EVALUATION OF DIFFERENT FIELD MANAGEMENT PRACTICES FOR EFFICIENT PRODUCTION OF UPLAND RICE (NERICA)

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ABSTRACT

Rice (*Oryza sativa L)* constitutes one of the most important staple foods of over half of the world's population . Globally, it's ranked third after wheat and maize in terms of production. In Kenya, rice is the 3rd most important cereal crop after maize and wheat. Upland rainfed rice cultivation is being promoted in Kenya against a background of increased rice demand in the country. About 90% of the rice grown in Kenya is from irrigation schemes established by Government while the remaining 10% is produced under rainfed conditions. The rainfed rice varieties promoted are the New Rice for Africa (NERICAs) produced through interspecific hybridization of *Oryza sativa* L and *Oryza glabberima* S which are cultivated under rainfed conditions where crop production is limited by soil moisture availability in Kenya. Research on NERICA has been on agronomy, pests, diseases and weeds but little is known about field management practices for NERICA rice production. The objectives of the study were to evaluate the seasonal evaporation of rainfall, quantify the plant available water capacity and evaluate the rainfall use efficiency of NERICA 4 rice variety grown on four management conditions. A field experiment was conducted during April 2012-August 2012 and October 2012 to February 2013 to evaluate the efficiency of field management practices on the yield and yield components of NERICA 4 in upland ecologies of western Kenya. Three replicates of each of four different methods of field management to create different water retention characteristics in the soil were established in a Randomized Complete Block Design (RCBD).The four field management practices included; (a) 10% sloping field, no bunds, no straw mulch (SF); (b) Flat field, no bunds, no straw mulch (FU); (c) Flat field with bunds, no straw mulch (FB); (d) Flat field, no bunds, with straw mulch (FUM). Seasonal evaporation was measured by use of microlysimeters, soil moisture was monitored using the soil moisture probe while the seasonal rainfall use efficiency was calculated from above ground biomass and grain yield.

Data were analyzed using the SAS computer package and differences between means were separated by the Duncan's critical range test and Fisher's least significance difference (LSD) test at 5% significance level. The FUM treatment reduced seasonal soil surface evaporation by 52.94% - 54.55% during the vegetative and reproductive phases of growth compared to other treatments and significantly increased soil moisture retention at 10 cm depth with a significant increase in the PAWC by 12%-16% which resulted to a significantly higher RUEb by 14.29% and subsequently increased RUEg by 20.89% .The FB treatment significantly increased AWC by 20-25% with a significant increase in RUEg by 10.99%. Adoption of the FUM practice will enhance NERICA rice grain production, conserve the environment for sustainable agricultural productivity and reduce on rice imports by the country.

CHAPTER ONE

INTRODUCTION

1.1. Background

Rice (*Oryza sativa L)* constitutes one of the most important staple foods of over half of the world's population (Akinibile & Abimbola, 2011).They derive about 80% of their food need (Conteh *et al.,* 2012, Nguyen, 2006) from rice. Globally, it's ranked third after wheat and maize in terms of production (FAO 2005; Nguyen, 2006). Rice can be grown under irrigated (lowland) or rain-fed (upland or lowland) conditions (Somado *et al*., 2008). Rain-fed rice occupies about 45% of the global rice area and accounts for about 25% of the rice production (Tuong & Bouman, 2003).Asia accounted for 90% of the world rice production in 2007 while Africa accounted for only 0.9% (FAO 2005). Rice consumption is growing faster than that of any other major staple in Africa at about 5.5% per year (2000–2010 average) than rice production (3.3%) (Atera *et* al., 2011; Onyango, 2006). Rice is the most rapidly growing food source in sub-Saharan Africa (Solh, 2005) mainly driven by population growth (4% per annum) and urbanization (38% in 2014 projected to reach 48% by 2030), rising incomes and a shift in consumer preferences in favor of rice (Balasubramanian, *et al*., 2007; Conteh *et al.,* 2012; Seck *et al.,* 2013; Timmer *et al.,* 2004). In the period 2001-2005, rice production expanded at the rate of 6% per annum, with 70% of the production increase due mainly to land expansion and only 30% being attributed to an increase in productivity (Conteh *et al.,* 2012, Africa rice center, 2013). The rate of expansion was still inadequate to cope with the rate of consumption. This global trend in the rice industry shows that there has been a growing import demand for the commodity in Africa so much so that in 2006, Africa's global rice imports accounted for 32% of global imports (Conteh *et al.,* 2012; Somado *et al.,* 2008). In sub Saharan Africa (SSA), rice is the fourth most important cereal (after sorghum, maize and millet) occupying 10% of the total land under cereal production and accounting for 15% of total cereal production (Rodenburg *et al.,* 2006). Promotion of rice production would help in making the majority of the citizens food secure

1.2 Rice Production in Kenya

In Kenya, rice is the 3rd most important cereal crop after maize and wheat ([MOA 2010, Short *et al.,* 2013; EPZ, 2014; Onyango, 2014). Rice is grown as a food crop for domestic consumption in addition to being a cash crop for income generation (MOA, 2009). Rice in Kenya is produced by small scale farmers under irrigated as well as rain-fed conditions (MAFAP, 2005.). During the period 2005 - 2010 about 78-80% of the rice grown in Kenya was from irrigation schemes established by the government and about 22-20% of rice was produced under rain-fed conditions (Emongor *et al.,* 2009). The acreage under rice production has stagnated between 15,000- 20,000 Ha while the yields have reduced to 1.9 t/ha from 3.6 t/ha between 2005 and 2010 (MAFAP, 2013). There are four national irrigation board (NIB) schemes currently producing rice in Kenya occupying 13000 Ha. (MAFAP, 2005: MOA 2010,). Rain-fed rice is grown in Kwale, Kilifi and Tana River Districts in coast province and Bunyala and Teso Districts in western Kenya (EPZ, 2005). There was a decline in production of rice between 2007 and 2008 mainly due to the spike in world commodity prices in 2007-2008 which affected the costs and availability of fertilizers needed to maintain the rice yields (Sasson, 2012). The civil disturbances that followed the December 2007 general elections and the subsequent drought that followed might have also led to the drop (MOA, 2010) in production of rice. Rice consumption in Kenya has grown much more rapidly than production at an average rate of 11% per year since 1960. As a result, imports have increased rapidly, and the import dependency ratio rose from 23% in the 1960s to 88% in the 1990s through to the period 2005- 2010. The national rice consumption in Kenya is estimated at 300,000 Metric tons compared to an annual production range of 45,000-80,000 metric tons (MOA, 2010). Kenya has therefore remained a net importer of rice (Onyango, 2006). Interventions aimed at boosting the production of rice would significantly reduce the import bill and improve food security. Kenya has a potential of about 540,000 ha irrigable land (and only 19% of has been developed) and one million hectares for rainfed rice production (Mambala, 2007; Oikeh, 2010) and only 21,000 Ha is under production(MOA 2010; short *et al.* 2013). Promotion of upland rice production would help increase food security as well as farm incomes (Africa Rice Center, 2011, Conteh *et al.,* 2012, Nguyen, 2005, Timmer *et al.,* 2013) in SSA in general and Kenya in particular. The target areas for rainfed rice production lie within altitude range of 15-1700 m.a.s.l. (MOA, 2009; MOA 2014) and include counties in Rift valley, Central, Nyanza, Western and coast regions. Growing upland rice is recommended in agro ecological zones (AEZ) with more than 1000mm of annual rainfall particularly with more than 15-20 mm of 5 day rainfall during the early growing stage and with 25mm during the panicle initiation stages (MOA, 2009).

Low yield constitutes one of the main challenges of rice production in SSA (Somado *et al.,* 2008; Atera *et al.,* 2011). Weed competition is the most important yield-reducing factor (Johnson *et al.,* 1997) followed by drought, blast, soil acidity and general soil infertility. *Oryza sativa* is susceptible to lodging, shattering and pest damage. Water stress due to erratic rainfall and poor soil fertility management ranks highest in yield loss (FAO, 2003; Kato *et al.,* 2008).

West Africa Regional Development Authority's (WARDA) breakthrough in producing the 'New Rice for Africa' (NERICA), which is an inter-specific hybrid between the local African rice (*Oryza glaberrima* Steud.*) a*nd the exotic Asian rice (*O. sativa* L) incorporates both the high yielding ability of *O. Sativa* and the resistance of *O. glaberrima* to major constraints such as diseases, drought and low soil fertility and they mature up to 30 - 50 days earlier than other upland varieties. These attributes make them have yield advantage over their *O. glaberrima* and *O. sativa* parents through superior weed competitiveness, drought tolerance and pest or disease resistance (Africa Rice Center, 2004). NERICAs thrive well at relatively low rainfall, a minimum of 20 mm per week, well-distributed during the three months of growing season (Somado *et al*., 2008). However, information with regards to agronomic factors influencing upland rice productivity and NERICA adaptation in Western Kenya is scarce.

Water is essential for NERICA rice cultivation and its supply in adequate quantity is one of the most important factors in production (Akinibile & Abimbola, 2011). Most studies on constraints to high rice yield shows that water is the main factor for yield gaps and yield variability from experimental stations to farm (Akinibile & Abimbola, 2011). Water use efficiency (WUE) represents a given level of biomass or grain yield per unit of water used by the crop (Hatfield *et al.,* 2001). Water use efficiency is a measure of the efficiency with which a crop uses water to produce a certain yield and it is based on evapotranspiration (Hatfield *et al.,* 2001; Hensley *et al*., 2007; Richard *et al.,* 2009; Turner 2004). Rainfall use efficiency (RUE) is a measure of the biomass or grain yield produced per increment of rainfall (Hensley *et al.,* 1990; Gardiner, 2010). However, WUE does not enable the comparison of different production practices. This is because certain water losses (runoff, evaporation and deep drainage), which can be minimized by using suitable field management practices to improve the efficiency of rainwater use in crop production, are not taken into account (Gardiner, 2010). Rainfall use efficiency (RUE) is considered to be a more appropriate parameter to describe the overall efficiency with which rainwater is used in rain-fed cropping, since the above named losses are taken into account (Hensley *et al.,* 1990).

The NERICA rice varieties have been accepted and become widespread in some parts of Kenya. However, NERICA rice was introduced to the farmers without information on field management practices that can conserve rainfall and reduces associated water losses. Soil management practices that result in more plant available water by reducing unproductive water losses, such as runoff, deep drainage, and excessive evaporation from the soil, result in more water being available for growth and therefore increased yield and increased RUE (Zere *et al.,* 2007;Wolka *et al.,* 2011). RUE therefore enables a meaningful and comprehensive comparison to be made between the efficiencies of different soil production practices.

Soil management practices affect the processes of evapotranspiration (ET) by modifying the available energy, the available water in the soil profile or the exchange rate between the soil and the atmosphere (Hatfield *et al.,* 2001; Lal, 1997). Rainfall use efficiency can be increased by 25%-40% through soil management practices especially those that increase water storage in the soil and thus contributing a positive impact on rainfall use efficiency (Hatfield *et al.,* 2001). Manipulation of the soil surface through tillage and surface residue management or mulching affects yield and ET (Hatfield *et al.,* 2001; Muchow *et al.,* 1994).

Plant available water capacity (PAWC) is the total amount of water a soil can hold that a particular crop can extract from that particular soil (Gardiner *et al*., 1984; Hochman, *et al*., 2001). Available water capacity is the capacity of soils to hold water available for use by most plants, usually defined as water between suction potentials of -33 kpa (field capacity)and -1500 kpa (permanent wilting point). Field capacity is the water remaining in a soil after it has been thoroughly saturated and allowed to drain freely, usually for one to two days. Permanent wilting point is the moisture content of a soil at which plants wilt and fail to recover when supplied with sufficient moisture. Plant available water capacity studies rely on the determination of the drained upper limit (DUL) and the crop specific lower limit of water availability (CLL) (Ratclif *et al.,* 1983). Soil water availability refers to the capacity of a soil to retain water available to plants (Allen *et al.,* 1998). Soil management practices that increase the soil water holding capacity, improve the ability of the roots to extract water from the soil profile, or decrease water (surface runoff, evaporation or leaching) losses, could all potentially have positive impacts on water use efficiency (WUE) and rainfall use efficiency (RUE) especially if the changes result in concurrent increase in crop yield (Hatfield *et al.,* 2001). Soil water evaporation is affected by the soil water content of the soil surface and the degree of crop residue/mulch cover (Scopel *et al.,* 2004). Field cultivation reduces soil water availability in the rootzone by as much as 20-30mm per day through evaporation (Hatfield *et al.,* 2001). Decreasing tillage improves WUE because of improved soil water availability through reduced evaporation losses. Covering the soil with mulch or surface residue reduces soil water evaporation by reducing soil temperature, impeding vapour diffusion, absorbing water vapour onto mulch tissue, and reducing the wind speed gradient at the soil –atmosphere interface (Lal, 1998) reducing soil water evaporation by 34-50% (Hatfield *et al.,* 2001).

Rainfed rice technology has not been widely adopted in Kenya yet it can contribute to increased rice production through exploitation of the existing vast potential in terms of suitable land. Data on contribution of soil management practices to increased yield in upland rice production in Kenya is lacking.

Past research efforts on the NERICA rice crop centered on the agronomic, soil and disease behavioral pattern (Okonje *et al.,* 2012. Apaseku & Dowbe, 2013., Mghase *et al* ., 2009) with little work on its field management practices for increased rainfall use efficiency. Thus little is known about the appropriate field management practice(s) with high RUE for growing NERICA rice under rainfed conditions.

1.3. Statement of the problem

Globally, out of the over 1 billion people who are food insecure, about 25% are in sub-Saharan Africa (Sasson, 2012). In Sub Saharan Africa (SSA), rice is one of the food commodities whose demand is rapidly growing mainly driven by high population growth, rapid urbanization and changes in eating habits. Rice consumption is increasing faster than that of any other food staple in Africa at about 5.5% per year (2000–2010.The key problem facing the rice sector in Africa in general is that local production has never caught up with demand. In Kenya, 51%, of the population is food poor while overall poverty is 53% of the rural population (GOK, 2010) with overall national incidence of poverty at 52%.The estimated area under rainfed rice crop production in Kenya is 29,000 Ha against a potential of 1.0 million Ha. Kenya consumes over 300,000 tons of rice against a national production of 45,000 to 50,000 and is therefore a net importer of rice. Promotion of rice production would help in making the majority of the citizen food secure. NERICA is suitable for rainfed conditions and is being promoted as a means to increase food security and saving of the foreign exchange. Since upland rice depends entirely on rainfall for water supply in the freely drained soils, it is limited to high rainfall areas with good rainfall distribution. In rain-fed lowland ecologies that are potential for rainfed rice production, the main challenge is erratic rainfall that is poorly distributed during the growing season. The yields of upland rice on smallholder farms are normally below those obtained from on- farm trials and it is hypothesized that field management practices contribute to low rainfall use efficiency due to losses of rain water through surface runoff and excessive soil evaporation that contributes to the poor yields. Expansion of the area under rainfed rice remains a strategic objective for increased rice production and is hampered by lack of appropriate production practices. Tillage practices should be developed to increase the water intake capacity of the soils and take advantage of rainfall, reduce excessive surface evaporation; reduce runoff and control erosion and increase water storage in the soil for uptake by plants. Proposed innovations to improve the productivity of upland rice via enhanced RUE is the use of leveled beds with crop residue mulch as well as the use of soil bunds. Data on the contribution of this practice to increase upland rice yield is lacking. Past research efforts on the NERICA rice crop centered on the agronomic, soil and disease behavioral pattern while research on its field management practices for increased rainfall use efficiency is lacking. The study provides knowledge on the efficient tillage practice(s) for growing NERICA rice under rain-fed conditions.

1.4 Overall objective

To evaluate field management practices for efficient production of upland rice

1.4.1 Specific objectives

i. To determine the evaporation component of the water balance for NERICA 4 rice crop under various field management practices.
ii. To quantify the plant available water capacity for NERICA 4rice crop growing on acrisols at Maseno.
iii. To determine the rainfall use efficiency for NERICA 4 rice crop grown under various field management practices expressed as biomass and grain yield.

1.4.2 Hypotheses (null)

i. Field management practices do not results into different quantities of surface rain water losses through evaporation from the soil surface.
ii. Different field management practices do not affect the plant available water capacity in the NERICA fields
iii. Field management practices for NERICA 4 rice variety on Maseno soils do not result in different Rainfall use efficiency (RUE) responses by NERICA 4 rice crop

1.4.3 Justification

Rainfed rice technology has not been widely adopted in Kenya yet it has potential to contribute to increased rice production through exploitation of the existing vast arable land and the current upland rice technology released in April 2009 (MOA, 2009). Low yields of NERICA rice on farmers fields below the potential yields obtained from on farm trials is partly due to poor farm management practices with low RUE due to high evaporation losses from the soil surface and runoff from the rice fields (Allen, 1998). After the release of NERICA seed varieties (MOA 2009) NERICA 4 rice was found to be the most suitable variety for most areas in Kenya and farmers have been encouraged to grow NERICA rice to reduce on the crops imports. However spread of upland rice production has been hampered by lack of readily available information on nutritional characteristics as well as the recommended production practices (Somado *et al.,* 2008; Kijima et al., 2012) and as a result yields have remained lower than 4.4 t/ha achieved in on farm trails (OFT) and demonstrations. Though one million hectares of land is suitable for upland rice production, the farms have varied topography including sloppy fields that generate runoff in extreme rainfall events, thus rainfall is lost through runoff affecting crop performance and hence the need for soil and water conservation. NERICA rice requires 800mm of seasonal rainfall but due to climate change rainfall distribution is poor and erratic with a high evaporative demand exposing the crop to moisture stress. Therefore there is an urgent need for soil management practices to conserve soil water for NERICA production. Mulching as a farming practice has the potential to enable increased productivity even under conditions of erratic and insufficient rainfall during the growing season. The output of this study contributes more knowledge on rain fed rice production which in turn may contribute to improved yield and improved food security and economic status in a sustainable environment.

1.4.4 Significance of the study

Assessing the efficiency of soil management practices on upland rice yield and rainfall use efficiency in Western Kenya has provided information on the effect of soil management practices on crop yield in the Humid agro-ecological zone in Western Kenya. Our study helps suggest alternative farming strategies to the NERICA rice farmers

CHAPTER TWO

LITERATURE REVIEW

2.1 The importance of rice in Africa

Rice is the third most important source of dietary energy for Africa as a whole after maize and sorghum (Seck *et al.*, 2013). Rice is a highly strategic and priority commodity for food security in Africa. Rice consumption has increased faster than that of any other food staple in Africa at about 5.5% per year (2000–2010 average).

