$) high in the sweet potato- dolichos rotation and least(53.46) in the sweet potato monocropping. Simulated soil moisture (79.63 mm) in the second season was highest (55.26 mm) in the sweet potato-dolichos rotation and least on sweet potato mono cropping (Fig 6).

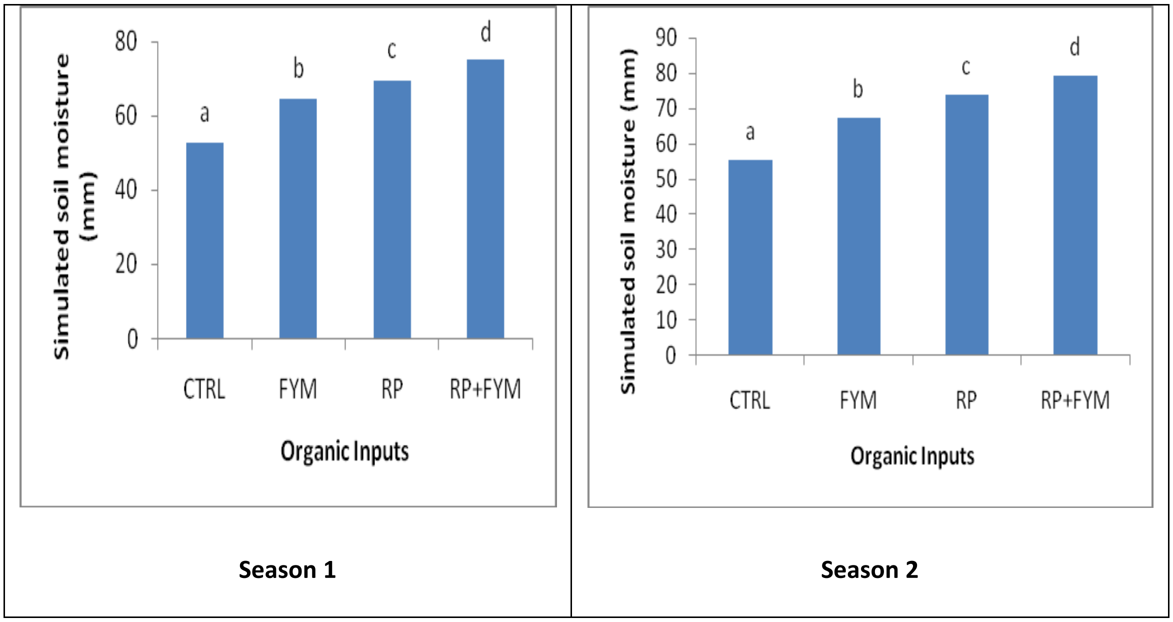


IC; intercropping, CR; crop rotation, SP; sweet potato, CP; chickpea, DOL; dolichos

Figure 6: Simulated soil moisture in the different cropping systems

Higher simulated soil moisture in the sweet potato- dolichos rotation could be attributed to high increased water availability since the sweet potato and dolichos have different rooting systems which increased water availability in the soil. According to Roder (1989), the rotation of legumes and cereals, with their different root systems optimizes the network of root channels in the soil to deeper soil depths. This leads to increased water penetration, water- holding capacity and available water for crop use.

Organic inputs; Simulated soil moisture (75.03 mm) in the first season was significantly high when RP + FYM and least (52.52 mm) in the control (Fig. 5). In the scond season, simulated soil moisture (79.39 mm) was highest in the RP + FYM and least (55.39 mm) in the control (Fig. 7)

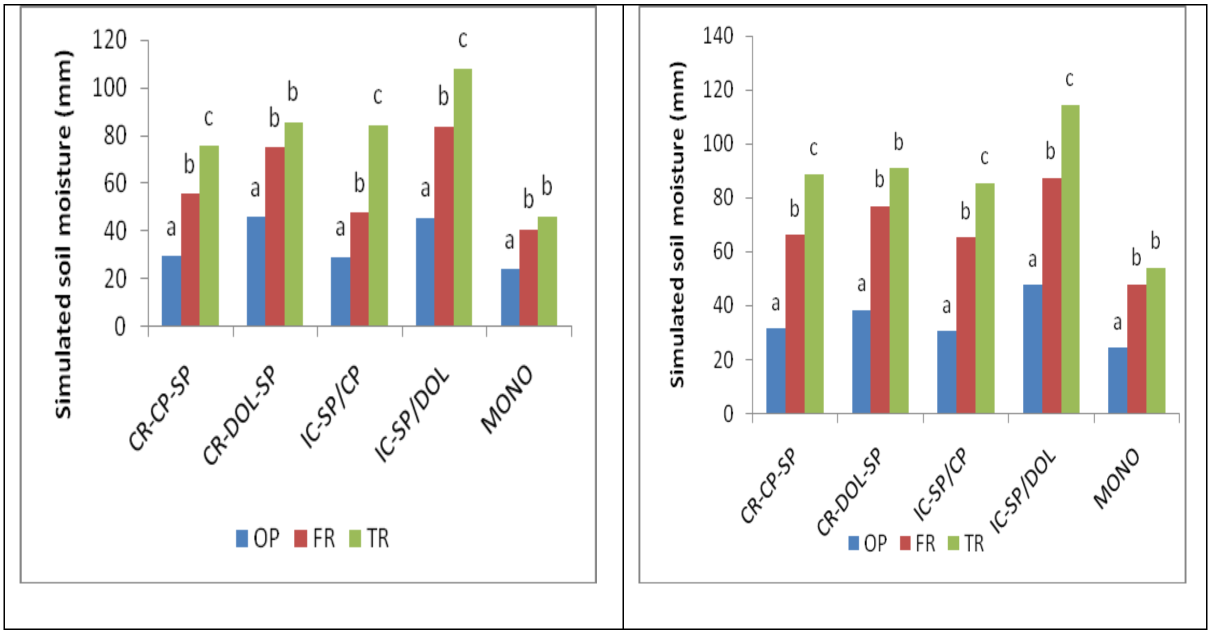


CTRL; control, FYM; farm yard manure, RP; rock phosphate

Figure 7: Simulated soil moisture in the different organic inputs

The FYM + RP had high soil moisture and this could be due to improvement of soil structure and hence increased soil water holding capacity. Combined FYM and RP could have improved the soil physical properties such as increased water infiltration rate. Lal (1997) and Sharif et al., (2013) reported that combined FYM and RP improved water infiltration rate hence increasing soil moisture.

Tillage practices and cropping systems interaction: In the first season simulated soil moisture (108.08 mm) was significantly ($P < 0.05$) in the interaction between tied ridges and sweet potato intercropped with dolichos and least (23.16 mm) in the interaction between oxen plough and sweet potato mono cropping (Fig. 8). In the second season, simulated soil moisture (114.48 mm) was significantly high in the interaction between tied ridges and sweet potato intercropped with dolichos and least (25.87 mm) in the interaction between oxen plough and sweet potato monocropping (Fig. 8).

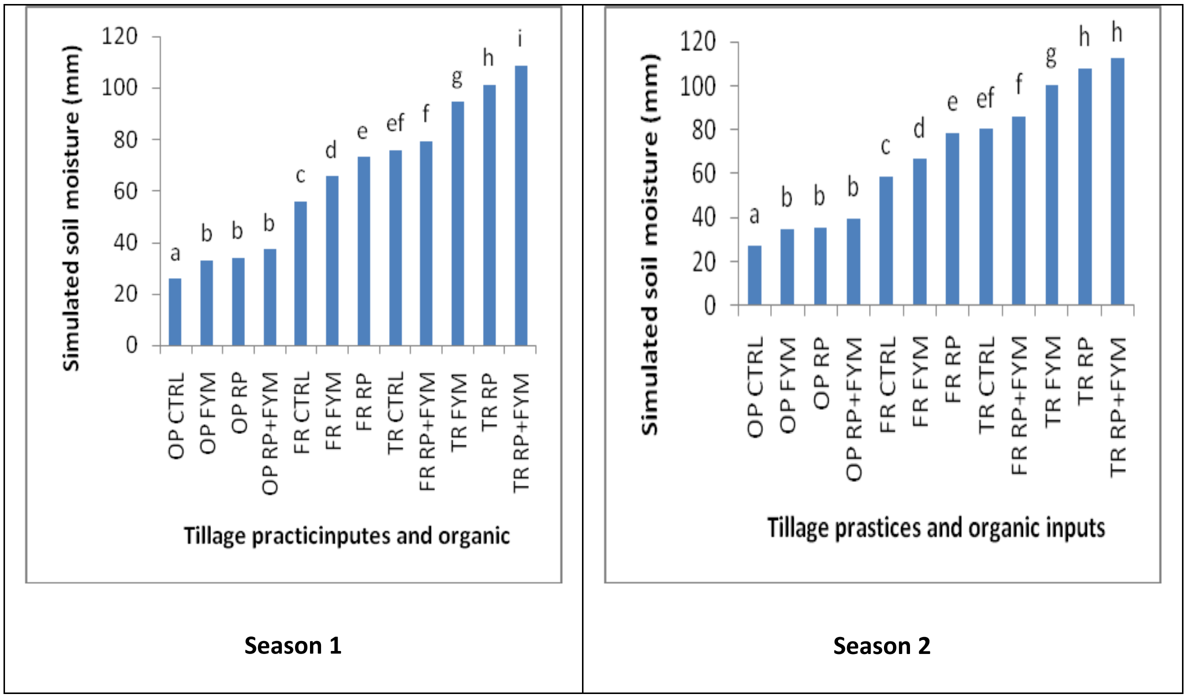


CR; Crop Rotation, IC; Intercropping, CP; chickpea, SP; sweet potato, DOL; dolichos, OP; oxen plough, FR; Furrows and Ridges, TR; Tied Ridges

Figure 8: Simulated soil moisture in the interaction between tillage practices and cropping systems.