Rice consumption grew faster than that of any other major staple on the continent because of high population growth rapid urbanization and changes in eating habits (Seck et al., 2013). The increase was driven by rapid urbanization and related changes in eating habits, and population growth (Seck et al., 2012; Onyango, 2014). With only about 60% of rice consumption being satisfied by domestic production, rice imports into Africa stood at 10–12 Mt. (Africa Rice Center, 2005; Balasubramanian *et al.* 2007; Africa Rice Center, 2008)) equivalent to one-third of the rice traded on the world market (Solh., 2005; Somado *et al.,* 2008). With the population of Africans living in urban areas expected to increase from 38% to 48% by 2030, rice consumption in Africa is expected to increase tremendously (Africa Rice Center, 2012; 2013).

Between 1970 and 2009, annual rice consumption in sub Saharan Africa (SSA) increased at a faster rate (4%) than rice production (3.3%) (Africa Rice Center, 2007; Onyango, 2014). In the period 2001-2005, rice production expanded at a rate of 6% per annum, with 70% being attributed to increase in land expansion and only 30% being attributed to productivity (Africa Rice Center, 2007; Somado *et al.,* 2008; Africa Rice Center, 2013). The production to consumption gap in the region was filled by imports, accounting for 32% of global imports in 2006 (Somado *et al.,* 2008).

Low yields at an average of 1t/ha, constitutes one of the main challenges of rice production in upland rainfed ecologies (Somado *et al.,* 2008). Weed competition is the most important yield reducing factor (Johnson *et al.,* 1997), followed by drought, blast, soil acidity and general soil infertility.

Nearly half of sub-Saharan Africa's 700 million people live below the poverty line (World Development Indicators, 2004).With the population growth rate exceeding the growth rate in regional food production and with only limited foreign resources to sustain increased levels of imports, the future of Africa's poor are grim. West Africa

Regional Development Association (WARDA)'s breakthrough in producing the 'New Rice for Africa (NERICA),based on crossings between African rice (*Oryza glaberimma* steud) and Asian rice (*Oryza sativa* L.) offers a relief to farmers (Somado *et al.,* 2008).

2.2 The Biology of Rice (*Oryza sativa*)

The genus Oryza belongs to the tribe oryzae of the family Poaceae. The oryzeae is believed to have 12 genera, oryza being one of them (Vaughan, 1994). It's further believed that the genus oryza has 22 species, 20 of which are wild while two; the *oryza sativa* and *oryza glaberrima* are cultivated. *Oryza sativa*, the Asian rice, is thought to have originated from *oryza rufipogon* and *oryza nivara* while *oryza glaberrima*, the African rice, on the other hand is thought to have originated from *oryza barthi* and *oryza longistaminata* (Vaughan *et al.,* 2003). The Asian cultivated rice *oryza sativa* is high yielding but is susceptible to the stresses of African ecologies while the *oryza glaberrima*, the African rice, is adapted to the African environment but prone to lodging and grain shattering (Somado *et al.*, 2008).

Rice is normally grown as an annual plant, although in tropical areas it can survive as a perennial and can produce a ratoon crop for up to 30 years (Expor, 2008) .The rice plant can grow to 1–1.8 m tall, occasionally more depending on the variety and soil fertility. Rice is an annual grass with round , hollow, jointed culms; narrow, flat sessile leaf blades joined to the leaf sheaths with collars, well defined , sickle shaped, hairy auricles, small acute to acuminate or two cleft ligules and terminal panicles (Olembo *et al.,* 2010). It has long, slender leaves 50–100 cm long and 2–2.5 cm broad. The small wind-pollinated flowers are produced in a branched arching to pendulous inflorescence 30–50 cm long. The edible seed is a grain (caryopsis) 5–12 mm long and 2–3 mm thick. The growth of rice from germination to maturity may be divided into three agronomic stages of development, the vegetative stage which runs from seed germination to panicle initiation followed by the reproductive stage that runs between panicle initiation to heading and the grain filling and ripening or maturation that runs between heading to maturity. All these stages influence the key yield components namely number of productive tillers per plant, number of panicles per unit land area, the average number of grain produced per panicle and the average weight of the individual grains (Olembo *et al.,* 2011). These components determine grain yield and the level of benefits to the farmers. Not all tillers are productive, productivity of tillers mainly depend on cultivars, tillering regime, water regime and plant density (Yoshida, 1981).

2.2.1 The New Rice for Africa (NERICA)

NERICA stands for New Rice for Africa (Somado *et al.,* 2008). It refers to the genetic material derived from the successful crossing that combines the best traits of both the two species of cultivated rice, the African rice (*Oryza glaberrima* steud) and Asian rice (*Oryza sativa* L) (Somado *et al.,* 2008). The African species is a robust plant that adapts well to local conditions while the Asian variety has a much higher yield (Jones *et al*., 1997; 1998). The inter-specific hybridization between *Oryza sativa* (Asian rice) and *Oryza glaberrima* (African rice), produced a new rice variety (NERICA) that carried advantages of both *Oryza sativa* (Asian rice) and *Oryza glaberrima* (African rice) and could grow under rainfed conditions or limited supplementary irrigation. The New Rice for Africa (NERICA) varieties have widely been used in Africa because of their high yielding traits and resistance to tropical diseases, erratic rainfall and low fertility soil of the African environment (Rice, 2006). New Rice for Africa (NERICA) rice combines the robustness of the African rice with the higher yield of the Asian rice. NERICA varieties adapt well to the difficult production environments and low levels of farming inputs. In Africa's sub-Saharan rice-growing environments where small producers do not have the means to irrigate their fields and apply chemical fertilizers, different varieties of NERICA can be grown. The basic characteristic of NERICA rice is profuse early vegetative growth giving rapid ground cover, followed by upright growth at reproductive stage (Somado *et al.,* 2008).The profuse tillering is characteristic of *glaberrima.* The rapid ground cover enables the crop to smoother and outcompete weeds. Upright growth, especially at reproductive stage, is a characteristic of *sativa*; it enables the plant to support heavy seed heads through maturity to harvest. NERICA rice typically matures early within 90-100 days after sowing. Furthermore, NERICA rice has high grain per panicle and high Protein content of the grains compared to the parents (Somado *et al.,* 2008). The NERICA rice varieties are both high yielding and tolerant /resistant to some of the common abiotic and biotic stresses like drought, pests and diseases. The protein content of NERICA is generally higher (by 25%) than that of the other rice widely available in

African markets. By December 2005, WARDA had named 18 upland NERICA varieties following their selection by farmers through participatory varietal selection trials across SSA. In Kenya the NERICA varieties released on 16th April 2009 for growing by farmers include NERICA 1,4,10,11 (MOA, 2009). According to Kijima *et al.,* (2006), the average yield of NERICA in Uganda was found to be 2.2 tons per hectare, which is twice as large as the average rice yield in sub-Saharan Africa.

Under good agricultural practices, it is possible to achieve high yields up to 5-6 tons/ha, when appropriate levels of fertilizer are used which is comparable to irrigated rice. However, NERICA rice technology was introduced to farmers without information on the soil management practices especially in upland ecologies with erratic rainfall prone to climate risks of moisture stress. NERICA responds better to inputs than the traditional varieties producing enhanced yield of ≥ 5 ton ha^{-1} (Atera *et al.,* 2011; Kijima *et al.,* 2006; Somado *et al.,* 2008).

2.3 Ecological requirements for NERICA varieties

Growing NERICA rice is recommended in agro-ecological zones with more than 800 mm of annual rainfall, particularly with more than 15mm of five day rainfall during the early growing stage and more than 25mm during the panicle initiation stage (Somado *et al.,* 2008; Bunyatta, 2010). During germination and early growth stages, 15 mm per five-day rainfall is sufficient. Upland rice performs best on fertile land with good drainage and good water retention capacity (contains some clay and/or organic matter, i.e. Loamy soil). Land with high water retention capacity containing some clay, silt, sand, and organic matter is recommended for NERICA production (Bunyatta, 2010). NERICA rice production in Western Kenya was evaluated on flat land (Bunyatta, 2010; Atera *et al.,* 2011). There is no information on other soil management practices to support production of NERICA rice in Kenya. In West Africa most of the soils in the upland rice production agro-ecology are sandy loams to sandy clays with pH ranging from 5.0 and 6.0. In the humid forest agro-ecosystem, where there are heavy losses of exchangeable bases due to excessive rainfall, the pH may range between 4.0 and 4.5 (Somado *et al.,* 2008).

2.4 Tillage practices for soil and water conservation in rainfed agriculture

Evidence from water balance analyses on farmers fields in Sub-Saharan Africa shows that only a small fraction of rainfall (15% to 30%) is used as plant transpiration supporting plant growth (Rockström 2003). On severely degraded land or land where yields are lower than 1 metric ton per hectare, as little as 5% of rainfall may be used productively to produce food. These analyses further reveal that 25%–35% of the rainfall flows as non productive evaporation, and 15%–20% as surface runoff. Soil degradation, through nutrient depletion and loss of organic matter, causes serious yield decline. It affects water availability for crops through poor rainfall infiltration and plant water uptake due to weak roots.

In the dry sub humid tropical regions, seasonal rainfall level is generally adequate to support good rice crop yields, and managing extreme rainfall variability over time and space is the largest water challenge (Molden *et al.*, 2007). However, extreme variability of rainfall, with high rainfall intensities, few rain events, and poor spatial and temporal distribution of rainfall (Rockström *et al.*, 2010) limits crop production. Within these sub humid regions, rainfall variability generates dry spells (short periods of water stress during critical growth stages) almost every rainy season (Molden *et al.*, 2007). Only 70%–80% of the rainfall is available to plants as soil moisture, and on poorly managed land the share of plant-available water can be as low as 40%–50% (Falkenmark & Rockström 2004). The large observed differences between farmers' yields and attainable yields was as a result of differences in water, soil, and crop management (Pretty & Hine, 2001) thus improving rainfall use efficiency doubles yields on average (Hatfield *et al.*, 2001; Molden *et al.*, 2007) illustrating the large potential for investments in upgrading rainfed agriculture.

Rainwater management strategies that improve crop yields and transpiration (Critchley & Siegert 1991) maximize plant water availability in the root zone through practices that reduce surface runoff and that redirect upstream runoff to farms thus maximizing plant water uptake capacity (Rockström *et al.*, 2010). The strategies include in situ water harvesting and evaporation management (Rockström *et al.*, 2010). Integrated land and water management options such as mulch practices focus on increasing water productivity through reduced non productive evaporation and surface runoff, while bunds aim at improving crop production by capturing more water (water productivity increases simultaneously because the on-farm water balance is used more effectively) as crop production increases. Bunds concentrate rainfall from runoff on a cropped area maximizing infiltration and increase plant water availability in the soil while mulching reduce non productive evaporation increasing plant water uptake capacity (Rockström *et al* ., 2010).

Adverse effects of continuous cropping systems, involving conventional tillage (CT), on soil organic carbon (SOC) dynamics and crop productivity are widely recognized (Lal, 2002). Soil erosion has increased in severity because of high and erratic rainfall coupled with uneven topography (Choudhary *et al.* 2012). Conservation tillage has been reported to reduce soil erosion and improve soil moisture and crop yields compared to CT. Yield increases under conservation tillage are linked to improved soil moisture (Sakin *et al*., 2011).

The knowledge of available water storage is very important in efficient management of soil and water. Adoption of superior tillage practice and mulch not only conserves soil water and energy but also increases crop yield. Crop residues on soil surface act as insulator for solar radiation, serve as vapour barrier against loss of water from soil, reduce runoff, increase the SOC contents and provide congenial conditions for crop growth (Saroa & Lal, 2002).

The major impact of agronomic management on rainfall use efficiency (RUE) has not arisen from increasing total water use by the crop in evapotranspiration but from increasing total water use by the crop itself in transpiration at the expense of water use by weeds or from the soil by soil evaporation, deep drainage, surface runoff or lateral thorough flows (Asseng *et al.,* 2001a; Turner, 2004).This increase in water use by the crop at the expense of other losses generally results in significantly increased yields with only 5-10% increase in evapotranspiration (Asseng *et al.,* 2001b). The key challenge for rainfed rice producers is to reduce evaporation water losses and increase transpiration through the crop to achieve 'more crop per drop'of rain (Passioura, 2006). Increasing water storage in the soil through increased infiltration and reduced evaporation increases plant available water (Hatfield *et al.,* 2001). Application of crop residues /mulch on fields and installation of soil and water conservation (SWC) measures have the potential to increase soil moisture through reduced water losses via surface runoff and increased infiltration into the soil during rainfall events (Sadras , 2003). Mulches significantly increases the soil electrical conductivity, organic matter, nitrogen, phosphorus, potassium content (Khurshid *et al.,* 2006; Pakdel *et al.,* 2013), reduce evaporation thus reducing water requirement of cop plants (Lal,1995; Kumar & Bhardwaj, 2012; Chawla, 2006; Concord, 2009). Mulching improves soil moisture status and structure of soil (Muhammad *et al.,* 2009), decreases salinity, controls weeds and soil erosion (Concord, 2009; Bu *et al.,* 2002; Kumar & Lal, 2012), and increase the number of fertile tillers, and biomass production of wheat crop increasing RUE (Ahmed *et al.,* 2009). Mulching improves water conservation by reducing runoff and decreasing losses due to soil surface evaporation. The effectiveness of mulching using rice straw and use of soil bunds created on level fields on soil surface evaporation, available water capacity and rainfall use efficiency on NERICA 4 rice variety is unknown.

2.4.1 Effects of crop residues

Water is often a major limiting factor for crop production in the tropics, particularly in semi-arid regions. Soil water availability is directly related to environmental factors (including precipitation, evapo-transpiration, soil type and topography), but may be influenced by agronomic practices, including irrigation, fallowing and sowing time, or via specific water conservation practices, such as terracing and mulching (Muchow *et al.,* 1994). The retention of crop residues on the soil surface is a key principle for reducing surface water runoff and erosion (Steiner, 1994). A mulch of crop residues enhances water infiltration and protects the soil from sealing and crusting by rainfall (Rao *et al.,* 1998; Findeling *et al.,* 2003). Crop residue reduces the energy of rainfall water droplets hitting the soil surface and reduces the detachment of fine soil particles that tend to seal the surface, reducing crust formation (Lal, 1995). Under semi-arid conditions surface plant residues also play an important role in conservation of soil water through reduced soil evaporation (Todd *et al.,* 1991) by acting as an insulating layer against solar radiation. Mulching with crop residues shields the soil surface from direct solar radiation .This reduces the evaporation rate from a residue-covered surface compared to bare soil (Aiken *et al.,* 1997).

The water conservation effect of surface residue may potentially increase crop yields in tropical environments, where there is a risk of drought stress (Lal, 1997; Liu *et al.*, 2013). Residue also increases surface storage of rain or irrigation water. In addition, it slows the velocity of runoff water across the soil surface, allowing more time for infiltration (Steiner, 1994). Corn yields were significantly increased on plots with crop residues (van Donk *et al.,* 2010) due to reduced evaporation component of Evapotranspiration of corn and increased transpiration. This "transfer" of evaporation to transpiration due to crop residue has been widely documented (Tolk *et al.,* 1999; Klocke *et al.,* 2009). Tolk *et al.* (1999) found that soil water under a mulched surface was being used for crop growth and yield rather than for evaporation. Lascano *et al.,* (1994) reported similar ET on mulched cotton and unmulched fields, however, the proportion of E & T was such that T was higher on cotton grown under mulch while E was higher on cotton grown on bare fields.

Gibson *et al.* (1992) found that retaining sorghum stubble on the soil increased the sorghum yield due to increased WUE because of the greater amount of water stored in and extracted from the soil profile compared with conventional tillage. Increasing the soil water availability to the crop in the absence of any other yield-limiting factors can lead to increased WUE. The effects of crop residues on soil physical properties in NERICA rice production is not known and is the basis of the study.

2.4.2 Effects of soil bunds on soil physical properties

The primary principles of controlling soil erosion by water include reducing raindrop impacts on the soil, reducing runoff volume and velocity and increasing the soil resistance to erosion (Troeh *et al.,* 1980). Young (1997) stated that these principles of soil and water conservation could be achieved through creation of barriers across the soil surfaces or covers on the soil surfaces. The barriers check runoff and soil removal and include terraces such as soil bunds, terraces, stone bunds and grass strips. The soil bunds consist of channel and embankment that impound excess water and enhance the possibility of its infiltration which otherwise would produce surface runoff, improving soil moisture content in soil profile for cropping in medium and low rainfall areas.

The function of terraces in humid areas include reduction of the length of hillside slopes which leads to reduced erosion whereas in drier areas , it serves to retain runoff and increase water availability for plant growth (Schwab *et al.,* 2002).The reduction of slope length between terraces reduces the volume of runoff thereby reducing the loss of soil and essential plant nutrients and applied fertilizers. The short term effects of bunds or terraces are reduction of slope lentgh and creation of of small retention basins for runoff and sediment and toreduce the quantity and eroding capacity of the overland flow (Nyssen *et al.,* 2007).The medium term and long term effects of bunds include reduction in slope angle by forminh bench terraces(Alemayehu *et al* 2006) with a high spatial variability in soil fertility and crop response(Nyssen *et al.,* 2007).

Construction of level soil bunds have been promoted for soil and water conservation for NERICA rice production (Africa Rice Centre, 2008). But the effects of those interventions on soil physical properties and NERICA rice production have not been investigated. Understanding how soil bunds reduce runoff and losses of soil and nutrients and its impact on crop yield is important to inform farmers on the effectiveness of the technology and persuade them to invest in soil bunds. The effects of soil bunds on siol physical properties for NERICA rice production is not known and forms the basis for the study

2.5 Soil surface evaporation under various management conditions

Evaporation is the process whereby liquid water is converted to water vapour (vaporization) and removed from the evaporating surface (Reichardt, 1985; Sinclair, 1990; Allen *et al.,* 1998; & 2005b). Evapotranspiration (ET) is the transfer of water from the soil surface (evaporation) and plants (transpiration) to the atmosphere (Allen *et al.,* 1998). Energy is required to change the state of the molecules of water from liquid to vapour. Direct solar radiation and, to a lesser extent, the ambient temperature of the air provide this energy. The driving force to remove water vapour from the evaporating surface is the difference between the water vapour pressure at the evaporating surface and that of the surrounding atmosphere (Flumignan *et al*., 2001). As evaporation proceeds, the surrounding air becomes gradually saturated and the process will slow down and might stop if the wet air is not transferred to the atmosphere. The replacement of the saturated air with drier air depends greatly on wind speed. Hence, solar radiation, air temperature, air humidity and wind speed are climatological parameters affecting the evaporation process (Tanner, 1957; Allen *et al.,* 1998).

Evaporation from bare soil occurs in two distinct stages. During the first stage also called ''the energy limited" stage, moisture is available at or is transported to near the soil surface at a rate sufficient to supply the potential rate of evaporation (Ritchie, 1972, 1974: Kanemasu *et al.,* 1976; Hanks & Hill 1980; Ritchie & Johnson 1990; Flumignan *et al.,* 2001; Ghildyal & Tripathi, 2005; Nhlabatsi, 2010). During the second stage, also termed as the "falling rate" stage or "soil limited" stage, the hydraulic transport of subsurface moisture to near the soil surface is unable to supply water at the potential evaporation rate (Allen *et al.,* 2005b). At this stage, the soil surface appears dry and a portion of the evaporation occurs below the soil surface. The subsurface evaporation is caused by transport of heat from the soil surface into the soil profile (Flumignan *et al*., 2001, Allen *et al.,* 2005b, Mutziger *et al.,* 2005, Nhlabatsi, 2010; Ghildyal & Tripathi , 2005). Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. Any agronomic practice that affects energy reaching the soil surface and soil water availability directly affects first stage of evaporation (Muchow *et al.,* 1994).

When the soil is wet, evaporation is driven by radiant energy reaching the soil surface; during the energy-limited phase while evaporation is governed or limited more by the movement of water in the soil to the surface; during the soil-limited phase (Ritchie, 1972). Any modification to the soil surface that may affect radiant energy reaching the soil surface or movement of water to the soil surface affects soil surface evaporation (Van Donk *et al.,* 2010).Van Donk *et al.,* (2010) suggested that if the soil surface is covered with straw/crop residues, it is shielded from solar radiation, and air movement just above the soil surface is reduced. This reduces the evaporation rate from a residue-covered surface compared to bare soil.

For evaporation to occur three conditions are necessary: first, the existence of a vapor pressure gradient between the soil and the atmosphere; second, the supply of energy needed for latent heat of vaporization of water and third, the supply of water to the surface (Flumignan *et al*., 2001). Potential soil evaporation is related to the energy available at the soil surface and is reduced in the presence of surface crop residue.

In rain-fed agriculture systems, crops often use a small fraction of the rainfall input since there can be substantial losses of water via soil evaporation, runoff and drainage (Wallace *et al.,* 1999) making soil evaporation often to be the largest component. Direct soil evaporation from sparsely populated crops accounts for between 30% & 60% of rainfall. If some of this unproductive loss of water could be retained in the soil and used as transpiration, yields could be increased without increasing rainfall amount or using supplemental irrigation (Wallace *et al.,* 1999; Turner, 2004).

2.5.1 Field management practices

Field /soil management includes any practice that alters any soil component within or on the soil surface and can affect water and nutrient status within the soil and the impact of these changes on plant response in terms of increased plant growth or yield offers opportunities to improve WUE (Hatfield *et al.,* 2001). Soil management practices impact WUE through changes in the energy exchanges (net solar radiation interception) through the water balance (rainfall interception) and through the plant photosynthetic efficiency. Modification of the soil surface results into changes in the soil water balance in terms of soil water evaporation (Sauer *et al.* 1998) and infiltration into the soil profile (Musick *et al.,* 1994, Hatfield *et al.,* 2001). The evapotranspiration flux (ET) from a soil surface is affected by availability of radiant energy, gradients of water vapor, temperature and wind speed and the amount of water stored in the soil and the ability of the plants to extract water from the soil profile. Manipulation of the soil surface by tillage and surface residue management or mulching affects evapo-transpiration (ET) as well as harvestable crop products affecting rainfall use efficiency (Zhai *et al.* 1990; Hatfied *et al.,* 2001). For a given amount and seasonality of rainfall, dominance of small events increases unproductive soil evaporation whereas dominance of large events favours unproductive runoff and deep drainage (Sadras, 2003).

2.5.1.1 Conventional tillage

Conventional tillage involves soil manipulation of an entire field, by ploughing followed by one or more harrowing mechanically or manually. Conservation tillage excludes conventional tillage operations that invert the soil and bury crop residues and embraces crop production systems involving the management of surface residues (Unger *et al.*, 1988; Parr *et al.* 1990) and includes no tillage, minimum tillage, reduced tillage and mulch tillage (Unger *et al.* 1988; Antapa & Angen 1990; Opara-Nadi 1990; Unger, 1990; Ahn & Hintze 1990).

Conventional tillage roughens the soil surface , breaks soil crusts increasing water storage through increased infiltration into the soil as well as increased water losses by evaporation compared to a residue covered surface or undisturbed surface. Tillage increases saturated hydraulic conductivity (Cresswell *et al,*. 1993) increasing evaporation during the energy limited phase (Ritchie, 1972) while unsaturated hydraulic conductivity is reduced by tillage (Cresswell *et al.* 1993) Tillage however moves moist soil to the surface where water losses to drying may offset benefits of increased infiltration rates. Decreasing tillage showed a trend toward improving WUE because of improved soil water availability through reduced evaporation losses (Tanaka, 1990).

2.5.1.2 Mulch tillage using crop residues

Tillage practices and crop residue management in annual cropping systems, such as grain production, play an important role on how the soil receives and retains moisture (Scopel *et al.,* 2004) and affect the way water moves into and off of the soil (infiltration and runoff), as well as the way water moves from the soil into the atmosphere (evaporation). Mulch materials affects soil water content; through rainfall interception and subsequent water evaporation; radiation interception with associated reduction of soil evaporation, and reduction of water runoff. Mulching with crop residues shields the soil surface from direct solar radiation. This reduces the evaporation rate from a residue-covered surface compared to bare soil (Aiken *et al.,* 1997).

Crop residues increase infiltration and storage of rainfall (van Donk *et al.,* 2010) into the soil by reducing sealing of soil surface thereby reducing surface runoff and water erosion. Crop residues reduce erosion (Shelton *et al.* 2000; Skidmore 1986) provide carbon and nitrogen to soil organisms (Crovetto, 2006) and reduce soil water evaporation (Klocke *et al.* 2009; van Donk *et al.* 2010), increasing crop residue levels on the soil surface and water conservation (Klocke *et al.,* 2009).

Crop residues reduce the evaporation (Scopel *et al.,* 2004) of water from soil by shading, causing a lower soil surface temperature and reducing wind effects (Klocke *et al.* 2009; van Donk *et al.* 2010). Surface residues influences interception of rainfall and solar radiation modifying the dynamics of surface water runoff and soil evaporation. Surface residue limits the energy reaching the soil surface, decreasing first-stage evaporation of soil water (Scopel *et al.,* 2004).

A mulch of crop residues provides a protective cover by intercepting and absorbing the direct impact of the raindrops reducing the energy of water droplets impacting the soil surface which in turn reduces the detachment of fine soil particles that tend to seal the surface, reducing crust formation (Molden *et al.*, 2007) and maintaining infiltration of the water throughout the rainstorm (Lal, 1995). Crust formation reduces infiltration and promotes runoff because precipitation or irrigation rates may be greater than the rates at which the soil is able to absorb water. Residue covers reduce velocity of surface runoff water across the soil surface, allowing more time for infiltration (Chalker-Scott, 2007) hence increasing water storage in the soil (Steiner, 1994). Mulching with crop residues shields the soil surface from direct solar radiation. This reduces the evaporation rate from a residue covered surface compared to bare soil (Scopel *et al.,* 2004). Mulching with crop byproducts such as wheat straw increases water retention and prevents soil evaporation (Steiner, 1989; Shengxiu, & Ling, , 1992; Baumhardt & Jones, 2002; Kar & Singh, 2004). The quantity of crop residues on the soil surface affect the amount of water lost through surface runoff, the rainfall intercepted by surface residue and the direct evaporation from the crop residue mulch, as well as the reduction of soil evaporation by surface residue (Scopel *et al.*, 2004). A partial covering of the soil surface with crop residues can strongly affect runoff dynamics, and reduce runoff amount (Findeling *et al.*, 2003; Rees *et al.*, 2002) increasing soil moisture storage (Ji & Unger, 2001).

Soil surface modifications that affect radiant energy reaching the soil surface and soil water availability directly affect first stage evaporation (Lal, 1995b; Muchow *et al.*, 1994). Intercropping reduces soil surface evaporation due to an early and higher leaf area index (LAI) which forms a green or living mulch that reduces the amount of energy available for soil surface evaporation (Ogindo & Walker, 2005). No tillage systems with mulching improves water conservation by reducing runoff and decreasing water losses due to soil evaporation through reduced temperatures at the soil surface (Lal, 1997).

The efficiency of the crop residues on reduction of surface evaporation depends on type and quantity of crop residues, for instance complete surface residue coverage with 6t/ha of corn stover and wheat stubble reduced soil surface evaporation by 50% to 65% compared to bare soil with no shading (Klocke *et al*., 2009) in corn field. The efficiency of water conservation by rice straw mulch on upland rice yield and rainfall use efficiency has not been evaluated in the AEZ of Western Kenya. Previous studies of the effects of mulch were carried out on corn and wheat in the dryland environments while no study on the benefits of mulch tillage in NERICA rice have been investigated. The objective of our study was to determine the effects of soil modifications including crop residues (rice straw) mulch on the soil surface evaporation, plant available water for NERICA rice production and rainfall use efficiency by the NERICA rice crop.

2.5. 1.3 Effects of soil bunds

Promotion of sustainable land management (SLM) technologies such as soil bunds has been suggested as a key strategy to reduce land degradation and increase crop production (Shiferaw & Holden, 1998;, 2000). The primary principles of controlling soil erosion by water include reducing raindrop impacts on the soil, reducing runoff volume and velocity and increasing the soil resistance to erosion (Troeh *et al.*, 1980). These principles of soil and water conservation can be achieved through creation of barriers/ bunds across the fields (Young, 1997).

Soil bunds are embankments of soil built along the contour to reduce the velocity of overland flow and consequently to reduce soil erosion (Morgan, 1995). The channel and embankment of the soil bunds impound excess water which otherwise would produce surface runoff (Tenge *et al.,* 2005) and enhance the possibility of its infiltration (Critchley *et al.*, 1994). Losses of rainwater as runoff limits the water available for crop production (Rao *et al*., 1998; Nyssen *et al*., 2005).

The short term effects of bunds or terraces are reduction of slope lentgh and creation of small retention basins for runoff and sediment which in turn reduce the quantity and eroding capacity of the overland flow (Nyssen *et al.,* 2007).The medium term and long term effects of bunds include reduction in slope angle by forming bench terraces (Alemayehu *et al.,* 2006) with a high spatial variability in soil fertility and crop response (Schwab *et al.,* 2002; Nyssen *et al.,* 2007).The reduction of slope length between terraces reduces the volume of runoff thereby reducing soil loss and essential plant nutrients and applied fertilizers(Scopel *et al.,* 2004).

Soil and stone bunds are an indispensable component of soil and water conservation (SWC) measures for the control of erosion in the high potential areas where it is not possible to maintain year-round vegetation cover under given ecological, economic, and social circumstances (Troeh, *et al.,* 1980; Herweg, & Ludi, 1999). Fields with soil and stone bunds are more productive than those without such technologies in semi-arid areas due to the moisture conserving benefits of this technology being critical in drier areas (Kassie *et al.,* 2007).Climate change, which alters precipitation patterns and intensities, is believed to substantially increase the risk of runoff, soil erosion, drought and other environmental problems (Kato *et al.,* 2011).

Erratic rainfall in the potential areas for rain-fed rice production (Mati, 2009) and land degradation associated with loss of soil nutrients through soil erosion has significantly lowered rice production in Kenya (Emongor *et al.,* 2009). Leveling fields and construction of soil bunds around the field especially along the slope promote rainwater infiltration (Critchley *et al.,* 1994) aiding rain water harvesting (Africa Rice Centre, 2008; Seck *et al*., 2012). Soil bunds occupy part of the farm land reducing the total cropped area, while water logging may occur uphill of the bunds after rainfall events. This affects the efficiency of soil bunds in increasing yield despite increased water storage in the soil (Wolka, 2014).This has affected the adoption of soil bunds for soil and water conservation compared to other measures (Wolka *et al* 2010).

Construction of level soil bunds have been promoted for soil and water conservation for NERICA rice production (Africa rice centre, 2008) but the efficiency of soil bunds on improving NERICA rice production have not been investigated. Understanding how soil bunds reduce runoff and losses of soil and nutrients and its impact on soil water availability and crop yield is important to inform farmers on the effectiveness and efficiency of the technology for NERICA rice production.

2.6 Drained upper limit and crop lower limits

Soil water content affects water infiltration, redistribution, percolation, evaporation, and plant transpiration (Bittelli, 2011). Soil water content is determined by the drained upper limit (DUL) of the soil and the crop determined lower limit (CLL) (Ratcliff *et al.*, 1983). The DUL is taken as the soil-water content at which drainage from a pre-wetted soil practically ceases or when the soil-water content decrease is about 0.001 to 0.002 $m^3 \cdot m^{-3} \cdot d^{-1}$ (Ritchie, 1981;Ratliff *et al.*, 1983;Ogindo & Walker, 2005). It is water held against gravity and may be removed only by plants (crops and weeds) or through direct evaporation. The field-measured crop lower limit is taken as the soil-water content at which plants are practically dead or dormant as a result of the soil-water deficit (Ratliff *et al.*, 1983; Ogindo & Walker, 2005). Crop lower limit measures the extent to which a particular crop can extract water from a particular soil type, The DUL for a field with a crop is higher than for a bare field because the water lost to ET is always higher than the water lost to soil evaporation (Hensley *et al* .,2000; 2011)

Water extraction limits by a crop in the field is obtained by determining the drained upper limit of the soil and the lower crop extraction limit (Ritchie, 1972; Ratcliff *et al.,* 1983) on plots with a crop. Plants extract water from the soil between the DUL and CLL. The ability of crops to extract soil water is determined by the length; density and osmotic potential of the roots and the duration of their growth and the soil management practices through their effect on water infiltration and surface runoff. The CLL depends on the density and osmotic potential of the roots while DUL is affected by the soil texture bulk density and organic matter content of the soil.

In the laboratory, the DUL and the CLL can be determined by extraction of water from undisturbed or disturbed soil samples using the soil water extraction apparatus

(Gebregiorgis & Savage , 2006) at matrix potentials of -10 to -33 kPa and -1500 kPa for the DUL and CLL respectively. The water content at a matrix potential of -33 kPa is used as an estimate of the drained upper limit for moderately coarse and fine-textured soils, whereas -10 kPa is used for coarse-textured soils (Gebregiorgis & Savage, 2006).

However, the laboratory measurements of CLL at -15 Bars and DUL at -0.33 Bars are frequently inaccurate for establishing field limits of water availability since these water potentials are never reached (Ritchie, 1981; Ratliff *et al*., 1983) and DUL is underestimated for coarse textured soils and overestimated for fine textured soils. The CLL was underestimated for fine textured soils and overestimated for the coarse textured soil types (Ratliff *et al.,* 1983; Gebregiorgis & Savage, 2006; Lukanu & Savage, 2006). Laboratory methods for determination of CLL are inaccurate because some plants extract water at <-15kPa while other plants do not reach these suction potential. Field measured limits provides more accurate values of water extraction limits than laboratory methods (Ratliff *et al.,* 1983).

Data on the CLL of NERICA rice crop and the DUL of the Maseno acrisols are lacking. Soil management practices affect plant available water capacity (PAWC) due to effects of on the water holding capacity of the soils (Gebregiorgis & Savage, 2006). Ogindo & Walker (2003) found a higher DUL, lower CLL and higher PAWC for the maize bean intercrop compared to sole maize and sole beans cropping systems. The maize bean intercrop acted as a living mulch and the maize bean intercrop was able to extract more water than either crops of maize and beans.

Assessing the Maseno acrisol soil in the University Botanic garden for the DUL and CLL may provide further information concerning the PAWC for growing NERICA 4 rice.

2.7 Plant available water capacity, Drained upper limit and crop determined lower limit

Plant available water capacity (PAWC) is the maximum volume of water a soil can hold that a particular crop can extract from that soil (Gardiner *et al.*, 1984; Burk & Dalgliesh, 2008) and varies with soil type and the crop. Heavy soil textured, have higher PAWC however, these soils have higher CLL limiting water availability to the plants (Gebregiorgis and Savage, 2006). The PAWC is an important soil property because plant growth and soil biological activity depend on PAWC for hydration and delivery of nutrients in soil solution and affects runoff and leaching from soils. It represents the difference between the upper water storage limit of the soil (DUL) and the lower extraction limit of a crop (CLL) over the depth of rooting (Ratliff *et al.*, 1983; Burk & Dalgliesh, 2008). PAWC in the field is obtained by determining the drained upper limit of the soil and the lower crop extraction limit (Ritchie, 1972; Ratcliff *et al.,* 1983) on plots with a crop.Soil management practices impacts PAWC through infiltration into the soil profile and evaporation of water from the soil surfaces (Gebregiorgis & Savage, 2006). PAWC for a depth interval is the product between the depth interval in mm and the difference between DUL and CLL (Ratcliff *et al.*, 1983). For the full profile, it's the sum of PAWC for each depth interval where DUL and CLL are expressed as volumetric water %. PAWC gives detailed information on soil water availability for crops (Ratcliff, 1983; Burk & Dalgliesh, 2008).

PAWC is dependent on the response of the plant itself, especially rooting depth and the physiological capacity of the roots to remove water from the soil as well as the soil management practices. PAWC therefore varies with each crop and season (Ritchie *et al.,* 1983; Ratcliff *et al.,* 1983; Burk & Dalgliesh, 2008). Available water capacity increases with increasingly fine textured soil, from sands through loams to silt loams. Coarse textured soils have lower field capacity since they are high in large pores that are subject to free drainage. Fine textured soils have a greater occurrence of small pores that hold water against free drainage, resulting in a comparatively higher field capacity. However, in comparison to well-aggregated loam and silt loam soils, the available water capacity of predominantly clay soils tends to be lower since these soils have a higher CLL.

Often there is a linear relationship between plant available water and crop yield. Evaluation of the capacity of the soil water reservoir requires knowledge of its upper drained limit water content and crop lower limit water content in the plant root zone (Ratliff *et al.,* 1983 Saxton & Rawls, 2006; Hensley *et al.,* 2011). Saxton & Rawls, (2006) and Hensley *et al.,* (2011) stated that accurate estimates of the upper water limit and the lower water limit per soil depth using drainage curves are required to calculate the plant available water capacity of the soil.