High simulated soil moisture in the tied ridges and sweet potato intercropping could be attributed to reduced run off due to the presence of tied ridges. Dense canopy created by the intercropping of two crops could have lowered evaporation rate. High plant densities in the intercropping together with the litter-fall block water flow while the increased volume of roots further opens up the soil hence improved infiltration. According to Zougmore et al. (2000), intercropping allows for the formation of a thick canopy which lower runoff. The dense canopy formed helps prevent soil erosion by rain water action. Fewer rain drops reach the soil surface with great impact because the dense canopy intercepts and break-up heavy rain drops. The FYM +RP had high soil moisture due to improvement of soil structure and this may have led to increased water holding capacity.

Tillage practices and organic input interaction: In the first season, simulated soil moisture (108.57 mm) was significantly highest in the interaction between tied ridges and RP + FYM and least (25.77 mm) in the interaction between oxen plough and control. In the second season, simulated soil moisture (112.69 mm) was highest in the interaction between tied ridges and RP + FYM and least (27.43 mm) in the interaction between oxen plough and control (Fig. 9).



OP; oxen plough, FR; furrows and ridges, TR; Tied ridges, CTRL; control, FYM; farm yard manure, RP; rock phosphate

Figure 9: Simulated soil moisture in the interaction between tillage practice with organic input.

High soil moisture in the tied ridges and FYM + RP could be attributed to the fact that tied ridges allow rainwater to be 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. According to Itabari et al., (2003) tied ridges increase rainwater retention thus increased soil moisture. Farm yard manure and rock phosphate could have increased water retention in the soil. Manure and rock phosphate increase the water retention and availability in the soil (Silva et al., 2006).

Conclusion

In sorghum and sweet potato based cropping systems, soil moisture was highest in the tied ridges, intercropping and rotation systems when FYM + RP was applied and least in the oxen plough, monocropping when no organic input was applied. In sorghum based cropping system, soil moisture was high in the interactions involving tied ridges with sorghum intercropped with dolichos when FYM + RP were applied. In the sweet potato based cropping system, highest soil moisture was observed in the interactions involving tied ridges with sweet potato intercropped with dolichos when FYM +RP were applied.

In the ASALs where crop production is limited by low soil moisture, use of tied ridges, inter-cropping, crop rotation systems and FYM + RP could improve on crop production.

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CHAPTER FIVE

Simulating Yields of Sorghum *(Sorghum bicolor L.*) and Sweet Potato (*Ipomea batatas L.lam*) under Different Tillage Practices, Cropping Systems and Organic Inputs Using CropSyst Model, in Matuu Division, Kenya

Abstract

There has been declining crop yields in the arid and semi-arid lands (ASALs) of Kenya due to low soil fertility and low soil water availability caused by low and unreliable rainfall. To increase crop yields, research on better use of available rainfall and the interaction between the effects of soil and management on crop production is required. CropSyst model was used as an analytical tool to study the effect of soils and management on cropping systems productivity. The aim of the study was to simulate sorghum and sweet potato yields under different tillage practices (oxen plough, tied ridges and furrows and ridges), cropping systems (monocropping, intercropping and rotation) and organic inputs (farm yard manure, rock phosphate and combined farm yard manure and rock phosphate). The study was conducted in Matuu Sub-County, Kenya for two seasons. The experiment was laid out in a Randomized Complete Block design with split-split plot arrangement and replicated three times. The main plots were tillage practices, split plots were cropping systems and split-split plots were organic inputs. The test crops were sorghum (*Sorghum bicolor L.*) and sweet potato (*Ipomea batatas L.lam*) rotated and/or intercropped with dolichos (*Lablab purpureus*) and chickpea (*Cicer arietinum*). The CropSyst model was calibrated using the observed final above ground biomass and yield of sorghum and sweet potato in the experimental site. Validation of the model was done using Root Mean Square Error (RMSE), percentage differences (PD) and Wilmot index (WI) of agreement.

In the sorghum based cropping systems, sorghum yield (1,611 kg/ha) was significantly high in tied ridges, when sorghum and dolichos were intercropped and (1,825 kg/ha) when RP +FYM were applied. Sorghum yield (1,955.6 kg/ha) was high in the interactions between tied ridges and sorghum/dolichos intercrop Sorghum yield (1383 kg/ha) was least in oxen plough, sorghum monocropping (1,191 kg/ha).and in control (1,436 kg/ha). In the second season, simulated sorghum yield (2,072 kg/ha) was significantly high in tied ridges, sorghum-dolichos rotation (2,218 kg/ha), and when RP + FYM was applied (2,025 kg/ha). Sorghum yield was significantly high in tied ridges interactions with sorghum and dolichos rotation (2,584 kg/ha) and least in the oxen plough interactions with sorghum monocropping (1,429 kg/ha).

In the sweet potato based cropping systems, sweet potato yield in the first season was significantly high in tied ridges (13,127 kg/ha), sweet potato-chick pea rotation (14,222 kg/ha), and when RP + FYM was applied (13,247 kg/ha). Sweet potato yield was significantly high in tied ridges interaction with sweet potato intercrop with dolichos (16,737 kg/ha) and least in the oxen plough with sweet potato monocropping (10,127 kg/ha). In the second season, sweet potato yield (14,768 kg/ha) was significantly high in interactions between tied ridges under sweet potato rotation with dolichos when RP + FYM was applied. Sweet potato yield was least in the oxen plough (11, 699 kg/ha), sweet potato mono cropping (10,993 kg/ha), control (10,995 Kg/ha) and in the oxen plough interaction with sweet potato monocrop (9643 kg/ha).

Tied ridges, intercropping and crop rotation systems and FYM + RP had high sorghum and sweet potato yield. Yield was high in sorghum based cropping systems when tied ridges, sorghum intercropping and rotation with dolichos were applied. High sweet potato yield was observed when tied ridges and sweet potato were intercropped and rotated with dolichos and chickpea. High sorghum and sweet potato yields observed in the tied ridges, intercropping and rotation systems and when FYM + RP were applied was due to improved soil moisture. These management practices improved on soil water retention and hence the high yields. In the ASALs were crop yields are limited by unreliable rainfall and low soil fertility, sorghum and sweet potato yields could be improved through the use of tied ridges, intercropping and rotation systems and use of FYM+RP which improve on soil fertility and soil moisture through increased water retention.

Keywords; Crop Rotation; Farm Yard Manure; Intercropping; Monocropping; OxenPlough Ridges and furrows; Rock Phosphate; Tied Ridges

5.1 Introduction

Agricultural production in the arid and semi-arid lands (ASALs) is negatively affected by the high rainfall variability distribution and frequent droughts which usually occur during the growing season resulting in depressed yields and persistent crop failures (Miriti et al., 2012). Growing of drought resistant crops such as sorghum in the ASALs could improve food production in these areas (KARI, 2006). Sorghum (*Sorghum bicolor L.*) is well adapted in ASALs and is appreciated as a food security crop (Mwadalu and Mwangi, 2013). The crop is the most important cereal crop in the semi –arid tropics (FAO, 1995) and quantitatively ranks second to maize (Zea mays) in Africa (Taylor, 2003). Sweet potato (*Ipomoea batatas (L.) Lam*.) is important in the economy of resource poor households in the arid and semi-arid lands (Qaim, 1999) and is a major source of subsistence and cash income to farmers in agroclimatically-disadvantaged regions of Kenya (Githunguri et al., 2007).

To guarantee food security in the ASALs where food production is majorly constrained by soil moisture stress, sound Agricultural Water Management (AWM) is necessary. AWM includes all deliberate human actions designed to optimize the availability and utilization of water for agricultural purposes (Mati, 2007). AWM include practices such as soil and water conservation, rain water harvesting, soil fertility management, and conservation agriculture. Sound agricultural management should ensure that available rain water becomes useful to crops and that it is not used for negative impacts such as soil erosion. Soil and water conservation with water harvesting, is one of the techniques for supporting rain-fed agriculture in the ASALs (Hai, 1998; Mati, 2006). On-farm rain water harvesting using structures such as ridges preserve soil moisture and result in improved crop yields (Mati, 2007). The effect of management practices on crop productivity can be determined using crop-simulation models.

These crop simulation models can be used to assess the likely impact of the environment and management on grain yield and yield variability (Tingem et al., 2008). CropSyst (Stockle *et al.*, 1994) is one of these models that could be used along with a set of daily weather data spanning a reasonable number of years to assess the impact of climate on agriculture. CropSyst is a multi-year, multi-crop, daily time step cropping systems simulation model developed to serve as an analytical tool to study the effect of climate, soils and management on cropping systems productivity and the environment. CropSyst simulates the soil water budget, soil plant nitrogen budget, crop phenology, canopy and root growth, biomass production, crop yield, residue production and decomposition, soil erosion by water and salinity. These processes are affected by weather, soil characteristics, crop characteristics and cropping system management options including crop rotation, cultivar selection, irrigation, nitrogen fertilization, soil and irrigation.

The objective of this study was therefore to simulate the effects of different tillage practices, cropping systems and organic inputs on sorghum and sweet potato yields.

5.2 Materials and Methods

5.2.1 Experimental site

The study was conducted in Matuu Sub-County in Eastern Kenya between 1º37’ S and 1º45’ S latitude and 37º15’ E and 37º23’ E longitude and an altitude of 700-800 metres above level. Matuu Division is in agro-climatic zone IV which is classified as semi-arid land (Jaetzold and Schmidt, 2006). Rainfall patterns exhibits distinct bimodal distribution. The first rains fall between mid- March and end of May and are locally known as long rains (LR). The second rains, the short rains (SR), are received between mid October and end of December. Average seasonal rainfall is between 250-400 mm. Interseasonal rainfall variation is large with a coefficient of variation ranging between 45-58 per cent, while temperature ranges between 17-24^0C.

The soils are a combination of Luvisols, Lithisols, and Ferralsols according to USDA (1978) and WRB (2006) criteria. The soils are well drained, moderately to very deep, dark reddish brown to dark yellowish brown, friable to firm, sandy clay to clay, with high moisture storage capacity and low nutrient availability (Kibunja et al., 2010). The majority of the farmers in the district are small-scale mixed farmers with low income investment for agricultural production. The major crops grown in semi-arid areas of eastern Africa include maize, beans, sorghum, millet, cassava, pigeon peas, sweet potatoes and cowpeas **(**Macharia, 2004) Crop performance and yield are significantly influenced by the amount of rainfall and distribution throughout the rainy season.

5.2.2 Treatments and Experimental design

For the purpose of both model calibration and validation, field experiments were conducted for two seasons; short rain season (2012) and long rain season (2013). Data for season one was used to calibrate the model while season two data used for model validation. The experimental layout was a Randomized Complete Block Design with split-split plot arrangement and replicated three times. The main plots were; tillage practices (Oxen plough, tied ridges and furrows, and ridges). Split plots were cropping systems (mono cropping, intercropping and crop rotation) and split-split plots were FYM, RP, RP+ FYM and a control (no organic input was applied). The test crops were sorghum and sweet potato intercropped or grown in rotation with legumes; Dolichos and chickpea.

5.3 Agronomic practices

5.3.1 Land preparation and planting

The land was prepared using oxen to plough in late September 2012. Before planting in October, furrows and ridges and tied ridges were prepared manually. Sorghum and sweet potato were planted in October during the short rains. Sorghum seeds were sown at a spacing of 30 cm by 60cm. Sweet potato cuttings were planted at a spacing of 30cm by 90cm. Weeding was done every 4 weeks after planting. Harvesting sorghum was done by hand after 3 months when it had reached physiological maturity while sweet potato was harvested manually using implements such as hoe after four months.

5.3.2 Soil analysis

Soil sampling was done before planting, during flowering stage and at harvest in a random manner. Soil was sampled using a soil auger at 0-15 cm, 15-30 cm and 30-45 cm depths and composited in to one sample**.** Soil was analyzed for chemical; pH, and mineral nitrogen and physical characteristics; soil texture, bulk density, field capacity and permanent wilting point. The soil characteristics were used to prepare the soil file to be used in calibrating CropSyst model. Soil moisture content was measured by the gravimetric method (Ref) for each plot before sowing, during flowering and at harvest. Soil moisture observed by gravimetric method (weight basis) was converted into volumetric proportion by multiplying by bulk density.

The particle size analysis was done by the hydrometer method as outlined by Anderson and Ingram (1993). Soil pH was observed in a 1:2.5 ratio soil to water (pH H_2O) and to KCl (pHKCl) using a pH meter (Okalebo et al., 2002) Bulk density was determined according to Blake and Hartage (1986). Field capacity and permanent wilting point was determined using Initial Drainage Curve described by Klute (1986), mineral nitrogen was determined by Kjeldahl method as described by Bremner and Mulvaney (1982). Chemical and physical soil analysis was done for site characterization. The soil properties were used to prepare the soil file required to run the CropSyst model.

5.4 CropSyst Model description

The CropSyst model is premised on the assumption that actual biomass/output growth is a result of interactions involving various independent variables which include weather, soil types, management practices and crop physiology (Table 1).

Table 6: Data sets required to run CropSyst model

File/	Parameters Required by the Model	Parameters used in the model
Location	Latitude, Longitude, Altitude	Latitude: 37º15’ E and 37º23’ E Longitude: 1º37’ S and 1º45’ S Altitude: 700-800m a.s.l
Soil	pH, Permanent wilting point, Field capacity, Bulk density, Soil texture	Table 2 (observed in the field)
Crop,	Growing degree days (GDD) to emergence, GDD to peak leaf area index, GDD to flowering, GDD to maximum grain filling, GDD to maturity,Base temperatures, Cut-off temperatures, maximum root depth.	(GDD were observed in the experimental site) Other crop input parameters were taken as default values.
Management	**Nitrogen fertilization** (application date, amount, source- organic and inorganic-, and application mode- broadcast, incorporated, injected), **Tillage operations** (primary and secondary tillage operations),	**Organic inputs;** FYM, RP, FYM + RP **,** calibration was done for RP which is not currently in the model **Tillage practices**; Tillage operations were calibrated for oxen plough, tied ridges, furrows and ridges

GDD; growing degree days, FYM; farm yard manure, RP; rock phosphate

Stockle et al., 2003

The model simulates soil water budget, crop canopy and root growth, dry matter production, yield, residue production and decomposition, and erosion. Management options include: cultivar selection, crop rotation, irrigation, nitrogen fertilization, tillage operations (over 80 options) and residue management. The dates for phenological stages; emergence, flowering stage, grain filling and physiological maturity were used to calculate growing degree days (GDD= T_{mean}-T_{base} where Tmean =(T_{max} + T_{min})/2). Location file was also prepared using observed weather data from Katumani which is the nearest weather station. For each tillage practices, management files were prepared to represent each cropping systems and organic inputs. Soil moisture measurements were used for model calibration. The values of crop input parameters (maximum harvest index, maximum expected LAI, base temperature, cut-off temperature and maximum root depth were taken from the CropSyst manual.

The calibrated values (Table 2) were permanent wilting point, field capacity and mineral nitrogen. Observed mineral nitrogen was adjusted from 24 Kg N ha^{-1} to 58.91 Kg N ha^{-1}. Permanent wilting point was adjusted from 0.17 $m3/m^3$ to 0.29 $m3/m^3$. Field capacity was also adjusted from 0.23 $m3/m^3$ to 0.38 $m3/m^3$. Permanent wilting point and field capacity affect the amount of water in the soil. Moisture and nitrogen stress are major limiting factors for yield and biomass production in CropSyst (Stockle et al., 2002). The values were adjusted by comparing the observed soil water content with the model output. Crop growth was majorly affected by the soil moisture and nitrogen content and adjustment to the required amount was done. Soil texture is used to calculate permanent wilting point, field capacity and bulk density in the soil editor if the values are not available.

Table 7: Observed and calibrated physic-chemical soil properties

Soil properties	Observed soil properties Depth (cm)			Calibrated soil properties Depth (cm)		
	0-10	**10-20**	**20-30**	**0-10**	**10-20**	**20-30**
Sand (%)	49.32	49.30	49.36	49.32	49.30	49.36
Silt (%)	**38.88**	**38.97**	38.77	38.88	38.97	38.77
Clay(%	11.8	11.71	11.78	11.8	11.71	11.78
Textural class	Sand Clay	Sand Clay	Sand Clay	Sand Clay	Sand Clay	Sand Clay
pH (H_20)	6.5	6.7	6.8	6.5	6.7	6.8
Permanent wilting point (m^3/m^3)	0.17	0.18	0.20	0.27	0.28	0.29
Field capacity (m^3/m^3)	0.23	0.25	0.27	0.34	0.36	0.38
Bulk density (g $cm^{-3)}$	1.503	1.508	1.67	1.503	1.508	1.67
NH_4-N (Kg N ha^{-1})	28.54	27.02	34.76	58.91	57.39	55.46
NO_3--N (Kg N ha^{-1})	24.87	29.34	25.72	52.67	51.83	50.44

5.5 Model Validation

CropSyst was validated by comparing model outputs with observed soil moisture in different tillage practices cropping systems and organic inputs. The agreement between model and was verified by means of percentage differences (PD) and root mean square error (RMSE): This is frequently used measure of the difference between values simulated by a model and those actually observed from the experiment that is being modeled (Eqn 1).

$$\text{RMSE} = [\, n^{-1} \sum(\text{Yield}_{meas} - \text{Yieldpred})^2 \,] \qquad (1)$$

Furthermore, Wilmott index (WI) of agreement was calculated, which take a value between 0.0 and 1.0; where 1.0 means perfect fit (Wilmott, 1981)

5.6 Simulations

The crop, soil, weather and management files required by the CropSyst model for Matuu Division, sorghum and sweet potato crops were used to run the model. Planting dates were set as 10th October, 2012 for both crops. Simulations were run from 10th, September, 2012 a month before planting and ended in 31st, March 2013 for sorghum and 31st May for sweet potato. The experiment was repeated for the second season in 2013. The starting and ending dates indicated the simulation period. Sweet potato required more time to mature compared to sorghum and hence the difference in the ending simulation date. Sorghum and sweet potato was simulated by specifying the soil, location, crop and management practices.