Soil properties are one of the most important factors influencing crop water availability due to their effects on the water holding capacity, evaporation, and runoff generation. Efficient soil management practices increase water infiltration and reduce water losses through evaporation and surface runoff increasing PAWC (Scopel *et al.,* 2004). The PAWC for an acrisol under upland NERICA rice has not been determined under rain fed conditions.

2.8 Water use efficiency and rainfall use efficiency

Water availability is the most important limiting factor for crop production in rainfed agriculture. Rainfall use efficiency (RUE_R) is the amount of dry matter or marketable yield produced per unit of rainfall received by the crop or cropping system (yield/rainfall).

Water use efficiency(WUE) is amount of harvestable product produced per unit of evapotranspiration from crop seeding to harvesting and biomass production, grain yield, and evapotranspiration dictate efficiency (Hatfield *et al.,* 2001).Water use efficiency is the yield of harvested crop product achieved from the water available to the crop through rainfall, irrigation and the contribution of soil water storage (Hatfield *et al.,* 2001; FAO, 2006; Richard *et al.,* 2009). Large yield gaps between the farmers fields and potential yields for major rainfed crops in SSA exists and technologies which increase yields without incremental rainfall increase RUE (Rockström & Falkenmark 2000;Wani *et al.*, 2003).

Land surface management options that bridge the yield gaps increase in situ soil water harvesting increasing water availability and minimize drought stress and includes., use of contour bunds as well as providing mulch cover to reduce runoff leading to higher yields and RUE (Koohafkan & Stewart, 2008; Hatfield *et al.* 2001; Molden *et al.,* 2007). Contour bunding consists of a series of narrow trapezoidal embankments along the contour to reduce and store runoff in the fields.

Tillage roughens the soil surface and breaks apart any soil crust or compaction. This leads to increased water storage by increased water infiltration into the soil as well as increased water loss by evaporation compared with residue-covered surface.

More aggressive and frequent tillage also damages the soil structure, reduces macro porosity and reduces rainwater infiltration into the soil through the effect on hydraulic conductivity (Hatfield *et al.*, 2001). Retention of crop residues on the soil surface promotes in-situ conservation of rainfall, reduces soil evaporation, moderates soil temperature, improves crop productivity and soil quality through reduced soil erosion, and improved soil organic matter and other soil physical, chemical, and biological properties (Rockström & Steiner2003; Rockström *et al.*, 2009) resulting to crop yield improvements ranging between 20% and 120%, with water productivity improving from 10% to 40% (Rockström *et al.*, 2009).

Water use efficiency is affected by modification of the soil surface that lead to changes in the soil water balance in terms of soil water evaporation from and water infiltration into the soil profile (Hatfield *et al.,* 2001). Soil management practices influence the evapotranspiration flux from a surface over a given period of time through availability of radiant energy, gradients of water vapor, temperature , wind speed, amount of soil water stored in the soil profile, and the ability of the plant to extract water from the soil profile (Scopel *et al.,* 2004).

Soil management practices that increase the soil water holding capacity, improve the ability of roots to extract more water from the soil profile, or decrease leaching losses could all potentially have positive impacts on WUE, assuming these changes result in a concurrent increase in crop yield. These practices would affect evapotranspiration rates and potentially increase crop yields, thereby increasing WUE. Increased soil-water storage and its availability to crop plants at critical growth stages improving utilization of fertilizer and other farm inputs (van Duivenbooden *et al.,* 1999).

Water use efficiency can be improved through an increase in crop water productivity (an increase in marketable crop yield per unit of water taken up by crop), a decrease in water outflows from the plant rooting zone other than that required by plants and an increase in soil water storage within the plant rooting zone through better soil and water management practices at farm and catchment scales (Hatfield *et al.,* 2001; FAO, 2006; Richard *et al.,* 2009). Under rainfed conditions, soil water can be lost from the soil surface through evaporation (soil evaporation) or through plant uptake and subsequently lost via openings on plant leaves (plant transpiration). It can also be lost through runoff and deep infiltration through the soil beyond the root zone. Many promising strategies for raising WUE include appropriate integrated land-water management practices such as adequate soil fertility to remove nutrient constraints on crop production for every drop of water available through either rainfall or irrigation, soil-water conservation measures through crop residue incorporation, adequate land preparation for crop establishment and rainwater harvesting and conservation tillage to increase water infiltration, reduce runoff and improve soil moisture storage (FAO, 2006).

The Rainfall Use Efficiency (RUE) is determined as the amount of dry matter (DM) produced in a given area over a given period of time per unit of rain and is usually expressed in kg dry matter ha^{-1} mm^{-1}(Turner, 2004; Morrison *et al.*, 2008; Gardiner, 2010). RUE is the measure of a cropping system's capacity to convert rain water into plant biomass or grain. Rainfall use efficiency relies on: the soil's ability to capture and store rain water; the crop's ability to access rain water stored in the soil and rainfall during the season; the crop's ability to convert water into biomass; and finally the crop's ability to convert biomass into grain (harvest index). Rainfall use efficiency is therefore the grain yield per unit of total rainfall associated with a particular crop, during a particular season and year (Hensley, 2001).

Strategies that increase RUE either increase harvestable yield without increased seasonal rainfall or maintain yields with reduced seasonal rainfall amounts (Hensley *et al.*, 2007). Reduction in water losses through surface evaporation, surface runoff or deep percolation/drainage from the soil profile increases water for crop growth (Farahani *et al.*, (1998) leading to increased rainfall use efficiency. Modification of the soil surface affects the soil water balance in terms of soil water evaporation and infiltration into the soil profile.

Modification of the soil surface through tillage and surface residue management or mulching affect water storage in the soil and the net solar radiation reaching the soil surface (Hatfield *et al.*, 2001).Tillage roughens the soil surface breaking apart any soil crust, increasing water storage in the soil through increased infiltration however, increased water losses through evaporation (Papendick *et al.* 1973) compared to a residue covered surface have been reported.

Soil surface modification affects the availability of radiant energy reaching the soil surface, gradients of water vapor, amount of soil water stored in the soil profile, and the ability of the plant to extract water from the soil profile which influences ET (Turner, 2004). Soil surface modifications impact WUE through changes in the energy exchanges and through the plant photosynthetic efficiency affecting ET and crop yields (Hatfield *et al.*, 2001). Modification of the soil surface will lead to changes in the soil water balance in terms of soil water evaporation and infiltration into the soil profile and affects how efficiently crops use precipitation as a water supply (Hensley *et al.*, 2007). Soil management practices affect water and nutrient status of the soil and the impact of these changes on plant response in terms of increased plant growth and yield offers opportunities for to improve WUE

Water conservation tillage practices such as crop residue management/mulching, use of soil bunds or terracing fields and reduced tillage minimizes certain water loss processes improving the efficiency of rain water use in crop production. These losses include runoff, excessive soil evaporation and deep drainage. Rainfall use efficiency describes the overall efficiency with which rainwater is used in rain-fed cropping, since the named losses are taken into account (Zere *et al.,* 2007)

During the growing season unproductive water losses, such as runoff, deep drainage, and excessive evaporation from the soil, will be less on water conservation tillage plots resulting in more water being available for growth and therefore increased yield and RUE.

Soil management practices affect the processes of evapotranspiration by modifying the available energy, the available water in the soil profile, or the exchange rate of water vapour between the soil and the atmosphere (Hatfield *et al.,* 2001). Soil management practices that result in more plant available water by reducing unproductive water losses, such as runoff, deep drainage, and excessive evaporation from the soil, result in more water being available for growth and therefore increased yield and increased RUE (Zere *et al.,* 2007). RUE therefore enables a meaningful and comprehensive comparison to be made between the efficiencies of different field management practices.

Efficient production systems have very little runoff and reduce evaporation with a higher biomass and grain yield resulting in higher RUE (Hensley *et al.,* 2001). Variation in RUE within the same location and between wheat and corn crops were attributed to soil management practice that affected biomass production or the interception of radiation for plant growth (Hatfield *et al.,* 2001). Any soil management practice that leads to increases in soil water in the upper portion of the root zone may have a positive impact on WUE due to increased water availability and improved nutrient uptake (Hatfield *et al.,* 2001).

Existing literature has not adequately addressed the role of soil management practices for increased rainfall use efficiency in upland rice crop production. This research study is directed towards understanding the role of soil management practices for increased rainfall use efficiency in upland rice. The objective of this study was to evaluate different field management practices for increased RUE for NERICA rice crop .The efficiency of different soil management practices in increasing RUE in upland rice production has not been analyzed. This study sought to compare the effects of soil management practices on RUE in NERICA rice production

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the study site

The experiment was conducted at the Botanic garden, Maseno University in Western Kenya. The Botanic garden lies at latitude 0^{o}1'N - 0'12'S and longitude 34^{o}36'E-47'E at an altitude of 1,560 m above sea level, 5 km east of Kisumu city. Maseno receives a mean annual rainfall of 1346 mm with bimodal distribution. The long rain season is from April to July and the short one is from September to December. The average temperature is 21.2^{0}C, with 20^{0} C being the minimum and 23^{0}C being the maximum daily temperature.The soils at Maseno are classified as acrisol being well drained, deep clay with pH ranging between 4.6 and 5.4 (Sikuku *et al.,* 2010).

3.2 Topography

The topography of the Botanic Garden, Maseno University is characterized by a slope down to a drainage channel adjacent to the forested area. The experimental plots were on a terrace of 20m wide with gently slope of 10-13%.

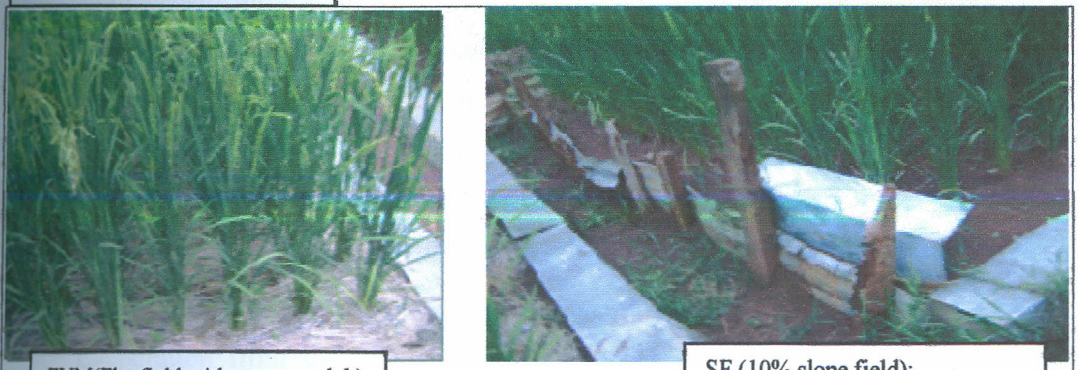
3.3 Eexperimental plots and design

The experimental field was laid out in October 2011 as part of an ongoing water balance study. The experiment was conducted during the long rains season beginning mid March 2012 to mid August 2012 and the short rains season beginning early September 2012 to end of January 2013. The plots were prepared by leveling and creating bunds of 0.3m height (flat with boundary), leveling fields (flat without boundary) and creation of a 10% slope field by earth moving.

Each plot occupied an area of 14m^{2} (4m by 3.5m). The experimental design consisted of four treatments with three replications laid out in three blocks in a randomized complete block design (Plate 1). Each block was composed of four treatments, flat field without bunds without rice straw (FU), flat field with bunds without rice straw (FB), flat field with rice straw mulch (FUM) and 10% slope field (SF). After field preparation, NERICA 4 rice variety was transplanted at 21 DAS in each of the plots at a spacing of 20 X 20 cm between plants, 2 plants per hill.

FB (Flat field with bunds)

FU(Flat field without bunds without straw mulch

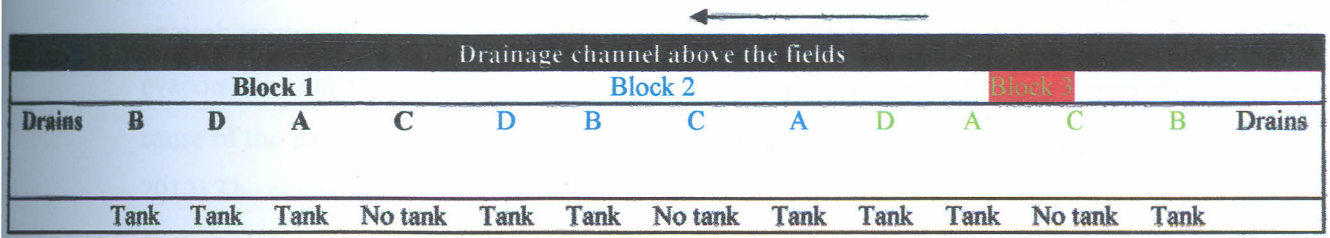


FUM(Flat field with straw mulch)

SF (10% slope field);

Plate 1. Field management practices used in the experiment

The rice straw mulch was applied to plots under mulch 21 days after transplanting. Conventional fertilizer use of 60kg/Ha P_2O and 45 kg/Ha N (Oikeh *et al.*, 2008b) was applied in three splits, 21 days after transplanting, 50 days after transplanting and at 72 days after transplanting (panicle initiation). The fields were kept weed free and pests were controlled (Somado *et al.*, 2008). A 500 litre PVC tank was installed at the base of all except the FB plots to capture runoff after each rainfall event (Figure 1, Plate 3). A 20 cm polythene sheet was used to enclose the plots all round to cut off runoff from outside plots. A retention ditch was installed upslope to drain off runoff away from the plots



Drainage channel above the fields													
	Block 1					Block 2				Block 3			
Drains	B	D	A	C	D	B	C	A	D	A	C	B	**Drains**
	Tank	Tank	Tank	No tank	Tank	Tank	No tank	Tank	Tank	Tank	No tank	Tank	

.Figure 1 Plot layout for the experiment. Arrows shows the general direction of the slope at the site.
Key: A-slope field 10% slope(SF);B-Flat field ,no bunds no straw ;
C-Flat field with bunds without straw; D-Flat field no bunds, with straw mulch.

3.4 Measurement of water balance components

Daily measurements of rainfall (mm) across the two seasons was recorded from the rain gauge located at Maseno agricultural training center within a radius of less than 2 Km from the Maseno University, Botanic garden. The seasonal daily rainfall data for the year 2012 and the months of January and February 2013 was recorded and was used as an input to determine rainfall use efficiency per treatment. Evaporation (mm) from the soil surface and soil surface runoff was measured daily and per rainfall event from the plots for the two growth seasons from April 2012 to Mid August2013 and from October 2012 to Mid Feb 2013 as stated in 3.4.1 and 3.4.2 below (Asseng *et al.,* 2001; Turner, 2004).

3.4.1 Determination of Evaporation using microlysimeters

Evaporation from the soil surface was estimated using microlysimeters (Walker, 1983; Ham *et al*., 1990; Evett *et al.,* 1995; Liu *et al*., 2002). Microlysimeters (MLs) made from polyvinyl chloride tubes (PVC) were used to measure daily evaporation loss over the two seasons from April 2012 to August 2012 and from October 2012 to Feb 2013.The MLs were constructed using PVC tubes with dimensions of 100mm inner diameter, 150mm depth and 2.5 mm wall thickness (Flumignan *et al.,* 2012) with one of the edges beveled to facilitate penetration into the soil (plate 2). The surface area of the ML evaporating surface was 0.00785m^2. The PVC tubes were inserted into the soil, removed with the soil inside intact, and then capped at their bottoms. Hollow cylindrical casing made from plain metallic sheet were inserted in the plots of NERICA rice for housing the MLs. The MLs were placed in hollow cylindrical cases in the soil such that the surface of the soil in the tube, the top of the tube, and the surrounding soil surface were at the same elevation. Three MLs installed on each treatment plot were removed and weighed on daily basis in order to estimate evaporation (mm) as change in mass (kg) per unit surface area of MLs (m^2) over the cause of the day during the cropping seasons (Wallace *et al.,* 1993; Flumignan *et al*., 2012).The change in mass of the MLs between 9:00 a.m. and 16:30 p.m. or before the next rainfall event represented water lost to evaporation (Ham *et al*., 1990; Evett *et al.,* 1995). On days without rainfall, MLs weights were taken once while two measurements were taken on days following a day of recorded rainfall. Capping of the

ML bottom was done to prevent soil or water from being lost through drainage and ensure that mass changes are due to evaporation alone (Evett *et al.,*1995). Erosion from the ML surface was considered zero or nil as well as drainage out of the MLs. The density of water was taken as 1000kg M^{-3}, one hectare has a surface of 10,000 m^2 and 1 mm is equal to 0.001m. Evaporation from the MLs was calculated using the following relationship (Evett *et al*,.1995; Flumignan *et al*., 2012)

$$E_{ML} = \frac{\Delta M_{ML}}{A_{ML}} + P$$

Equation 1

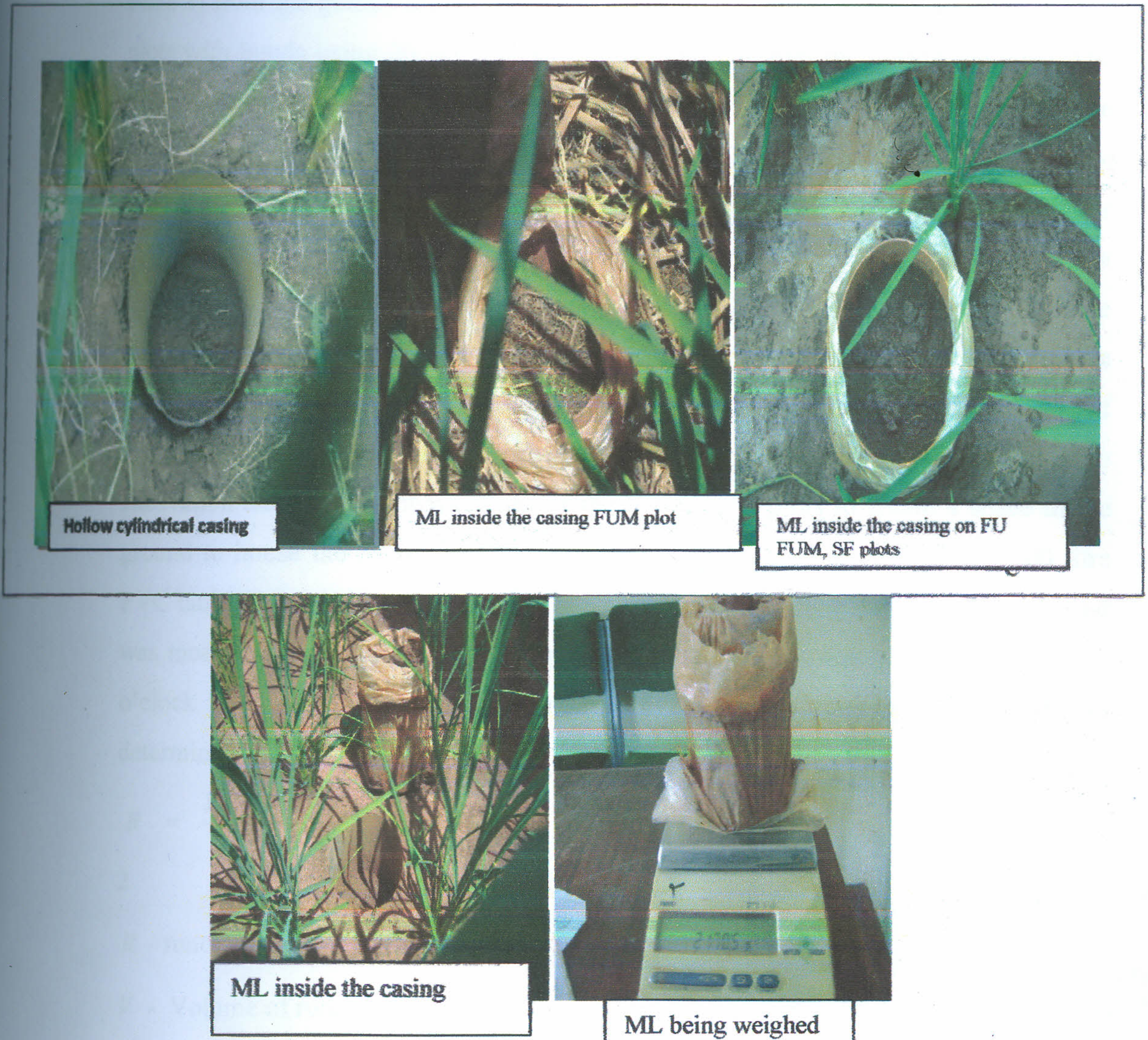
Where

E_{ML} Soil evaporation measured with microlysimeter (mm)

ΔM_{ML} microlysimeter variation of mass (kg)

A_{ML} Microlysimeter surface area with a value of 0.00785 m^2

P Precipitation, (mm).