5.7 Statistical test

Effect of the different treatments on soil moisture were statistically evaluated by analysis of variance (ANOVA) as a split split plot design with three replicates (Genstat 15.0 for Windows). Least Significant Differences (LSD) at the 5% level were used to detect differences among means.

CropSyst model Validation for sorghum and sweet potato based cropping system

Sorghum based cropping system CropSyst model simulated sorghum yield with values close to those observed in the experimental site (Table 6).

In the oxen plough, percentage differences (PD) between observed and simulated values in all cropping systems ranged from -0.15 to +0.41 when FYM was applied, with RMSE of 2.01 and WI 0.992. When RP + FYM were applied, PD ranged from -0.07 to + 0.28 with RMSE of 1.935and WI of 0.998. PD ranged from -0.328 to + 0.03 when RP was applied with RMSE of 1.41 and WI of 0.990 while in the control, PD ranged from -0.21 to + 0.53 with RMSE of 1.715 and WI of 0.994 (Table 6).

In the furrows and ridges, PD between observed and simulated values in all cropping systems ranged from -0.21 to +0.08 when FYM was applied with RMSE of 1.99 and WI of 0.997 . When RP + FYM was applied PD ranged -0.12 to +0.30 with RMSE of 1.653 and WI of 0.989. PD ranged from -0.92 to +0.11 when RP was used with RMSE of 1.431 and WI of 0.993 while in the control, PD ranged from -0.05 to +0.24 with RMSE of 2.27 and WI of 0.991 (Table 6).

Under tied ridges and in all cropping systems, PD ranged from -0.31 to +0.45 with RMSE of 1.385 and WI of 0.996 when FYM was applied PD ranged from -0.12 to +0.32 with RMSE of 0.993 and WI of 0.991 when RP + FYM were applied. When RP was used, PD ranged from -0.30 to +0.06 with RMSE of 1.498 and WI of 0.997 while in control PD ranged from -0.38 to +0.07 with RMSE of 1.253 and WI of 0.998 (Table 6).

Validation of CropSyst model showed closeness between observed and simulated sorghum grain yield reflected by the low percentage of difference (±3.5%) between observed and simulated values, low RMSE (less than 2.27) and high WI (0.989-0.999) of agreement. These low values of RMSE and higher WI values for sorghum grain yield indicated that the CropSyst model reasonably simulated sorghum grain yield. According to Ventrella and Rinaldi, 1999, CropSyst model simulated grain yield with a percentage difference of 0.4 which is close to the results observed in Table 6. Likewise, Singh et al. (2008) reported that RMSE between observed and predicted biomass by CropSyst was 1.27 ton/ha. According to Claudio et al., 2003 Wilmot index of agreement fluctuated from 0.92 to 0.97 which is similar to the above results.

Table 8: Statistical comparisons of observed and simulated sorghum yields under different tillage practices, cropping systems and organic inputs

Treatments	FYM			FYM+ RP			RP			CTRL		
Oxen plough	Observed	Simulated	PC (%)	Observed	Simulated	PC (%)	Observed	Simulated	PC (%)	Observed	Simulated	PC (%)
SOR- MONO	1003.44	1007.98	+0.38	1209.54	1212.88	+0.28	1184.01	1196.83	-1.08	1131.16	1125.13	+0.53
SOR/ DOL	1311.23	1305.88	+0.41	1423.38	1420.29	+0.22	1203.02	1242.46	-3.28	1177.44	1175.41	+0.17
SOR/CP	1497.90	1504.82	-0.15	1505.07	1504.29	+ 0.05	1434.56	1435.76	-0.08	1221.74	1224.31	-0.21
SOR-DOL	1447.87	1450.29	-0.10	1460.01	1462.97	-0.07	1413.95	1416.90	-0.03	1257.91	1260.09	-0.06
SOR-CP	1453.06	1455.58	-0.04	1498.93	1493.82	+0.10	1437.06	1440.44	-0.08	1314.68	1309.87	+0.37
RMSE	**2.01**			**1.935**			**1.41**			**1.715**		
WI	**0.992**			**0.998**			**0.990**			**0.994**		
Furrows and ridges												
SOR- MONO	1117.26	1116.28	0.07	1425.22	1427.03	-0.11	1107.55	1106.06	0.11	1278.26	1276.62	0.12
SOR/ DOL	1931.13	1930.22	0.05	1937.99	1940.32	-0.12	1915.42	1919.29	-0.20	1847.28	1842.76	0.24
SOR/CP	1364.33	1463.21	0.08	1478.98	1474.61	0.30	1420.11	1433.16	-0.92	1378.26	1376.62	0.12
SOR-DOL	1633.73	1637.18	-0.21	1685.01	1681.89	0.19	1614.92	1616.70	-0.13	1479.88	1478.48	0.01
SOR-CP	1681.36	1683.76	-0.14	1698.9	1697.04	0.03	1660.36	1661.39	-0.06	1596.97	1597.84	-0.05
RMSE	**1.99**			**1.653**			**1.431**			**2.27**		
WI	**0.997**			**0.989**			**0.993**			**0.991**		
Tied Ridges												
SOR- MONO	1465.83	1469.46	-0.31	1457.05	1458.11	-0.07	1425.66	1428.21	-0.23	1352.34	1353.92	-0.13
SOR/ DOL	1962.87	1960.64	0.45	1984.80	1987.21	-0.12	1958.97	1960.53	-0.07	1889.07	1890.44	-0.07
SOR/CP	1469.98	1370.20	-0.02	1528.93	1530.87	-0.05	1353.98	1357.98	-0.30	1305.89	1310.91	-0.38
SOR-DOL	1752.18	1750.63	0.03	1785.48	1783.92	+0.32	1731.09	1733.74	+0.0	1705.34	1703.08	0.07
SOR-CP	1744.92	1743.96	0.07	1758.92	1757.63	0.07	1705.11	1706.41	6	1542.72	1547.25	-0.29
									-0.08			
RMSE	**1.385**			**0.993**			**1.498**			**1.253**		
WI	**0.996**			**0.991**			**0.997**			**0.998**		

SOR-MONO; Sorghum monocropping, SOR/DOL; Sorghum dolichos intercrop, SOR/CP; Sorghum chickpea intercrop, SOR-DOL; Sorghum dolichos rotation, SOR-CP; Sorghum chickpea rotation, RP; Rock phosphate, FYM; Farm yard manure, PD; Percentage differences, RMSE; root mean square error, WI; willmott index of agreement

Sweet potato tuber yield

In the oxen plough, PD in all cropping systems ranged from -0.018 to +0.012 with RMSE of 1.63 and WI of 0.998 when FYM was applied. When RP + FYM were applied, PD ranged from -0.018 to -0.006 with RMSE of 1.263 and WI of 0.999, When RP was applied PD ranged from +0.002 to +0.032 with RMSE of 1.50 and WI of 0.996 while PD ranged from -0.012 to +0.033 with RMSE of 1.85 and WI of 0.99 in the control (Table 7).

In the furrows and ridges and in all cropping systems, PD ranged from -0.013 to +0.033 with RMSE of 0.999 and WI of 0.099 when FYM was applied and a PD ranging from -0.031 to +0.007 with RMSE of 1.202 and WI of 0.992 when RP + FYM were used. When RP was used, PD ranged from-0.009 to +0.237 with RMSE of 1.493 and WI of 0.99 while in the control, PD ranged from -0.017 to +0.03 with RMSE of 1.298 and WI of 0.999 (Table 7).

In the tied ridges and in all cropping systems, PD ranged from -0.024 to +0.05 with RMSE of 2.722 and WI of 0.997 when FYM was used and PD ranging from -0.011 to +0.007, RMSE of 0.629 and WI of 0.992 when RP + FYM were used. When RP was used, PD ranged from -0.0.018 to + 0.028 with RMSE of 1.429 and WI of 0.992 while in control PD ranged from -0.012 to +0.029 with RMSE of 2.155 and WI of 0.996 (Table 7).

Percentage differences between observed and simulated sweet potato yield were less than 1% indicating a good agreement between observed and simulated values. Root mean square error were low (0.999 – 2.722) while Wilmot index of agreement was close to 1(0.990 -0.999). The low values of RMSE and high WI indicate that the model reasonably simulated yields of sweet potato. Abdrabbo et al., 2013 obtained percent difference between measured and predicted maize yield less than 1% and Wilmot index of agreement was 0.99 which is similar to the results shown in Table 4. Likewise EL Baroudy et al., 2013 obtained low RMSE of 0.29 and 0.32 for sorghum grain yield.

Table 9: Statistical comparisons of observed and simulated sweet potato yields under different tillage practices, cropping systems and organic input

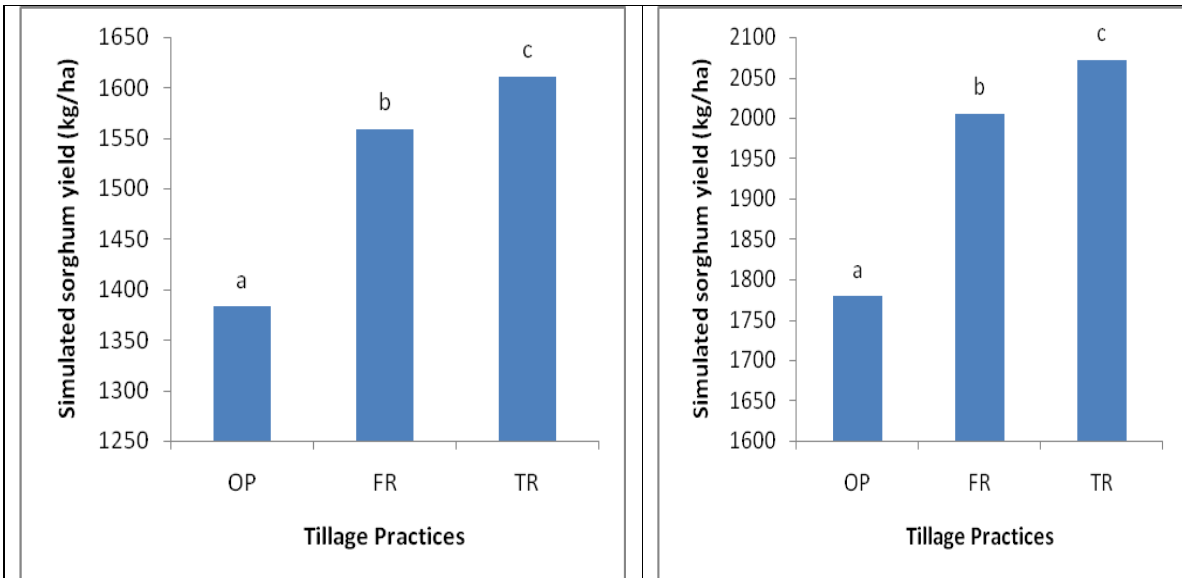
Treatment	FARM YARD MANURE			RP+FYM			RP			CONTROL		
Oxen plough	Observed	Simulated	PC (%)	Observed	Simulated	PC (%)	Observed	Simulated	PC (%)	Observed	Simulated	PC (%)
SP- MONO	9044.50	9043.43	+0.012	10267.02	10268.88	-0.018	9199.49	9196.56	+0.032	8845.32	8844.52	+0.009
SP/ DOL	9337.24	9338.88	-0.018	1107.24	11008.31	-0.009	9635.08	9634.05	+0.002	8445.39	8446.44	-0.012
SP/CP	10941.09	10940.03	+0.009	12217.59	12219.05	-0.012	10994.08	10991.53	+0.023	9896.78	9895.96	+0.008
SP-DOL	11758.88	11759.97	-0.009	12170.03	12170.79	-0.006	12178.06	12174.5	+0.029	10740.00	10739.12	+0.008
SP-CP	11588.68	11589.76	-0.009	13651.26	13652.07	-0.006	11951.22	11949/76	+0.012	10519.71	10516.2	+0.033
RMSE	**1.63**			**1.263**			**1.50**			**1.85**		
WI	**0.998**			**0.999**			**0.996**			**0.99**		
Furrows and ridges												
SP- MONO	9404.26	9404.85	-0.006	10845.05	10844.26	+0.007	9490.56	9489.232	+0.014	9213.55	9210.75	+0.03
SP/ DOL	9775.59	9772.38	+0.033	10762.99	10764.11	-0.01	10398.60	10398.6	-0.009	9319.18	9320.05	-0.009
SP/CP	8918.10	8915.20	+0.032	10506.07	10509.39	-0.031	9201.00	9198.23	+0.030	8064.71	8066.14	-0.017
SP-DOL	14435.83	14432.75	+0.021	14442.19	14445.02	-0.019	13950.86	13917.79	+0.237	13321.04	13321.46	-0.003
SP-CP	14260.64	14262.46	-0.013	16784.73	16783.86	+0.005	14692.24	14688.42	+0.026	12985.19	12984.57	+0.005
RMSE	**0.999**			**1.202**			**1.493**			**1.298**		
WI	**0.999**			**0.992**			**0.990**			**0.999**		
Tied Ridges												
SP- MONO	10627.26	10629.65	-0.022	12261.71	12263.1	-0.011	10729.23	10728.28	+0.008	10405.89	10402.82	+0.029
SP/ DOL	11077.00	11079.66	-0.024	13711.77	13710.82	+0.007	12003.68	12000.65	+0.025	8316.62	8315.11	+0.018
SP/CP	11197.09	11987.70	+0.05	14087.34	14088.26	-0.006	11991.09	11987.70	+0.028	7764.90	7763.78	+0.015
SP-DOL	15583.51	15580.60	+0.019	18333.35	18334.02	-0.004	16042.14	16045.04	-0.018	14187.95	14187.26	+0.018
SP-CP	15459.20	15459.71	-0.003	18785.51	18784.16	+0.007	15923.35	15924.15	-0.005	14068.11	14066.37	+0.012
RMSE	**2.722**			**0.629**			**1.429**			**2.155**		
WI	**0.997**			**0.998**			**0.992**			**0.996**		

SP-MONO; Sweet potato monocropping, SP/DOL; Sweet potato dolichos intercrop, SP/CP; Sweet potato chickpea intercrop, SP-DOL; Sweet potato dolichos rotation, SP-CP; Sweet potato chickpea rotation, RP; Rock phosphate, FYM; Farm yard manure, PD; Percentage differences, RMSE; root mean square error, WI; Wilmott index of agreement

5.8 Results and Discussions

Simulated sorghum and sweet potato yield

Sorghum yield: In the first season, there were significant differences (P < 0.05) in the different tillage practices, cropping systems and organic inputs (Fig. 10). There were also significant interactions in tillage practices and cropping systems. In season 1, simulated sorghum yield (1611 kg/ha) was significantly high in tied ridges, followed by furrows and ridges (1559 kg/ha) and least (1383 kg/ha) in oxen plough (Fig. 1). In second season, simulated sorghum yield (2,072 kg/ha) was significantly high in tied ridges, followed by furrows and ridges (2,005 kg/ha) and least (1,779 kg/ha) in oxen plough (Fig. 10)