Hollow cylindrical casing

ML inside the casing FUM plot

ML inside the casing on FU FUM, SF plots

ML inside the casing

ML being weighed

Plate 2 Hollow cylindrical casing with ML inside the casing being weighed using and electronic weighing balance (Denver instrument model XL -31000)(F).

3.4.2 Measurement of Surface runoff

Surface runoff caused by overflows of excess rainfall was measured at the lower parts of the runoff plots (Hudson, 1993) during a two-growth period for experimental seasons (2012-2013). The plots were surrounded by 30 cm metal ridges and runoff-collecting installations consisting of gutter pipes, pipes and 70-litre plastic tanks (Hudson, 1993). After each natural rainfall event producing runoff at the plots which was collected into the collecting tank, the volume of runoff water was measured in litres and converted into mm. Surface runoff was determined by measuring and recording surface discharge collected into polyvinyl chloride (PVC) tanks (Fig.1;

Plate 3) from the gutters around the plots per treatment and per replication for all but plots with bunds using 20 litre measuring can and one liter measuring cylinder. The PVC tanks were installed at the base of the plots FU, SF and FUM treatments. The plots were provided with boundaries of troughs to define the area from which the runoff and soil were collected. The troughs consisted of a small collecting gutter installed into the soil surface and connected to a small collecting container on the downstream side. The boundary troughs directed and limited the runoff into the collecting gutters. The amount of runoff collected depended on the chance occurrence of overflows from the plot surfaces only. Building a collector drain down the side of the plot limited overtopping in channels and breaks of banks and walls. Earth excavation and movement was done at the base of the plots to create a space in the ground to house the 500 litre PVC tank. The runoff was directed into the 500 litre PVC tanks (Plate 3) that was emptied the morning following each rainfall event, and was measured and recorded in litres per plot. The measurements were taken at 9.00 o'clock in the morning following a rainfall event the previous day.The runoff was determined by the following formula (Hudson, 1993):

$$R = \frac{V}{A}$$ Equation

2

R - runoff (mm),

V - Volume of runoff (m^3)

A - Experimental plot area (m^2)

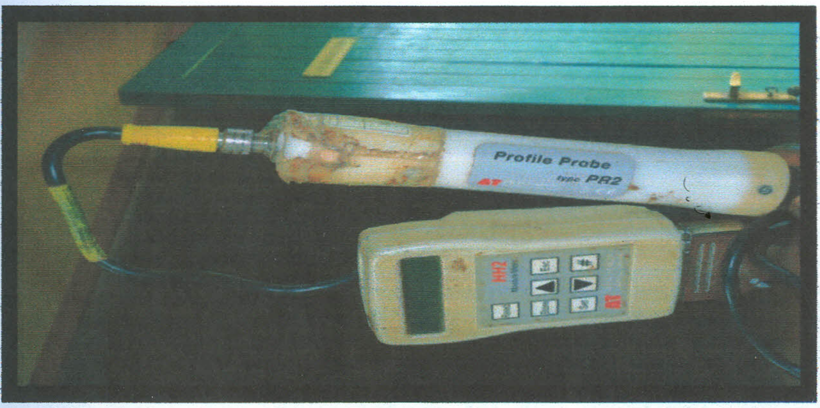


Plate 5 The PR2 profile probe and HH2 moisture meter (Delta -T Devices , Cambridge , UK.)

3.5 Determination of drained upper limit and crop lower limit

The soil water extraction limits determined in the experiment were the crop extraction lower limit and the drained upper limit of the soil at 10, 20, 30, 40, 60 and 100 cm depths. The drained upper limit was determined as stated in 3.5.1 while the crop extraction lower limit was determined as stated in 3.5.2 below respectively.

3.5.1 Measurement of Drained upper limit

A plot of 2 m by 2 m was set up for determination of the drained upper limit in the botanical garden alongside the plot for the crop extraction lower limit (Hochman *et al.*, 2001). A 15 cm trench was dug and a bund of 30cm was constructed around the field, an access tube for monitoring soil moisture was installed at the center of the plot (Plate.6).

The plot was leveled to ensure uniform water infiltration during saturation and was wetted for a period of two weeks, after which it was covered by a polythene sheet (Plate 6) to prevent evaporation, care being taken to ensure a good seal around the access tube to prevent wetting from subsequent rains (Burk & Dalgleish, 2008). Monitoring of the volumetric soil moisture content was started at 14 days after transplanting with a portable soil water monitoring system (Profile probe and soil moisture meter-PR2 & HH2) plate 6 (Delta-T Devices, Cambridge, UK) at 10,20,30,40,60,100 cm depths of the soil profile. The PR 2 profile probe and soil moisture meter HH2 (Plate 6) were used to monitor volumetric soil moisture content during drainage through the thin walled access tube (plate 6 b). The highest field measured volumetric water content of a soil depth after it had been thoroughly wetted and allowed to drain until drainage became practically negligible was considered to be

PVC tank placed in dug out hole

Side view of the layout of the PVC tanks,

gutter channels directing runoff water into the PVC tanks

Plate 3 Plastic tanks with pipes and gutters for collection of runoff water.

3.4.3 Measurement of Soil moisture

An access tube, was installed at the centre of each treatment plot and replication up to 110cm depth (Plate 4), Soil water content was measured by use of profile probe (PR2) (Verhoef *et al*., 2006) and soil moisture meter HH2 (Delta-T Devices, Cambridge, United Kingdom) (Plate 5) at 10, 20, 30, 40, 60 and 100 cm depths of the soil profile after every two days and at 8.00 a.m of the following day after a rainfall event from 4th week after transplanting to harvest.

Plate 4 Access tubes inserted at the centre of each plot to measure soil moisture content per depth and treatment.

the drained upper limit (DUL) (Ratcliff *et al.,* 1983). The water content for each soil layer at that stage provided the DUL for the individual layer within the soil profile (Hensley, 1984; Hensley *et al.,* 2000; Mukhala 1998; Ogindo & Walker 2005).

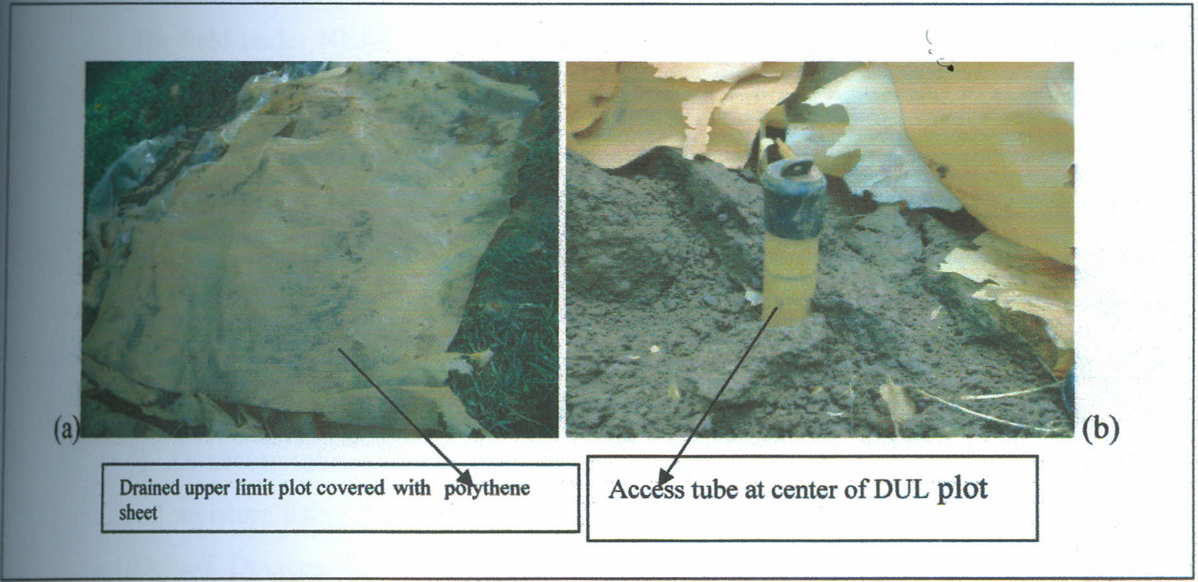


Plate 6 The plot for measurement of the drained upper limit (a) and an access tube(b) at the centre of the field.

3.5.2 Measurement of crop lower limit for NERICA 4 rice crop

The field under NERICA 4 rice crop received adequate nutrition and watering until flowering before watering stopped. A rain exclusion tent frame was constructed over the NERICA 4 rice field at initiation of flowering for determination of the crop lower limit (plate 8), consisting of six posts of 4 x 2 inch timber with three runners of 2 x 2 inch as the roof. These posts were positioned to support a 3m x 3 m tent. A side trench was dug outside the plot where the tent was inserted to prevent runoff water or overland flow from entering the plot. The rain exclusion frame was covered by a 3m by 3m tent using builders PVC sheet to cut out rainfall from subsequent rains (Plate 7). An access tube, inserted in the centre of the plot, was used for determination of soil moisture using the profile probe (PR2) (Plate 7) and soil moisture meter (HH2) (Delta-T Devices, Cambridge, UK) which provides measurements at 10, 20, 30, 40, 60 and 100 cm depths (Verhoef, *et al* 2006) of the soil profile. The depths were chosen to represent the root zones within the cultivated soil and immediately below the depth of cultivation. Daily soil moisture measurements were taken per soil depth until the crop completely wilted. Complete crop wilting was determined by sampling plants and recovery sensitivity done by immersing sampled plants in moisture for 24 hours. The volumetric soil moisture content at which wilted sampled plants failed to recover on immersion in moisture was recorded as the crop lower limit for that depth.The lowest field measured water content of a soil after plants had stopped extracting water and were irreversibly dead/wilted as a result of water stress, was determined to be the CLL. The field-measured lower limit is taken as the soil-water content at which plants were practically dead or dormant as a result of the soil-water deficit (Ratliff *et al.*, 1983).

the drained upper limit (DUL) (Ratcliff *et al.,* 1983). The water content for each soil layer at that stage provided the DUL for the individual layer within the soil profile (Hensley, 1984; Hensley *et al.,* 2000; Mukhala 1998; Ogindo & Walker 2005).

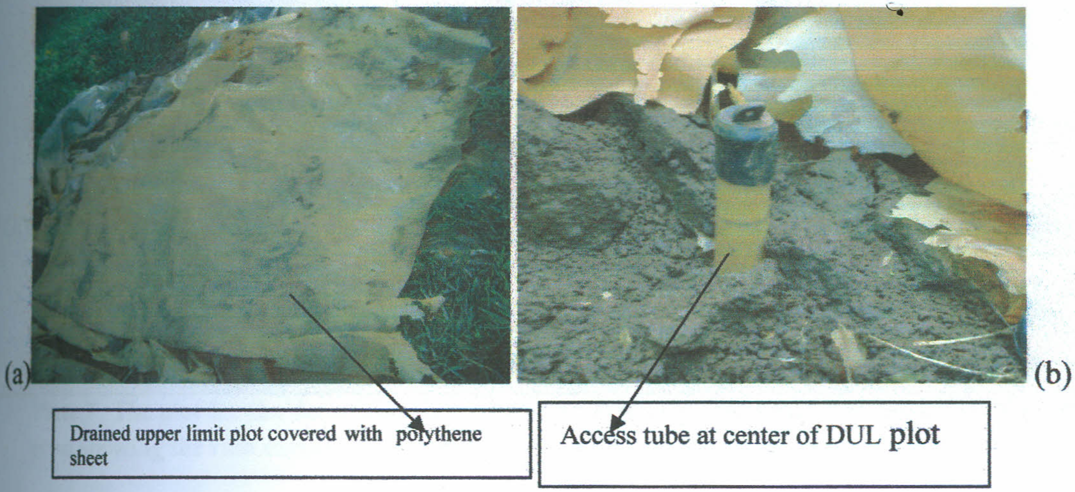


Plate 6 The plot for measurement of the drained upper limit (a) and an access tube(b) at the centre of the field.

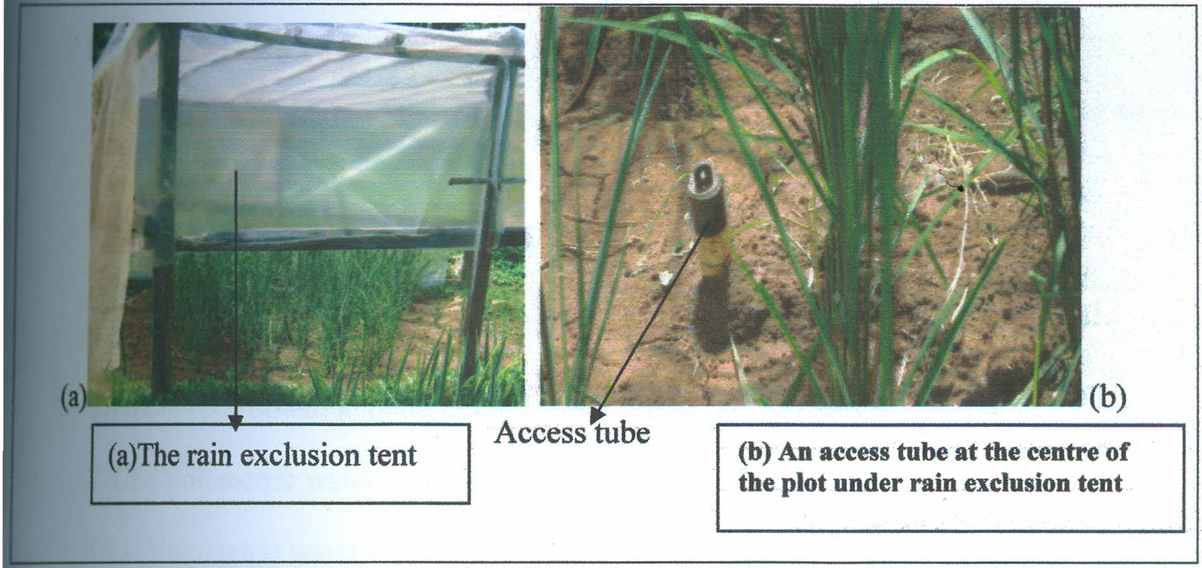


Plate 7 The plot for the determination of the crop extraction lower limit for the NERICA 4 rice crop showing the rain exclusion tent (a) and an access tube (b) at the centre of the plot.

3.5.3 Determination of plant available water capacity

To quantify plant available water capacity (PAWC), the soil moisture content (MC) and the volumetric water content at the crop lower extraction limit (CLL) measured per soil depth at 10, 20, 30, 40, 60, 100 cm along the soil profile in the field (Ratcliff *et al.,* 1983; Gardner *et al*., 1984; Hochman *et al*., 2001; Ogindo & Walker 2005) was used for calculation (Equation 3a). The drained upper limit (DUL), determined for the site as stated in 3.5.1 and the crop lower limit determined for the crop as stated in 3.5.2 was used(Equation 4) to calculate the total potential available water capacity. The potential plant available water capacity for a specific soil depth was determined as the difference between the DUL and CLL for each depth (Equation 3 b). The potential plant available water capacity (TAWC) for the soil profile was determined as the summation of the PAWC of the various soil depths and was calculated as indicated in the equation 3 a below:

$$PAWC = MC - CLL$$

Equation
3 a

Where;

$PAWC$ Plant available water capacity

CLL Volumetric water content at the crop lower limit per depth

MC Soil moisture content per depth (mm)

The total potential plant available water capacity (TAWC) was calculated for the soil profile using equation 3 b below:

$$TAWC = DUL - CLL$$

Equation 3 b

Where

$TAWC$ Total potential plant available water capacity per depth

DUL Volumetric water content at the drained upper limit

CLL Volumetric water content at the crop lower limit

3.6. Measurement of plant growth parameters

3.6.1 Tiller number

Tiller number for 10 sampled plants per treatment and per replication (Plate 8) at 53, 60, 67, 74, 81, 88 and 95 days after transplanting was determined by counting and recording all emerging shoots in each hill .

Plate 8 Tillers of rice

3.6.2 Plant height

Shoot height was determined on ten hills per treatment and per replication at 53, 60, 67, 74, 81, 88 and 95 days after transplanting (Bell & Fisher 1994). Measurements were made using a metre rule from the stem base to shoot apex in plants and recorded.

3.6.3 Panicle number and length

Total number of panicles per hill was counted and recorded at harvest across all the ten sampled plants, one plant per row per treatment and per replication across the two seasons. Panicle length per treatment and per replication was measured on ten sampled hills using a meter ruler and recorded.

3.6.4 Determination of Biomass yield

Above ground biomass per treatment and replication was determined across all the ten sampled rows, which at maturity were harvested (Bell & Fischer, 1994; Schwinning & Weiner. 1998; Tackenberg , 2007).

The two border rows of rice hills around the plots were cut and discarded from all the replications and treatment. The 10 sampled hills were carefully cut at the ground surface making sure that no leaves or stems (including dead tillers) were lost. The plant material from all 10 hills were pooled into one composite sub sample per replication and treatment and put in separate sugar bag labeled with treatment and replication. The stems with green leaves and dead leaves were separated from panicles by cutting off panicles with grains intact. These panicles with grain intact were put in separate bags per treatment and replication. Immediately measurement of the fresh stems per treatment and replication was taken and recorded. The fresh panicle weight was taken by measuring pooled fresh panicles with grain intact and recorded per treatment and replication. The stem/shoot and panicle samples were dried at 80°C for 3–5 days to constant weight. The samples were weighed on the third day to check when constant weight was achieved and drying could be stopped. The final oven-dry weight was recorded when no further change in weight occurred within 24 hours. Samples were weighed immediately after taking them out from the oven to obtain the oven-dry weight of aboveground biomass. The weights were determined using an electronic weighing balance (Denver instrument model XL - 31000) adjusted to 14 % moisture content and recorded per plant and replication. The biomass was expressed on per Ha basis.

Total aboveground dry matter yield (kg/ha) was calculated as below,

- Two border rows per treatment and replication were cut and discarded, the above ground biomass of plants from the experimental area (A) per treatment replication was cut and collected.
- Determination of the total dry weight(DWS)

A subsample of 10 hills was cut, pooled and oven-dried and total dry weight (DWS) was calculated from the total sample fresh weight (FWS), or remainder fresh weight (FWR), and the subsample fresh weight (FWSS) using equation 4a, b, c (Bell and Fisher, 1994).

a) Total Fresh weight of samples(FWS):

$FWS = FWR + RWSS$ Equation 4 a

Where
FWS (Total sample fresh weight) ; FWR(Remainder fresh weight) ; FWSS (Sub sample fresh weight)(Kg)

b) Total dry weight of the samples(DWS)

$DWS = DWSS \times (FWS/FWSS)$ Equation 4 b

DWS(Total dry weight of sample) ;DWSS(Sub sample oven dry weight) ;(FWS/FWSS) (Kg)

c) Above ground biomass on an area basis (TDW):

$TDW = DWS \div A$ Equation 4 c

TDW(Total above ground biomass(Kg/M^2)); DWS (Total dry weight of sample (Kg)); A (Experimental plot area(M^2)

3.6.5 Determination of grain yield

All the Above-ground biomass in a pre-determined area (A) of (3.3 by 3.8) m^2 was cut avoiding border effects by cutting off the two border rows. Panicles from the ten sampled hills were threshed and fresh grain weighed per treatment and replication and fresh grain weights recorded (DWSS): The remaining bulk sample was threshed and fresh grain weights per treatment and replication measured and recorded (FWR). The grain per panicle sub sample per treatment and replication was dried at 80°C for 3-5 days to constant weight and recorded (DWSS). The fresh weight of the grain from the bulk sample was taken per treatment and replication and recorded (TG): The weights were determined using an electronic weighing balance (Denver instrument model XL -31000) adjusted to 14 % moisture content and recorded per plant and replication. A sub sample of grain from the bulk sample was taken and weighed per treatment and replication before oven drying and recorded (LWG). The sub sample of grain was oven dried per treatment and replication at 80°C for 3-5 days to constant weight , weighed and weights recorded (DG).The weight of two sub samples of 100 oven dried grains was measured per treatment and replication and recorded (Wl, W2):

Calculation of Grain yield (GY)

Grain yield at 0% moisture content was calculated as shown in equation 5 while grain yield at 14 % moisture content was calculated as shown in equation 6,

$$GY = \{(\frac{DG}{WG}) \times TG\} \times \frac{(FWR+FSS)}{FWR} \div A(\frac{Kg}{m2})$$

Equation

5

GY at 14 % MC

$$GY = GY \times \{\frac{100}{100-14}\} \text{ Kg/m}^2$$

Equation

6

3.7 Determination of rainfall use efficiency (RUE)

3.7.1. Determination of the RUE for NERICA 4 rice based on biomass yield

Total dry weight of the sample (DWS) as determined in section 3.6.4 equation 4b and 4c (Bell & Fisher, 1994) gave the biomass yield per ha. The RUE based on biomass was calculated as yield in kg (DM) per ha per mm of rain used by the crop based on the following relationship in equation 7 (Hatfield, 2001)

$$RUEb = \frac{BY}{(R-(Es+RO))}$$

Equation

7

Where

RUE_b Rainfall use efficiency based on total above ground biomass (Kg ha^{-1}mm^{-1})

BY Total Biomass yield (DWS) (Kg/ha) from equation 4 c

R Total seasonal Rainfall (mm) ;

Es-soil surface evaporation (mm) and

(RO)- surface runoff (mm)

3.7.2 Determination RUE for NERICA 4 rice based on Grain yield.

The harvested shoots with panicles intact from the whole field were threshed separately, filled grain was separated from bird eaten grains and empty husks were put in separate paper bags. The filled grains samples were oven dried at 80^0C for 72-96 hours to a constant dry weight. The weights were determined using an electronic weighing balance (Denver instrument model XL -31000) adjusted to 14 % moisture content. A total count of the bird eaten grain was done per plot and the weight of 100 filled grains per plot was used to account for the bird eaten grains. The total grain (filled and bird eaten) per treatment per plant and from the whole plot was expressed on per Ha basis and the RUE was calculated as grain yield (DM) per Ha per mm of rain used by the crop using equation 8 (Hatfield, 2001).

$$RUEg = \frac{GY}{(R-(Es+RO))}$$

Equation

8

Where

RUE_g Rainfall use efficiency (Kg $ha^{-1}mm^{-1}$)

GY - Total Grain yield (Kg/ha)

R - Total seasonal Rainfall (mm) less evaporation (mm) and surface runoff (mm)

3.8 Data analysis

Data were subjected to analysis of variance (ANOVA) according to the generalized linear model (GLM) procedure using the SAS computer package. Differences between means were compared by Fisher's least significant difference (LSD) test at 5% significance level.

CHAPTER FOUR
RESULTS

4.1. Effect of field management practices on soil surface evaporation.

4.1.1 Effect of field management practices on daily evaporation

The daily evaporation from the four treatments during the long and the short rain seasons is shown in Table 1.

Table 1 Daily average evaporation per treatment and season

Treatment	Season one mean daily Evaporation (mm)	Season two mean daily Evaporation (mm)	% increase in evaporation during season one compared to FUM	% increase in evaporation during season two compared to FUM
FB	1.538^{a}	1.6924^{a}	67.5	68.8
FU	1.536^{a}	1.700^{a}	67.8	68.49
SF	1.451^{b}	1.725^{a}	71.8	68.50
FUM	1.042^{c}	1.1644^{b}		
LSD	0.0341	0.0514		

Means within columns with the same letter are not significantly different;

Key FU-Flat without mulch without bunds; FUM-Flat with straw mulch; FB-Flat without straw mulch with bunds; SF- 10% Slope field

During season one and two, the average daily evaporation from the FUM treatment was significantly lower than from the bare treatments without mulch ($p<.05$). The evaporation from the FB and FU treatments did not differ significantly but were significantly different from the SF treatment during season one (Table 1). The FB, FU and SF treatments were at par while the FUM treatment was significantly lower than the bare treatments in soil surface evaporation during season two (Table 1)

The application of rice straw mulch at 6t/ha consistently reduced daily surface evaporation by over 20% during both growth seasons. Creation of soil bunds (FB) on flat fields (FU) had no significant effect on reduction of soil surface evaporation. Leveling fields with 10% slope (SF) to create level fields (FU) had no significant effect on reduction of daily soil surface evaporation in this study.

4.1.2 Effect of field management practices on evaporation across the seasons

Table 2 shows the total evaporation per growth stage and season across the four field management practices. The FUM treatment was significantly lower than the bare (FB, FU&SF) treatments (p<0.05) in soil surface evaporation during the vegetative and the reproductive growth stages as well as in total seasonal evaporation.

Table 2. Seasonal evaporation per treatment pet growth stage

	Evaporation				
	FU	FB	SF	FUM	LSD
Evaporation vegetative phase	105.359^{a}	103.528^{a}	105.049^{a}	47.876^{b}	11.586
Evaporation reproductive phase	60.797^{a}	63.46^{a}	63.221^{a}	29.751^{b}	11.983
Total Seasonal Evaporation	166.156^{a}	166.988^{a}	168.270^{a}	77.627^{b}	19.477
% Evaporation vegetative phase	18.215^{a}	17.898^{a}	18.1817^{a}	8.2852^{b}	2.0645
% Evaporation reproductive phase	10.5017^{a}	10.9767^{a}	10.9017^{a}	5.1047^{b}	2.141
% reduction in evaporation vegetative phase compared to FUM	54.55	53.75	54.42		
% reduction in evaporation reproductive phase compared to FUM	51.065	53.11	52.94		

Means within columns with the same letter are not significantly different at 5% significance level
Key FU-Flat without mulch without bunds; FUM-Flat with straw mulch;
FB-Flat without straw mulch with bunds; SF- 10% Slope field

Across the growth phases and seasons, evaporation from the FUM treatment was significantly lower than from the bare treatments without mulch (p<0.05). There was no significant difference in seasonal evaporation between the FB, FU and SF treatments. The evaporation from the FB and FU and SF treatments did not differ significantly but were significantly different from the FUM treatment (Table 2).

The reduction in soil surface evaporation on FUM treatment was > 50% at (p<0.05) compared to the bare (FB, FU & SF) treatments (Table 2). Overall, the FUM treatment reduced soil surface evaporation by more than half compared to evaporation from the bare treatments (Table 2).

Application of rice straw mulch significantly reduced total seasonal evaporation during the growth stages by more than half with a higher reduction during the vegetative phase. Creation of soil bunds (FB) on flat fields (FU) had no significant effect on reduction of seasonal evaporation. Similarly leveling fields with 10% slope had no significant effect on reduction of seasonal evaporation. The flat fields with soil bunds, flat level fields as well as fields with 10% slope were at par in total seasonal evaporation.

4.1.3 Effect of field management practices on water balance .

The table 3 shows the water balance components per treatment per growth stage across the two seasons.

Table 3 Water balance components per treatment, growth stage and season.

Trt	Evaporation			RO	% RO	Evaporation %		RI	RNU	PAWC
	Vegetative	reproductive	Total			Vegetative	reproductive			
FU	105.36^a	60.7966^a	166.155^a	93.618^a	16.079^A	18.215^A	10.5016^A	333.02^c	253.98 ^{a}	272.7^b
FB	103.528^a	63.46^a	166.988^a	0^b	0^{bb}	17.898^a	10.9766^a	420.01 ^{b}	166.99 ^{b}	493.41^a
SF	105.0516^a	63.2216^a	168.2633^a	81.4133^a	13.91^a	18.1816^a	10.9816^a	337.32 ^{c}	249.68 ^{a}	338.41^b
FUM	47.876^b	29.7516^b	77.626^b	9.655^b	1.73^{bb}	8.28^b	5.105^b	506.5 ^{a}	80.5 ^{c}	493.13^a
LSD	11.586	11.993	19.479	24.656	4.4167	2.0645	2.1418	35.051	35.051	88.855

Values within a column with the same letters are not significantly different ($p<0.05$)

Key ; RO-Surface runoff;; RI-Total Rainfall infiltration ;RNU-Total rainfall lost via RO & evaporation ;PAWC-plant available water capacity

The FUM treatment was significantly lower than the FU, FB & SF treatments in soil surface evaporation during both the vegetative and reproductive growth phases. Similarly, the FUM treatment was significantly lower than the FU and SF treatments in seasonal surface runoff (Table 3) but was at par with the FB treatment in seasonal runoff ($p<0.05$)(Table 3).The FUM treatment was the least significant in total rainfall losses(RNU) and was the most significant in total rainfall capture(RI) (total rainfall captured and infiltrated into the soil profile) as shown in table 3. The FUM treatment was the most efficient in evaporation management while it was at par with the FB treatment on surface runoff management.

The plant available water capacity (PAWC) on FUM and FB treatments were at par and were significantly higher than PAWC on FU and SF (Table 3).

Application of straw mulch cover (FUM) on flat fields (FU) significantly reduced the surface runoff by tenfold and reduced surface evaporation by half (Table 3).Creation of soil bunds (FB) on flat fields (FU) significantly eliminated surface runoff. However, there was no significant effect on surface evaporation, there being no statistical differences in surface evaporation between these treatments (Table 3). Flattening fields with 10% slope (SF) to create flat fields (FU) led to an increase in surface runoff, although the increase was not significant.

4.2 Evaluation of the water extraction limits

4.2.1 Effect of field management practices on soil moisture content

Table 4 shows the soil moisture content per treatment during season one and two respectively.

Table 4 Daily mean soil moisture content (MC) per treatment during season one and two

Treatment	Soil moisture content season one	Soil moisture content ' season two
FB	35.0928 [a]	35.6759 [a]
FUM	32.4221 [b]	32.6070 [b]
FU	28.7402 [c]	30.3489 [c]
SF	23.8064 [d]	23.4219 [d]
Critical Range	0.7468	0.9353

Values within columns with the same letter are not significantly different ($p<0.05$)

Field management practices had a significant effect on soil moisture content ($p<0.05$) in the top 100 cm depth. The FB treatment had significantly higher soil moisture content (SMC) than other treatments followed by FUM, and FU while the SF treatment had the least significant effect on SMC across the seasons (Table 4).The soil moisture content on the FUM treatment was significantly lower than the FB treatment; however, the FUM treatment had a significantly higher daily mean soil moisture content than the control (FU) and the SF treatments (Table 4). Creation of soil bunds (FB) on flat fields (FU) significantly increased soil moisture content in the top 100 cm of the soil profile than application of straw mulch (FUM) on flat fields(FU) across the two seasons (Table 4). Creation of soil bunds on flat fields increased soil moisture content by 18.1% and 14.93% while application of straw mulch increased soil moisture content by10.4% and 6.9% during season one and two respectively (Table 4). Flattening fields with 10% slope (SF) significantly increased on soil moisture content (Table 4) by 16.96% and 22.8% during season one and two respectively.

4.2.2 Effect of interactions of depth and treatment on soil moisture content

The mean soil moisture content per treatment and depth is tabulated in Table 5 & 6 for season one and two respectively

Table 5 .Mean soil moisture content per treatment and depth during season one

Treatment	Depth(cm)					
	10	20	30	40	60	100
FUM	21.48^{a}	17.27^{b}	26.29^{c}	34.85^{b}	38.72^{b}	55.90^{a}
FB	17.36^{b}	21.78^{a}	32.34^{a}	35.94^{b}	47.39^{a}	55.712^{a}
SF	17.20^{b}	11.02^{d}	13.36^{d}	12.54^{c}	36.21^{c}	52.48^{b}
FU	15.78^{c}	13.79^{c}	29.74^{b}	38.00^{a}	32.99^{d}	42.12^{c}
Critical Range	0.7521	1.432	1.990	1.455	1.996	2.185

Values within a column with the same letter are not significantly different (p<0.05)

Table 6 .Mean soil moisture content per treatment and depth during season two.

Treatment	Depth(cm)					
	10	20	30	40	60	100
FUM	19.52^{a}	17.02^{b}	27.0^{b}	36.26^{a}	40.11^{b}	55.69^{a}
FU	17.81^{b}	17.36^{b}	29.75^{a}	37.21^{a}	33.77^{d}	46.15^{c}
FB	17.46^{b}	22.80^{a}	31.73^{a}	38.31^{a}	47.93^{a}	55.79^{a}
SF	14.70^{c}	12.40^{c}	12.28^{c}	12.19^{b}	37.04^{c}	51.89^{b}
Critical Range	1.103	1.946	2.266	2.254	2.778	2.060

Values within a column with the same letter are not significantly different (p<0.05)

The interaction between treatment and depth had a statistically significant effect on soil moisture content (p<.05). The FUM treatment significantly increased soil moisture content (MC) than the bare treatments at 10 cm depths during season one and two as well as at 100 cm during season one (Table 5& 6). The FB treatment significantly increased soil moisture content at 20 cm, 30 cm and 60 cm depths during season one and two, at 40 cm and 100 cm depths during season two (Table 5 & 6). Compared to the SF treatment, the FU treatment had a higher SMC at 10 cm during season two, at 20, 30 and 40 cm depths during season one and two respectively. The SF treatment significantly reduced soil moisture content at 20, 30 and 40 cm depths across the two seasons, however, a significant increase in soil moisture content was recorded on the SF treatment compared to the FU treatment at 10 cm depth during season one and at 60 and 100 cm depths across the two seasons (Table 5& 6). The

10% slope field had higher SMC than the flat fields at 10 cm during season one as well as at 60 and 100 cm across the two seasons

Application of rice straw mulch on flat fields significantly increased SMC at 10 cm depth across the two growth seasons as well as at 100 cm depth during season one. Creation of soil bunds around flat fields significantly increased SMC at 20 cm, 30 cm and 60 cm depths across the two growth seasons as well as at 40 cm and 100 cm depths during season two. Flattening fields with a 10 % slope significantly increased SMC at 10 cm depth during season two as well as at 20, 30 and 40 cm depths across the two growth seasons ,however, flattening fields with 10% slope reduced SMC at 10 cm depth during season one as well as at 60 and 100 cm across the two seasons.
Creation of flat fields from 10 % sloping terrain increased the soil moisture content by 17.4% at 10 cm depth during season two although a reduction of 2% was recorded during season one while application of straw mulch on flat fields increased SMC by 26.53% and 8.7% during season one and two respectively. Creation of soil bunds on flat fields increased SMC by 9.2% during season one but reduced SMC by 2% during season two.
A straw mulch cover applied on flat fields significantly increased soil moisture content at 10 cm depth much more than soil bunds created around the flat fields. Application of rice straw mulch on flat fields significantly increased soil moisture content at 10 cm depth while creation of soil bunds was not consistent in increasing soil moisture content at 10 cm depth in this study.