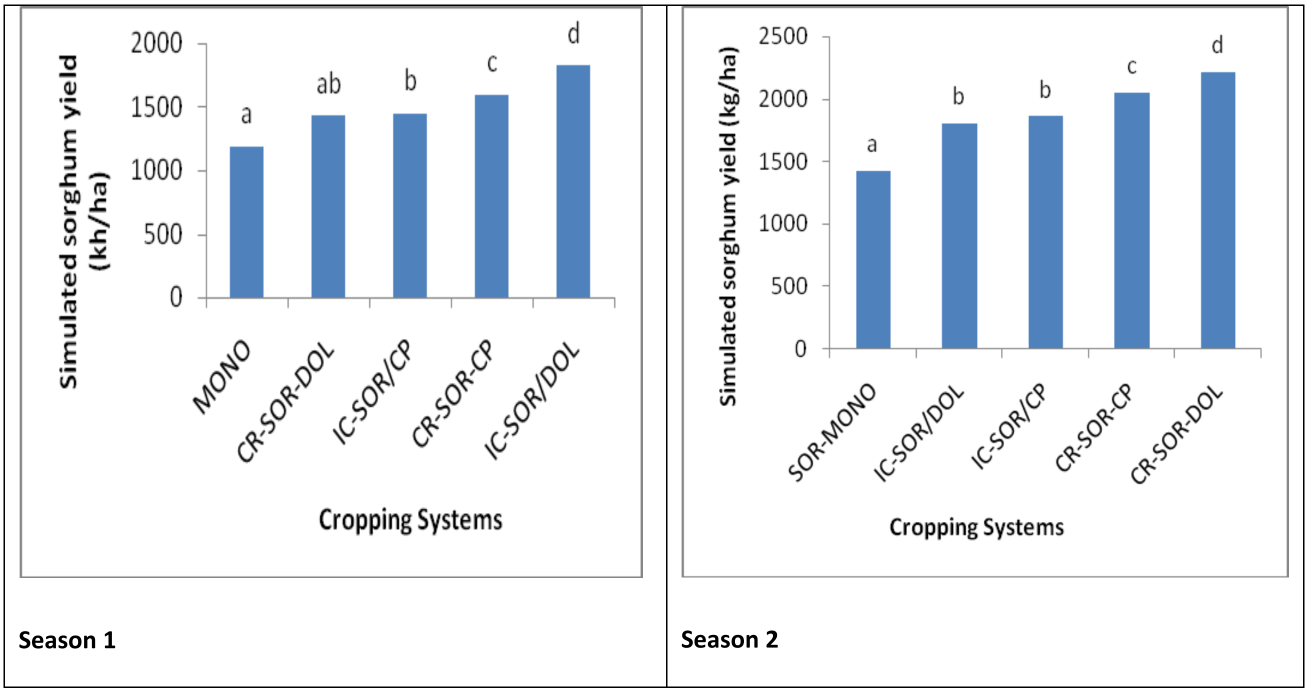
Season 1 Season 2

OP; oxen plough, FR; furrows and ridges, TR; tied ridges

Figure 10: Simulated sorghum yield in the different practices for two seasons

Tied ridges had the highest sorghum yield compared to oxen plough and furrows and ridges, the increased yield in tied ridges could have been due to the fact that tied ridges retain rainwater in the farms for longer period as the water infiltrates the soil. The prolonged rainwater infiltration and retention for long period increases soil moisture for the crops and hence increased sorghum yield. Itabari et al.(2003) indicated that farming techniques that increase rainwater harvesting such as tied and open ridges are able to improve on crop productivity. According to Mati, 2005 tied ridges have been found to be efficient in storing rain water, resulting in substantial grain yield increase in some of the major dryland crops such as sorghum.

Cropping systems: In the first season, simulated sorghum yield (1,825 kg/ha) was significantly high in the sorghum/dolichos intercrop and least (1,191 kg/ha) in sorghum monocropping (Fig.11). In the second season, sorghum yield (2,218 kg/ha) was significantly high in sorghum-dolichos rotation and least (1,429 kg/ha) in sorghum monocropping (Fig. 11).

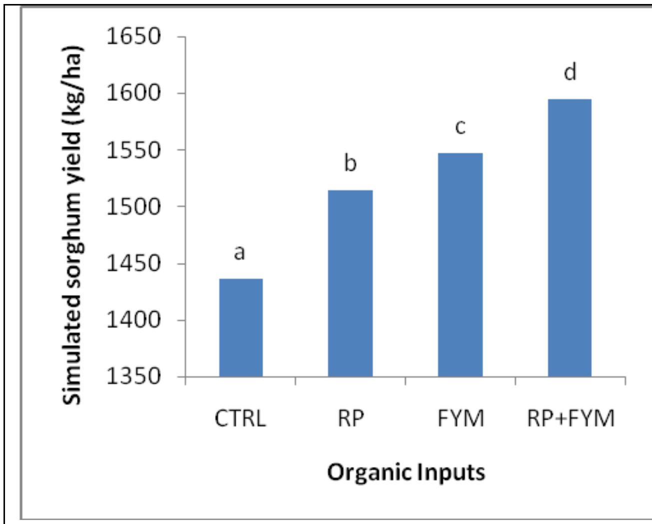


CR; crop rotation, IC; intercropping, CP; Chick pea; SOR; Sorghum

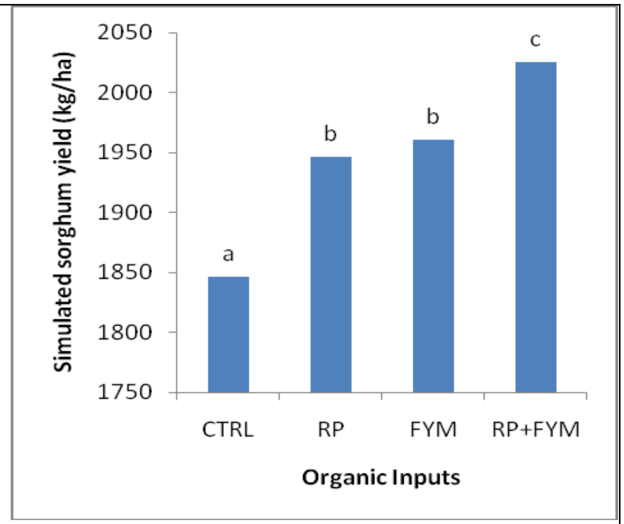
Figure 11: Simulated sorghum yield in different cropping systems

Sorghum dolichos intercrop had the highest yield compared to sorghum monocropping and this could be attributed to increased soil fertility via raising soil organic content and available nitrogen fixed by legumes especially from dolichos. Vandermeer, (1989) stated that average dry matter and yields are higher with intercropping than when each of the plant species in the mixture is grown as a monoculture. When legumes are included in a crop mixture, an extra benefit is improved soil fertility due to the legume species' fixation of biological nitrogen (N), and increased protein content of the cereal component (Jensen, 2006)

Organic inputs: In the first season; simulated sorghum yield (1595 kg/ha) was significantly high in RP +FYM and least (1436 kg/ha) in control (Fig.3). In the second season, sorghum yield (2,025 kg/ha) was significantly high when RP + FYM was applied and least (1,846 kg/ha) in control with no organic input (Fig. 12)



Season 1



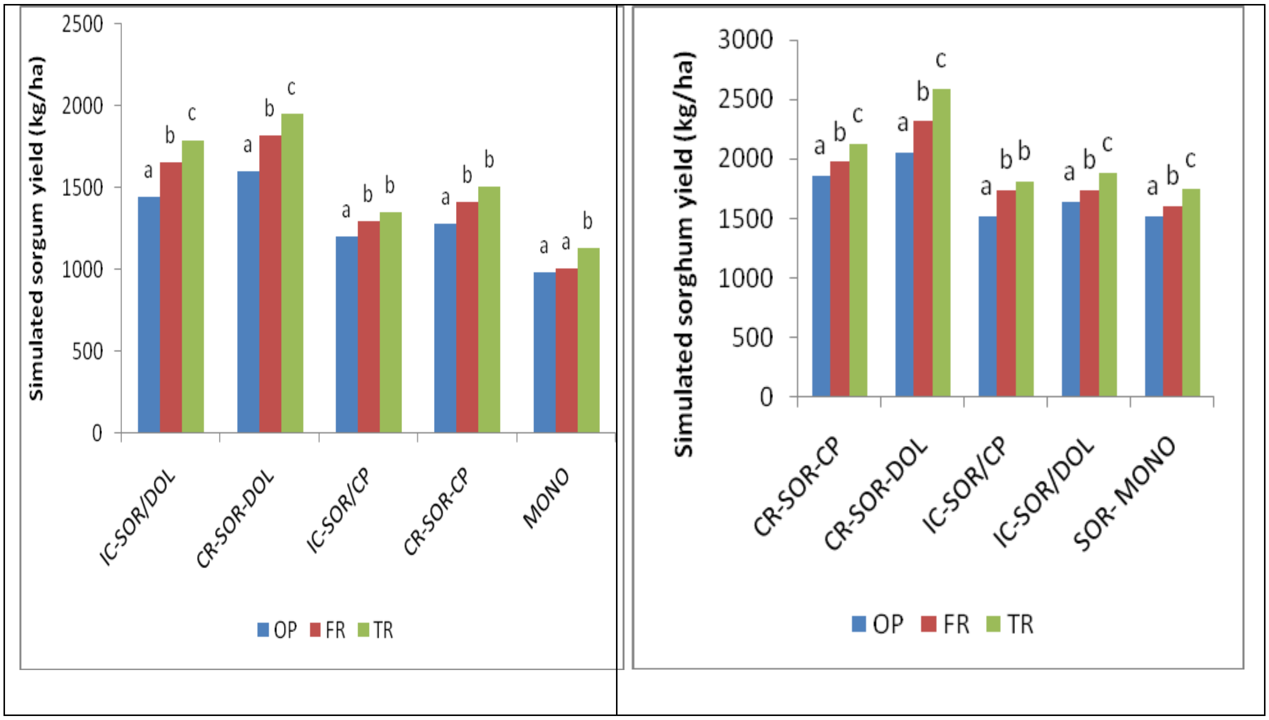
Season 2

CRTL; control, RP; Rock phosphate, FYM; farm yard manure

Figure 12: Simulated sorghum yield (kg/ha) in different organic inputs

RP + FYM increased sorghum yields than when the organic inputs were used solely. The increase in sorghum yield could be attributed to improved soil fertility which could have been due to high soil organic matter. Okalebo et al., 1999 stated that soil fertility could be improved by the use of combinations of farm yard manure and organic inputs since this combinations provide a cheap N input from organics and solubilization of phosphorus.