Creation of soil bunds (FB) around flat fields (FU) significantly increased soil moisture content at 20 cm depth during season one and two more than application of straw mulch (FUM) on flat fields (FU) which significantly increased soil moisture content at 20 cm depth during the 1st season only while leveling of fields with 10% slope (SF) to create flat fields (FU) significantly increased SMC during both seasons (Table 5 & 6).

Creation of soil bunds (FB) around flat fields (FU) had a significant increase on SMC at 30 cm depth during season one while the increase in season two was not significant. Application of straw mulch cover (FUM) on flat fields (FU) significantly reduced SMC at 30 cm across the seasons (Table 5 and 6) while leveling fields with 10% slope significantly doubled the soil moisture content at 30 cm depth across the seasons in this study. Application of mulch cover on flat fields reduced SMC at 30 cm depth by 11.6% during the long rain season and by 9.24% reduction during the short rain season. Creation of soil bunds around flat fields increased SMC at 30 cm depth by 8.04% and 6.26% in season one and two but there was no difference in SMC during season one.

Creation of soil bunds (FB) around flat fields (FU) had no significant effect on SMC at 40 cm depth across the two seasons. Similarly, application of straw mulch (FUM) on flat fields (FU) had no significant effect on soil moisture content at this depth during season two although, the soil moisture content significantly reduced during season one after application of straw mulch on flat fields (Table 5). Flattening/leveling fields with 10% slope significantly increased soil moisture content across the two seasons at 40 cm depth threefold.

Creation of soil bunds (FB) around flat fields significantly increased soil moisture content at 60 cm depth during season one and two respectively. Similarly, application of a straw mulch cover (FUM) on flat fields (FU) significantly increased soil moisture content at 60 cm depth during the two seasons. However, leveling fields with a 10% slope led to significant reduction in soil moisture content across the two seasons (Table 5 and 6).

Creation of soil bunds (FB) on flat fields (FU) increased soil moisture content by 38.6% and 24.7% during season one and two while application of straw mulch (FUM) on flat fields (FU) increased soil moisture content by 14.79% and 7.6% during season one and two respectively. The effect of soil bunds on soil moisture content at 60 cm depth was higher during season one compared to season two. Similarly, the effect of straw mulch cover on soil moisture content at 60 cm depth was higher during season one compared to season two.

Creation of soil bunds (FB) and application of mulch cover (FUM) on flat fields significantly increased soil moisture content at 100 cm depth across the two seasons. However, flattening fields with 10% slope significantly reduced soil moisture content at 100 cm depth across the two seasons.(Table 5 and 6). Application of straw mulch cover (FUM) on flat fields (FU) increased soil moisture content by 17.13% and

24.65% during season one and two respectively while creation of bunds (FB) on flat fields (FU) increased soil moisture content by 17.27% and 24.39% respectively during season one and two. Application of straw mulch cover at 6t/ha and creation of soil bunds around flat fields were at par on soil moisture content, however, leveling fields with a 10% slope significantly reduced soil moisture content at 100 cm depth across the seasons.

4.2.3 Soil water extraction characteristics of NERICA 4 rice under rainfed conditions

4.2.3.1 The drained upper limit and the crop lower limit

The drained upper limit (DUL) and the crop lower limit (CLL) per soil depth from 10 cm to 100 cm depth are shown in table 7 below.

Table 7 Drained upper limit(DUL) and crop extraction lower limit (CLL) and Plant available water capacity (PAWC_{P}) for the 100cm

Depth (cm)	DUL (%v/v)	CLL (%v/v)	PAWC_{P}(mm)
10	30.4	3.4	27
20	40.9	7.3	33.6
30	42.2	9.2	33
40	45.3	9.5	35.8
60	22	15.7	6.3
100	42.7	14.7	28
Total	223.5	59.8	163.7

The 10 cm depth had the lowest DUL as well as the lowest CLL while the 60 cm depth had the highest DUL as well as the highest CLL within the plant root zone of 10-60 cm depth. The DUL at 60 cm depth was about half the DUL at 100 cm depth while the CLL at 60 cm was more the CLL at 100 cm depth by 6.3%.

The drained upper limit increased down the soil profile per 10 cm depth with the highest DUL at 40 cm depth at 45.3mm. The lowest DUL was at 10 cm depth in the plant root zone of 10 -40 cm depth while the 60 cm depth had the lowest DUL in the top 100 cm depth (Table 7). The crop extraction lower limit (CLL) for the top 100 cm depth was 59.8 mm (Table 7). The CLL increased down the soil profile per 10 cm depth with the highest CLL at 60 cm depth of 15.7mm (Table 7) while the lowest CLL was 3.4 mm at 10 cm depth in the plant root zone of 10-40 cm depth

The potential plant available water capacity (PAWC_{P}) for the NERICA 4 rice on the soil in Maseno University Botanic Garden at each depth differ only slightly except at the 60 cm soil depth (Table 7). The PAWC_{p} at 60 cm depth was less than 25% of the depths because the DUL was much lower than the DUL of the other depths. The factors contributing to the drastically low DUL at 60 cm depth were not investigated. The DUL at 10 cm depth was much lower than the rest of the soil horizons though the PAWC was similar to the rest of the horizons since the CLL was low (3.4) at 10 cm depth (Table 7)

4.3 Plant available water capacity per treatment

The plant available water capacity (AWC) per treatment is captured in Figure 2 for season one and two respectively.

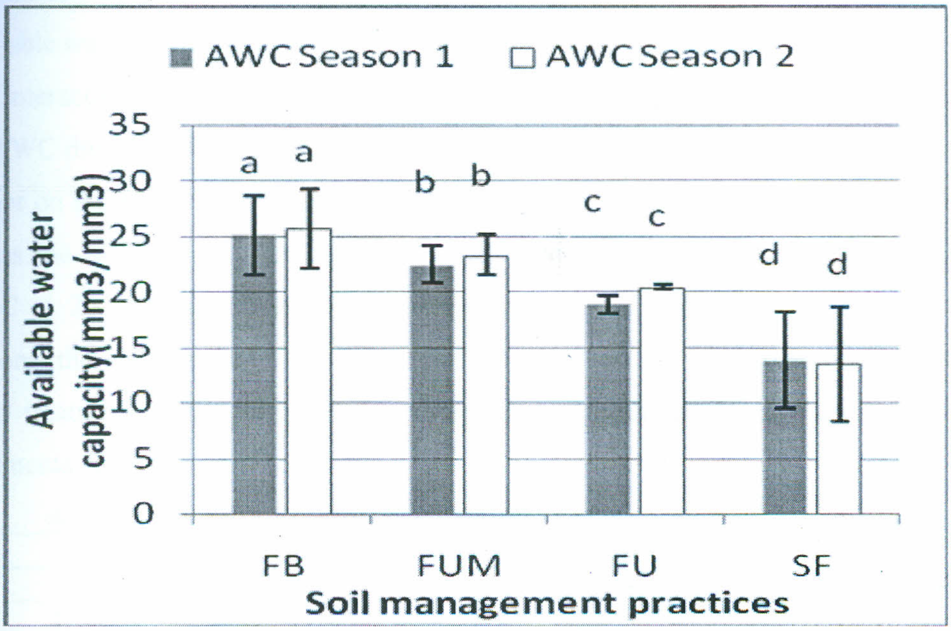


Figure 2. Available water capacity per treatment per season

Available water capacity (AWC) showed significant differences amoung all the treatments (Fig. 2) during the two growth seasons. All treatments were significantly different in AWC during both growth seasons. The FB treatment had significantly higher AWC than other treatments followed by the FUM and FU treatments while the SF treatment was the least significant across the two seasons(Fig. 2).

Creation of soil bunds (FB) on flat fields(FU) increased AWC by 26% and 20 % in season one and two while application of straw mulch cover (FUM) increased AWC by 14% and 11% across season one and two respectively (Fig. 2). Levelling fields that have a 10% slope (SF) significantly increased AWC by 26% and 33% across season one and two respectively. Creation of soil bunds on flat fields had higher significant increase on AWC than application of straw mulch cover across the two seasons Though application of straw mulch increased AWC in the top 100 cm depth during the two growth seasons, creation of bunds on flat fields had a bigger increase on AWC in the top 100 cm.

4.3.1 Effect of interaction between depth and field management practices on available water capacity

Table 8 & 9 shows the interaction effects of field management practices and depth on available water capacity during season one and two.

The interaction between field management practices and depth had a significant effect on AWC during both season one and two (Table 8 & 9). The AWC was significantly higher on the FUM treatment at 10 and 100 cm depths compared to other treatments across the two seasons (Table 8 & 9), the FB treatment had a significantly higher AWC at 20, 30 and 60 cm depths compared to other treatments across the two seasons; the FU treatment was only significant on AWC at 40 cm depth compared to other treatments during season two. The 20 cm depth had the least AWC on all treatments during the two seasons

Table 8. Available water capacity per treatment and depth during season one.

Treatment	Depth(cm)						
	10	20	30	40	60	100	PAWC
FB	13.96^{b}	14.4882^{a}	23.1480^{a}	26.4451^{b}	31.6951^{a}	41.012^{a}	150.7484
FUM	18.08^{a}	9.9725^{b}	17.1284^{c}	25.3588^{b}	23.0206^{b}	41.200^{a}	134.7603
FU	12.38^{c}	6.8618^{c}	20.5471^{b}	28.5010^{a}	17.2971^{d}	27.420^{c}	113.007
SF	13.80^{b}	3.7225^{d}	4.1667^{d}	3.0441^{c}	20.5118^{c}	37.788^{b}	83.0331
Critical Range	0.7521	1.432	1.990	1.455	1.996	2.185	

Means within columns with the same letter are not statistically significant($p<0.05$)

Table 9. Available water capacity per treatment per depth season two.

Treatment	Depth(cm)						
	10	20	30	40	60	100	PAWC
FUM	16.351^{a}	10.213^{b}	22.916^{b}	27.400^{a}	25.458^{b}	41.973^{a}	144.3
FU	14.417^{b}	10.068^{b}	24.137^{ab}	27.718^{a}	18.073^{d}	31.457^{c}	125.8
FB	14.068^{b}	15.506^{a}	25.674^{a}	28.813^{a}	32.238^{a}	41.093^{a}	157.3
SF	11.304^{c}	5.108^{c}	2.887^{c}	2.693^{b}	21.349^{c}	37.193^{b}	80.5
Critical Range	1.103	1.946	1.999	2.254	2.778	2.060	
PAWC	27	33.6	33	33.5	6.3	28	161.4

Means within columns with the same letter are not statistically significant ($p<0.05$)

Application of straw mulch cover (FUM) on flat fields (FU) significantly increased AWC at 10 and 100 cm depths across the two seasons. Creation of soil bunds (FB) on flat fields (FU) had a significant increase on AWC at 20, 30 and 60 cm depths across the two seasons (Table 9 &10) as well as at 40 cm depth during season two. Flattening fields with 10% slope increased AWC at all depths across the two seasons apart from the 10 cm depth during season one.

The FUM treatment was the most significant on AWC at 10 cm across the two seasons while FU and SF treatments were the least significant during season one and two respectively. At 10 cm depth, the FUM treatment had a significantly higher AWC than other treatments (Table 8 and 9) followed by FB and SF while FU had the least significant effect on AWC during season two. During season two, the FUM was significantly higher on AWC than other treatments followed by FU &FB while SF had the least significant effect on AWC at 20 cm depth.

Application of straw mulch (FUM) on flat fields (FU) led to a significant increase in AWC at 10 cm depth during both seasons. Creation of soil bunds (FB) on flat fields (FU) significantly increased the AWC during the long season while there a significant reduction effect on AWC during the short rain season (Table 9). Flattening fields with 10% slope (SF) to create flat fields (FU) significantly reduced AWC at 10 cm depth during the long rains season although, a significant increase in AWC was recorded during the short rain season. Application of straw mulch increased AWC on flat fields (FU) at 10 cm depth by 31.5% during the long ran season and 11.8% during the short season while creation of bunds significantly increased AWC by11.3% during season one but there was no significant effect during season two with a reduction in AWC of 2.4% (Table 9).

The FB treatment was significantly higher than other treatments in AWC at 20 cm depth (Table 8 and 9) followed by the FUM and FU while the SF treatment had the least significant effect on AWC during both seasons. There was no a significant difference between the FUM and the FU treatment in AWC at 20 cm depth during season two, however, during season one, the FUM treatment was significantly higher in AWC than the FU treatment(Table 8& 9).

Creation of bunds on flat fields significantly increased AWC at 20 cm depth during season one and two respectively. Application straw mulch (FUM) on flat fields (FU) increased the AWC in season one but these effects was not recorded in season two.

Flattening fields with 10% slope to create flat fields significantly increased AWC at 20 cm depth across the two seasons.

The FB treatment was significantly higher in AWC at 30 cm depth than the other treatments during season one followed by the FU and FUM while the SF had the least significant effect on AWC at 30 cm depth (Table 8). During season two, the FB treatment was significantly higher in AWC than other treatments, while the FU and FUM were significantly at par and the SF treatment was the least significant on AWC at 30 cm depth (Table 9).The effect of straw mulch (FUM) on flat fields (FU) significantly decreased AWC at 30 cm in season one, however, there was no statistically significant difference between straw mulch (FUM) and flat fields (FU) in AWC at 30 cm depth in season two.

The soil bunds (FB) created on flat fields (FU) significantly increased the AWC at 30 cm depth during season one and two respectively by 26% and 10% while application of straw mulch reduced the AWC in season one and had no significant increase in AWC during season two at 30 cm depth. Flattening fields with 10% slope (SF) significantly increased the AWC at 30 cm depth in both seasons (Table 8 & 9).

The FU treatment was significantly higher in AWC at 40 cm depth than the other treatments (Table 8) during season one, however, during season two, the AWC on the FB, FUM and FU treatments were not significantly different ($p<0.05$). Creation of soil bunds (FB) on flat fields (FU) and application of straw mulch (FUM) on flat fields(FU) significantly reduced the AWC at 40 cm depth during season one ,although, the increase in AWC when straw mulch (FUM) and soil bunds (FB) treatments were installed on flat fields (FU) during season two was not significant ($p<0.05$). Flattening fields with 10% slope (SF) to create flat fields (FU) had a significant effect on AWC at 40 cm depth during season one and two respectively.(Table 8 & 9).

The FB treatment was significantly higher on AWC at 60 cm depth than other treatments during season one and two followed by the FUM, SF while FU was the least significant (Fig. 14). Creation of soil bunds (FB) on flat fields (FU) significantly increased AWC at 60 cm depth during season one and two, similarly, application of straw mulch (FUM)on flat fields (FU) significantly increased AWC at 60 cm depth during both seasons(Fig. 14). However, flattening fields with 10% slope (SF) to create flat fields(FU) lead to a significant reduction in AWC at 60 cm depth during both seasons($p<0.05$)

The FUM and FB treatments were not significantly different in AWC at 100 cm depth during the two seasons (Table 9). The SF treatment had a significantly higher AWC than the FU treatment at 100 cm depth during the two seasons (Table 8 & 9). Application of straw mulch cover (FUM) on flat fields (FU) caused a higher increase in AWC at 100 cm depth than creation of soil bunds (FB) on flat fields(FU), although, the effect of the FUM and FB treatments on AWC was statistically the same. The effect of straw mulch (FUM) applied on flat fields (FU) as well as soil bunds (FB) created on flat fields(FU) on AWC was highest at 100 cm depth(Table 8 & 9).

4.4 Effect of field management practices on rainfall use efficiency

4.4.1 Effect of field management practices on plant growth parameters

Results on tiller count, the plant height, the number of panicles and panicle length for the NERICA 4 rice crop at harvest were as shown in Table 10. The panicle number and tiller number did not statistically differ between treatments, however, the FUM treatment significantly increased plant height and panicle length ($p<0.05$)

Table 10 Plant growth parameters per treatment at harvest.

Treatment	Panicle No	Tiller No.	Panicle Length(cm)	Plant Height (cm)
FUM	8.38^a	8.81^a	20.33^a	90.10^a
FU	8.26^a	8.92^a	18.45^b	82.87^b
FB	7.45^a	8.20^a	18.48^b	85.40^b
SF	7.30^a	8.40^a	17.96^b	80.85^b
LSD	1.347	1.4546	1.3281	4.6873

Values with the same letters within a column are not significantly different ($p<0.05$)

Key: FUM-Flat field with straw mulch; FU-Flat field without straw mulch; FB-Flat field with bunds without straw; SF- 10% Slope field

NERICA 4 rice plants were significantly ($p<0.05$) taller with longer panicles when grown on straw mulch (FUM) in comparison with the other three treatments (FU; FB and SF) (Table 10). There was no significant difference in the panicle number and tiller number of NERICA 4 rice plants among the four treatments (Table 10).

4.4.2 Effect of field management practices on above ground biomass and grain yield

Table 11 shows the above ground biomass yield, grain yield, rainfall use efficiency based on above ground biomass (RUE_b) and rainfall use efficiency based on grain yield (RUE_g) across seasons.

Table 11 Above ground biomass , grain yield and Rainfall use efficiency.

Treatment	Biomass Yield	Grain Yield	RUE_b	RUE_g
FUM	5057.5^a	1556.8^a	8.605^a	2.6800^a
FU	4357.2^{ab}	1245.8^{ab}	7.375^a	2.1200^{ab}
FB	4235.6^b	1391.4^a	7.195^b	2.3819^a
SF	4023.6^b	974.0^b	6.8533^b	1.6650^b
LSD	819.52	338.61	1.3518	0.5796
P value	0.0495	0.0156	0.0702	0.0405

+Figures with the same letters in a column are not significantly different ($p<0.05$)
Key: FUM-Flat field with straw mulch; FU-Flat field without straw mulch;
FB- Flat field with bunds without straw; SF- 10% Slope field

Biomass yield was significantly affected by soil management practices ($p=0.0495$). The FUM treatment had a significantly ($p<0.05$) higher above ground biomass yield than the FU and SF treatments (Table 11). There was no significantly difference between FUM and FU treatments on biomass yield; similarly there was no significant difference in biomass yield between FB, FU and SF treatments (Table 11).

Grain yield was significantly affected by soil management practices. The FUM management practice had a significant increase on grain yield compared to FB management practice.

Mean grain yields were at par in FUM and FB field management practices and were significantly higher than in SF treatments (Table 11).

Similarly there was no statistically significant difference between FU and SF treatments in mean grain yield (Table 11).