Tillage practice and cropping systems interactions: In the first season, sorghum yield (1,955.6 kg/ha) was significantly high in interaction between tied ridges and sorghum/dolichos intercrop and least (981.5 kg/ha) in interaction between oxen plough and sorghum monocrop (Fig.13). In the second season, sorghum yield (2,584 kg/ha) was significantly high in tied ridges interaction with sorghum and dolichos rotation and least (11,519 kg/ha) in oxen plough with sorghum monocropping (Fig.13)

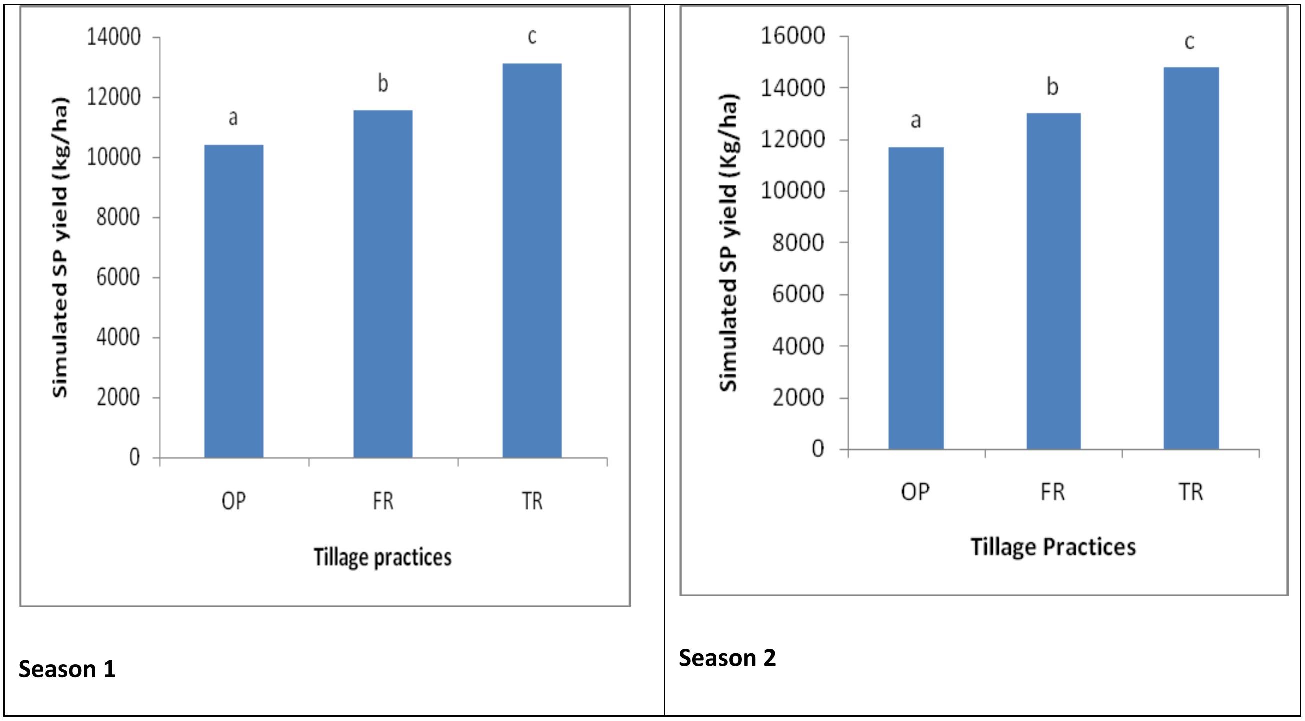


SOR- sorghum, DOL- dolichos, CP-

Figure 13: Simulated sorghum yield (kg/ha) in the tillage practices interaction with cropping systems

High sorghum yield in tied ridges and sorghum-dolichos rotation could be attributed to improved soil moisture since tied ridges are able to retain rainwater for long period.. Soil moisture conservation under such conditions requires appropriate tillage practices that not only improve rainwater infiltration but also conserves adequate soil moisture for plant growth (Miriti et al., 2012).

Sweet potato yield: There were significant ($P < 0.05$) differences in sweet potato yield in tillage practices, cropping systems and organic inputs. There were also significant interactions in tillage practices and copping systems. In the first season, sweet potato yield (13,127 kg/ha) was significantly high in tied ridges and least (10,127 kg/ha) in oxen plough (Fig. 14). In the second season, sweet potato yield (14,768 kg/ha) was significantly high in tied ridges and least (11, 699 kg/ha) in oxen plough (Fig. 14)

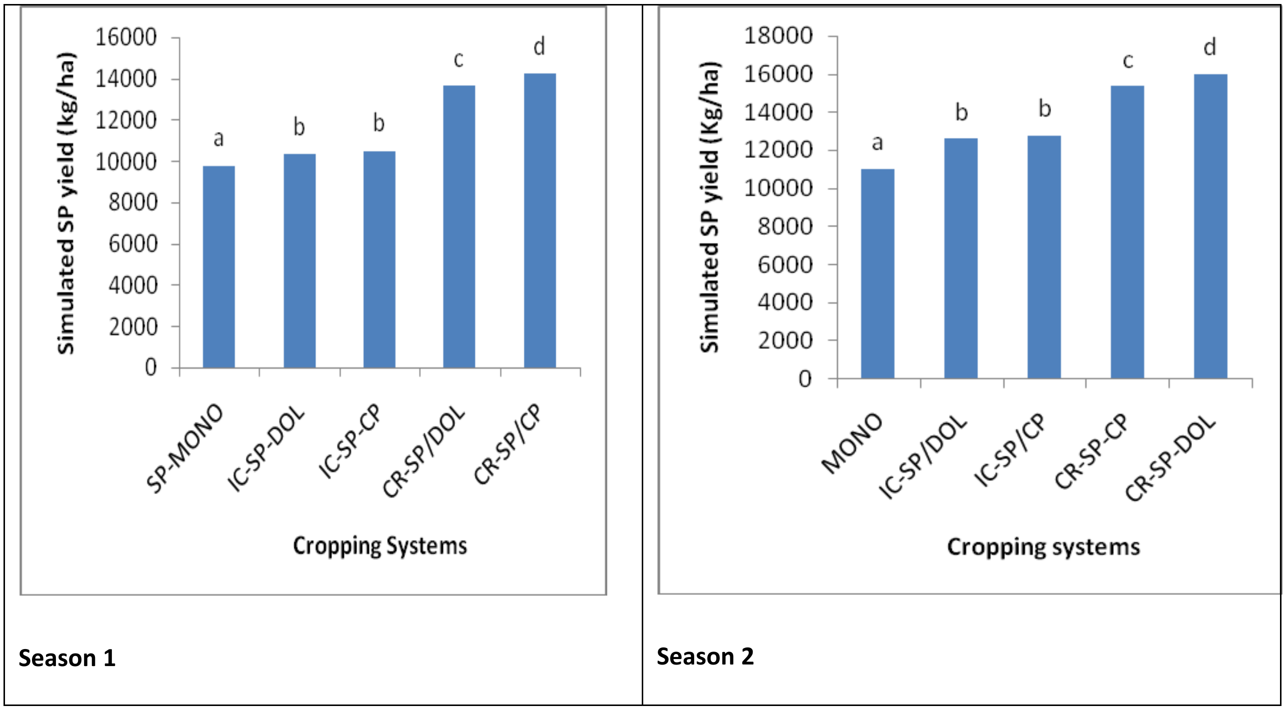


OP; Open plough, FR; furrows and ridges, TR; tied ridges, SP; sweet potato

Figure 14: Simulated Sweet potato yield in different tillage practices

Results of the simulations show that tied ridges had highest sweet potato yield compared to oxen plough and furrows and ridges which could be attributed to better on-farm rainwater management that led high sweet potato. Tied ridges are known to improve yields due to improved soil moisture (Rockstrom, 2003). Results from tied ridges techniques have given superior yields for different crops (Miriti et al., 2003; Kipserem, 1996).

Cropping Systems: In the first season, sweet potato yield (14,222 kg/ha) was significantly high in the sweet potato-chick pea rotation and least (9,772 kg/ha) in sweet potato monocropping (Fig. 15). In second season sweet potato yield (16,000 kg/ha) was significantly high in sweet potato rotation with dolichos and least (10,993 kg/ha) in sweet potato mono cropping (Fig. 15)



SP; Sweet Potato, IC; Intercropping, CR; crop rotation, DOL; Dolichos, CP; Chickpea

Figure 15: Simulated sweet potato yield (kg/ha) in different cropping systems

Sweet potato yield was highest when intercropped with chickpea in the first season. Intercropping could have improved on the soil fertility of the soil since chickpea has the capacity to fix nitrogen in the soil. Intercropping sweet potato with chickpea improves and maintains soil fertility through the fallen leaves and decaying roots after the chickpea is harvested which provide nitrogen and other nutrients in soil. Legumes are known to fix nitrogen in soil hence improving soil fertility and thus sweet potato yield. Guretzky et al. (2004) reported that legumes have the potential to improve soil fertility through release of nitrogen from decomposing leaf residues, roots and nodules which results to increased crop production.

Sweet potato rotation with dolichos increased sweet potato yield in the second season. Increased sweet potato could be attributed to improved soil fertility due litter fall from dolichos. The high yields could be attributed to improved soil fertility. Legumes have proven to be an effective means of sustaining soil fertility (Cheer et al., 2006).

Organic inputs

In the first season, sweet potato yield (13,247 kg/ha) was significantly ($P < 0.05$) high when RP + FYM was applied and least (10,405 kg/ha) in control with no organic input was applied (Fig.

16). In the second season sweet potato yield (14,034 Kg/ha) was significantly (P < 0.05) high in RP + FYM and least (10,995 Kg/ha) in control when no organic input was applied. (Fig. 16)

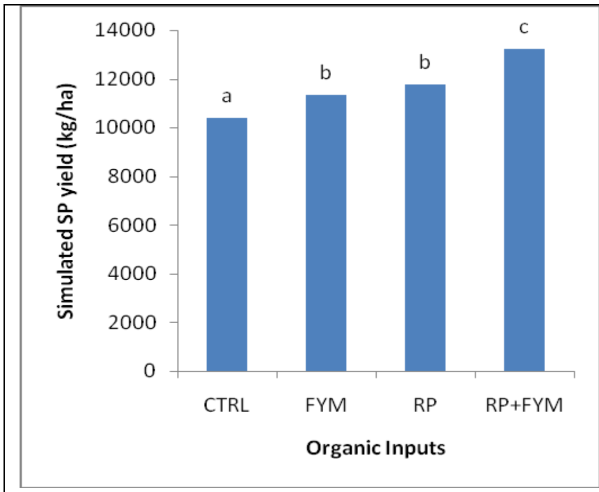


Figure 16 Season 1

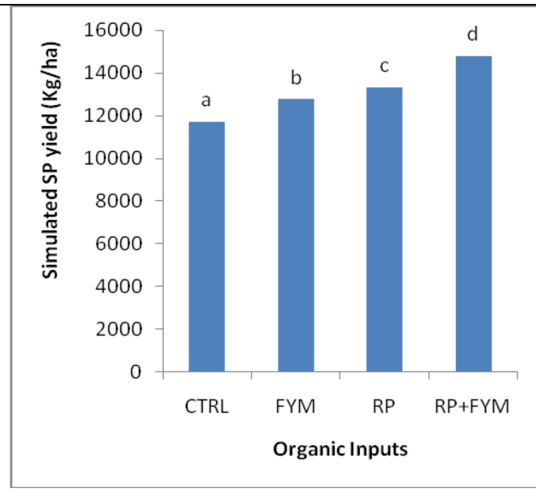


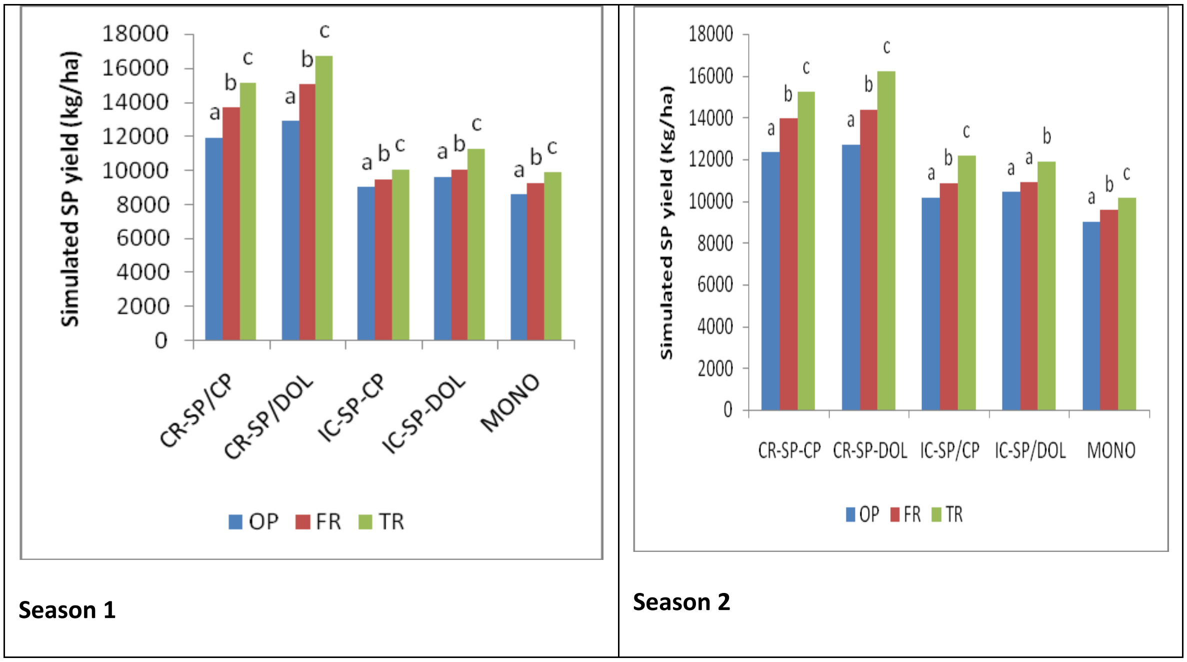
Figure 17 Season 2

SP; sweet potato, CTRL; control, FYM; Farm yard manure, RP; Rock Phosphate

Figure 16: Simulated sweet potato yield (Kg/ha) in different organic inputs

RP + FYM had high sweet potato yield compared to sole application of the organic inputs and least in control. The high sweet potato yield could be attributed to increased soil fertility and improved soil moisture due to increased water retention. Combined application of farm yard manure and rock phosphate have resulted in significant increases in crop yield and increases in soil nutrients as compared with sole application of inorganic fertilizers (Liu et al., 1996).

Tillage practice and cropping systems interactions: In the first season, sweet potato yield (16,737 kg/ha) was high in tied ridges interaction with sweet potato intercrop with dolichos and least (8572 kg/ha) in oxen plough interaction with sorghum mono crop (Fig. 17). In the second season, sweet potato yield (18, 066 kg/ha) was significantly high in tied ridges interaction with sweet potato rotation with chick pea and least (9643 kg/ha) in oxen plough interaction with sweet potato monocrop (Fig. 17)



OP; oxen plough, FR; Furrows and ridges, TR; Tied ridges, CR; crop rotation, SP; sweet potato, CP; Chickpea, DOL; Dolichos, IC; intercropping

Figure 17: Simulated sweet potato yield (kg/ha) in tillage and cropping systems interactions

The combined use of tied ridges, intercropping and rotating sweet potato with dolichos improved on sweet potato yields due to increased soil moisture as a result of rainwater harvesting from tied ridges and improved soil fertility from dolichos residues resulting in considerable crop yield increases. According to Gardener et al. (1999) tied ridges increase soil moisture content due to increased water storage and hence improve crop yields.

5.9 Conclusion

Oxen plough, monocropping and control interaction had the least sorghum and sweet potato yields. Tied ridges, intercropping, crop rotation systems and FYM + RP had high sorghum and sweet potato yield. Sorghum was high in tied ridges, sorghum intercropping and rotation with dolichos interactions. Sweet potato yield was high in tied ridges and sweet potato intercropping and rotation with dolichos and chickpea interactions. High sorghum and sweet potato yield in tied ridges, intercropping and rotation with legumes and application of FYM + RP was due to increased soil moisture as a result of rainwater conservation.

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CHAPTER SIX

6.0 General conclusions and Recommendations.

6.1 Conclusions

The study revealed the potential advantages of tillage practices, cropping systems and use of organic fertilizers that enhance soil moisture and fertility. In reference to the rationale of adopting tillage techniques and depending on the results of this work the following conclusions can be summarized as follows: 1. Tied ridges improved soil moisture stored within the root zone as compared to the furrows and ridges and oxen plough resulting in higher sorghum grain and sweet potato tuber yield. 2. Crop rotation and intercropping sorghum and sweet potatoes with legumes improved soil moisture and subsequently yields as compared to mono cropping. 3. The use of FYM + RP resulted into higher soil moisture, sorghum and sweet potato yields compared to the use of the sole organic inputs.

6.2 Recommendations

The use of tied ridges in ASALs should be promoted in order to minimize soil moisture loss through surface runoff. Intercropping and crop rotation should be promoted so as to improve on soil fertility and avoid the risk of total crop loss. A combination of tied ridges with intercrop of dolichos with sorghum and sweet potato with the application of FYM+RP can be used for moisture conservation for increased crop yield in the Matuu Sub County. Generally, the adoption of tied ridges, intercropping and crop rotation with the application of a combination of farm yard manure and rock phosphate are worthwhile techniques applied for semi-arid areas as compared to the oxen plough and furrows and ridges and, mono cropping and the use of sole organic inputs evaluated in this study.

The shortcomings in determining crop yield from cropping systems in Kenya through experimentation, field research or on-farm trials, such as time consumption, limited resources and climate change effects could be countered by the use of crop simulation models.

Further research is also required to test the CropSyst model under different locations, soil types, management styles and scales of production.

CHAPTER SEVEN

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