Application of straw mulch cover (FUM) on flat fields (FU) significantly increased above ground biomass while the increase in grain yield was not significant (Table 11). Creation of soil bunds (FB) on flat fields (FU) increased the biomass yield, however, the increase was not significant(Table 11). Similarly, creation of soil bunds (FB) on flat fields (FU) increased the grain yield but the increase was not significant ($p<0.05$).

Creation of flat fields (FU) from fields with 10% slope (SF) had no significant effect on above ground biomass while the increase in grain yield was not statistically significant (Table 11).

Figure 3 shows the percentage of unfilled grains per treatment during season one.

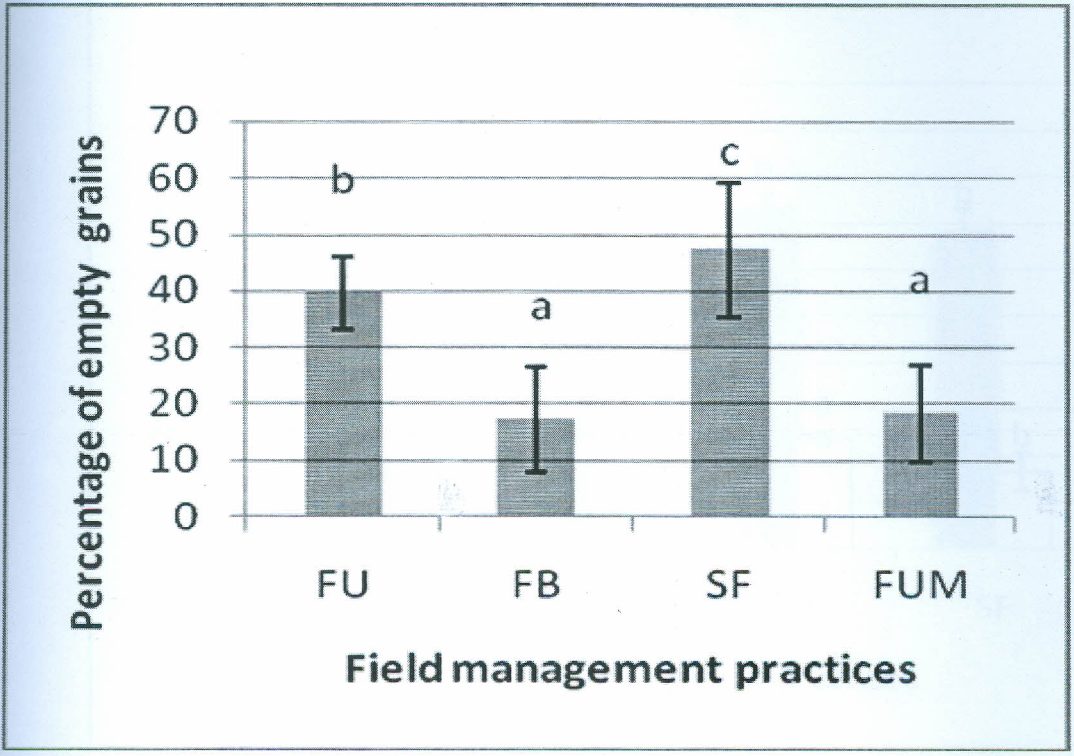


Figure 3. Proportion of empty husks per treatment

The effect of field management practices on the percentage of unfilled grains/empty husks was significant (Fig, 3).The FB field management practice significantly reduced the % of unfilled grains/empty husks more than other field management practices, however, there was no significant difference in % of empty husks between the FB and FUM field management practices across the two seasons.

The FUM and FB field management practices significantly reduced the occurrence of empty husks to less than 20% while the FU and SF field management practices increased development of empty husks by more than 40% across the growth seasons. In all the treatments, % of unfilled grains was reduced with increased soil moisture levels in FB and FUM treatments (Table 3: Fig. 2).

4.4.3. Effect of field management practices on rainfall use efficiency

Figure 4 shows the rainfall use efficiency based on above ground biomass (RUEb)and rainfall use efficiency based on grain yield (RUEg) per treatment per season.

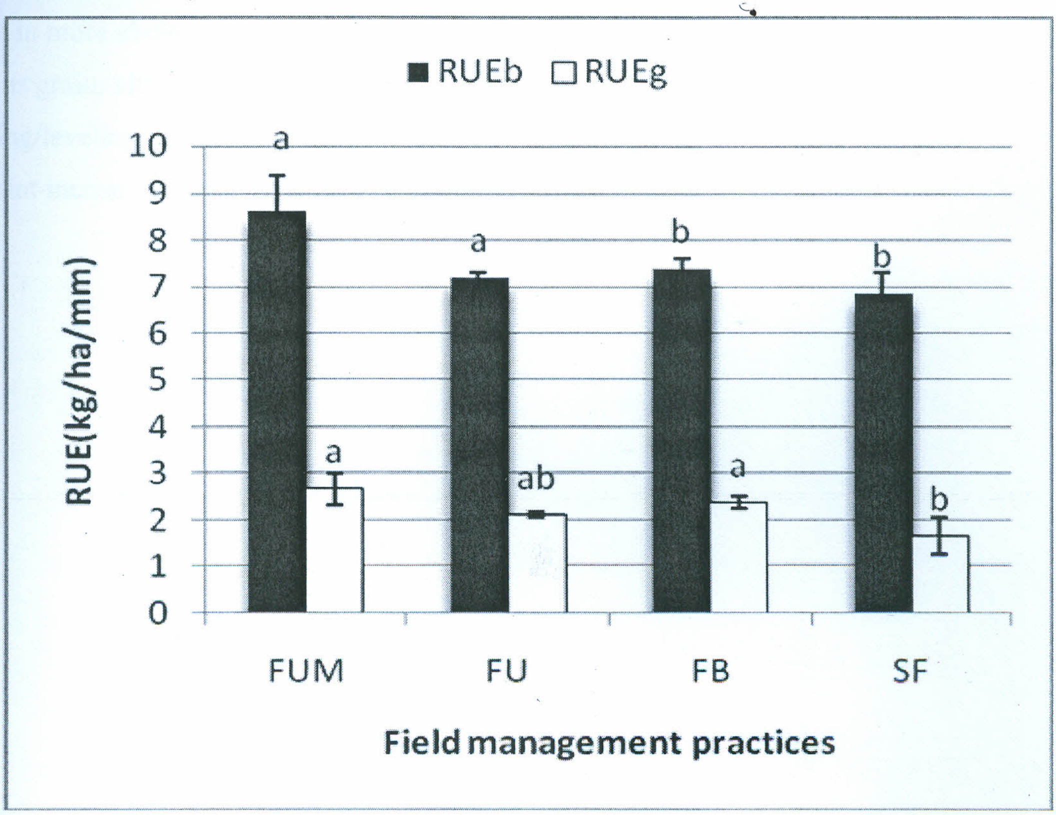


Figure 4 Rainfall use efficiency (RUEb & RUEg) per treatment across two seasons

The FUM and FU treatments had significantly higher RUE_b than the FB and SF treatments (Table 11; Fig. 4) and the FUM and FU treatments were not statistically different in RUE_b; Similarly, there was no significant difference between FB and SF treatments on RUE_b(Fig. 4).

The FUM and FB treatments had significantly higher RUEg than the SF treatment, however, there was no significant difference among FUM , FB and FU treatments in RUEg (Fig. 4).Similarly, there was no significant difference in RUEg between FU and SF treatments amoung the two seasons. Application of straw mulch (FUM) on flat fields (FU) increased RUEg of NERICA 4 rice by 20.89% while creation of soil bunds (FB) on flat fields (FU) increased RUEg of NERICA 4 rice by 10.99% compared to the FU treatment. The increase in RUEg due to application of straw mulch on flat fields was twice compared to the increase in RUEg due to creation of soil bunds.

Creation of soil bunds (FB) on flat fields (FU) led to a significant reduction in RUE_b (Fig.4) while the resultant increase in RUE_g was not statistically significant (Fig. 4). Application of straw mulch (FUM) on flat fields (FU) had no significant effect on RUE_b as well as RUEg (Table 11, Fig. 4). Application of straw mulch on flat fields resulted in more above ground biomass production per unit of rainfall per unit of land as well as grain, although, the increase were not significant (Fig.4).

Flattening/leveling fields with 10% slope (SF) to create flat fields (FU) led to a significant increase in RUEb but the effect on RUEg was not significant (Fig.4).

CHAPTER FIVE

DISCUSSION

5.1. Effect of field management practices on seasonal evaporation and surface runoff

The study revealed that seasonal evaporation was affected by field management practices. The least significant difference test ($p<0.05$) shows that significantly lower seasonal evaporation was generated from surface straw mulched (FUM) plots as compared with flat fields with soil bunds (FB), flat fields without straw and without soil bunds (FU) and fields with 10% slope (SF) plots during the experimental seasons (Table 1& 2). Application of straw mulch reduced evaporation from the soil surface by over 53% across the two seasons (Table 2). The presence of straw mulch on the soil surface perhaps led to increased rainfall interception and infiltration and further removed water from the evaporating surface to the lower soil horizons and limited solar radiation from reaching the evaporating surface especially during the first phase of evaporation process.This may have reulted in less soil moisture available for evaporation at the soil surface as well as less solar energy to change the soil moisture to water vapour reducing evaporation on the straw mulch fields.

Two processes govern soil water evaporation. When the soil is wet, evaporation is driven by radiant energy reaching the soil surface; the energy-limited phase. Once the soil dries, evaporation is governed or limited more by the movement of water in the soil to the surface; the soil-limited phase. Straw mulch limits the energy reaching the soil surface, reducing the evaporation during the energy limited phase (Ritchie, 1972). The mulch materials prevents and/or weakens the intensity of turbulent exchange between the atmosphere and soil water, which in turn inhibits the soil moisture evaporation and thus reduces evapotranspiration (Dong & Qian 2002) resulting in a lower evaporation rate (van Donk *et al.* 2010) during the soil limited phase. Any modification to the soil surface that may affect radiant energy reaching the soil surface or movement of water to the soil surface affects soil surface evaporation (Hatfield *et al.*, 2001). Application of crop residues on the soil surface reduce the evaporation of water from soil by shading, causing a lower surface soil temperature and reducing wind effects (Klocke *et al.* 2009; van Donk *et al.* 2010).

Our results show a higher evaporation from bare soil treatments than from soil under mulch residues (Table 1& 2). This was attributed to the shielding of the soil surface from solar radiation by the rice straw mulch reducing the radiant energy reaching the soil surface and reducing the soil evaporation during the energy limited phase. Similar results were reported by Khan & Pervej (2011) and van Donk *et al.* (2010) who also attributed lower evaporation on mulched plots to reduced air movement resulting in a lower evaporation rate. Reduction of solar energy reaching the soil surface presents an opportunity for crop residues to reduce soil evaporation rates and retain water in the soil to be used by the crop through transpiration that directly affect grain yield and RUE.

Scopel *et al,* (2004) demonstrated that the radiation effect of straw mulch was much more important for governing total evaporation than the effect of intercepting rain for maize production in humid and dry areas. With high amounts of surface residue use at (6-7.5 t/ha) the effect of rainfall interception and subsequent mulch evaporation becomes relatively more important, but in absolute terms more water is conserved. Higher rates of surface residue were recommended at 4-6t/ha (Scopel *et al.*, 2004) to control evaporative water losses though production of such huge amounts of straw could be a limitation (Scopel *et al.,* 2004) and N immobilization may limit plant growth when retaining high amounts of crop residues on the soil (Unger ,1986). Van Donk *et al.* (2010) reported that if the soil surface is covered with straw/crop residues, it is shielded from solar radiation, and turbulent air movement just above the soil surface is reduced. This reduces the evaporation rate from a residue-covered surface compared to bare soil.

Sauer *et al.* (1996a) reported reduced soil water evaporation by 34-50% by crop residues and mulches while Zhai *et al.* (1990) reported a significant increase in interception of precipitation. Mulching with crop residues shields the soil surface from direct solar radiation reducing the evaporation rate from a residue covered surface compared to bare soil (Aiken *et al.,* 1997). Mulching with rice straw directly affects solar radiation energy reaching the soil surface and increases infiltration of rainfall thus affecting first stage evaporation (Muchow *et al.,* 1994). Potential evaporation is related to the energy available at the soil surface and is reduced in the presence of surface crop residue. All the water held by surface residue is evaporates in proportion to the energy incident upon the surface residue layer. Surface crop residue limits the energy reaching the soil surface, decreasing first-stage evaporation of soil water while soil bunds collect surface run-off, increase water infiltration and prevent soil erosion (Teshome *et al.,* 2013) increasing soil water availability that promotes first stage evaporation. Surface crop residue and soil bunds had significant effect on soil moisture content in the soil profile (Table 4) due to increased rainfall interception and infiltration and reduced surface runoff (Table 3).

Our study shows that straw mulch covered plots significantly reduced soil surface runoff compared to bare plots and it was at par with flat fields with soil bunds (Table 3). This was perhaps due to increased infiltration of rainfall falling on the mulch tissues thus water was removed from the surface into the lower soil horizons reducing time for surface water to overflow.The energy of raindrops falling on a bare soil results in destruction of soil aggregates, clogging of soil pores and rapid reduction in water infiltration (Wood, 1991) which increases run-off and soil erosion. Mulch intercepted this energy and protected the surface soil from soil aggregate destruction, enhanced the infiltration of water and reduced the loss of soil by erosion (Hobbs *et al.*, 2008).

Reduction in surface runoff from a soil with surface crop residues was reported by Scopel *et al.* (2004); Findeling *et al.* (2003) and Rao *et al.* (1998). Lal (1995) reported that a mulch of crop residues enhances water infiltration and protected the soil from sealing and crusting by rainfall. Ghosh *et al.* (2015) reported less runoff coefficients and soil loss with conservation agriculture (CA) plots by 45% less and 54% less than conventional agriculture plots.

Covering the flat fields with surface residue was effective at reducing water loss (surface runoff and soil evaporation), giving rise to higher NERICA 4 rice yields. Effects of crop residue on water balance are three fold, rainfall interception increasing soil moisture in the profile (Table 4), radiation interception modifying the dynamics of soil evaporation (Table 2) and reducing surface runoff (Table 3).

Surface crop residues had a significant effect on soil moisture content (Table 5& 6) and AWC (Table 8 & 9), which resulted in lower water stress on NERICA 4 rice plants. This implies that the NERICA rice plants are able to access the moisture retained in the soil and are likely to be less water stressed whenever drought occurs. Our results are in agreement with the earlier studies, where crop residues on the soil retained more soil moisture in the 10 cm depth.

This coraborates the results of Lal (1975) and Nguyen *et al.* (2013) who reported a significant increase in soil water content at 10cm depth by the mulched compost plot both during the dry and wet seasons during the growing seasons. Liu *et al.* (2002) and Mcmillen (2013) reported that mulching with production byproducts such as wheat straw increases water retention and prevents soil evaporation. Mcmillen (2013) reported that a mulch layer of at least 5 cm reduced surface evaporation to 40% compared to the water losses from bare soil and a 10% higher soil moisture in mulched fields with a 5-10 cm layer of mulch compared to bare trays. A mulch layer of straw mulch reduces the amount of sunlight hitting the soil (Philips & Philips 1983). The mulch also maintains the humidity right at the soil surface, and prevents airflow which keeps the moisture in the soil. This limits water loss through evaporation.

Lal (1976c) and Wood (1991) observed significantly higher water infiltration rates on plots with mulch than unmulched plots with a mechanically broken crust soil surface.

Our results coraborates results from Acharya *et al.,*(2005), who reported that mulching (FUM) reduced evaporation component of ET from the soil surface through its influence on the hydrothermal regime of the soil surface by influencing the radiation balance, rate of heat and water vapour transfer and the heat capacity of the soil. Lal (1974), Ji & Unger (2001) ; and Kar & Kumar (2007) reported reduced water evaporation from mulched soil and that the mulch helped maintain stable soil temperatures.

Straw mulching management practicet in this study significantly reduced evaporation and delayed the soil drying process compared to the bare treatments.This result corraborates Dong *et al.* (2006) who reported 61.8% reduction in ET of non flooded rice cultivation with straw mulching. Phillips & Phillips, (1983) attributed reduced ET to reduced quantity of direct solar radiation reaching the soil surface leading to reduction in soil temperature and thereby decreasing the amount of energy available for change of state of water from liquid to vapour as well as the mulch acting as insulators to downward conduction of heat into the soil. Mulching with straw had the lowest evaporation as a percentage of rainfall and evapotranspiration. This confirms many studies finding that mulching, due to presence of a cover on the soil surface , is able to reduce the amount of radiation and solar energy for soil surface evaporation .These leads to an increase in soil moisture retention at the top 10 cm depth. The effect of mulch is similar to the effect of intercropping for instance Ogindo (2003) showed reduced vapour deficits indicating a lower evaporative demand in the mulched plots compared to the bare treatments.

Turner (2004), stated that the major impact of agronomic management on rainfall use efficiency arose from increasing water use by the crop itself in transpiration at the expense of water loss from the soil by soil evaporation, deep drainage, surface runoff and lateral flow. This increase in water use by the crop at the expense of other losses generally results in significantly increased yields, with only a 5–10% increase in total evapotranspiration (Asseng *et al.,* 2001c). The use of mulch led to reduced losses of soil water by soil evaporation. Straw mulching reduced soil evaporation by 50-60% and this will resulted into reduced water stress by the NERICA ric crop during periods when rainfall did not occur and lead to increased yields.

Our study shows that significantly lower seasonal runoff was generated from FB plots (Table 3) as compared with FU and SF plots during the experimental seasons.
This was attributed to the increased rainfall interception and retention increasing infiltration of water into the soil profile. The FB fields conserved 16% of rain water in this study which was lost to surface runoff by the FU fields per season across the two seasons (Table 3).This implies that 16% more rainfall was available for NERICA 4 rice in the soil profile which led to increased soil moisture content (Table 4) and AWC (Fig. 2). Similar results have been reported by Unger & Parker (1976) ; Rao *et al.* (1998) on barley ; by Adimassu *et al.* (2014); by Klocke *et al.* (2009) and by van Donk *et al.* (2010) on corn. Soil bunds are among the most common techniques used in agriculture to collect surface run-off, increase water infiltration and prevent soil erosion (Teshome *et al.,* 2013) significantly increasing soil moisture in the soil profile for crop production.

5.2 Water extraction characteristics for NERICA 4 rice crop grown on Maseno soils

The soil moistuure content and the AWC increased down the soil profile .The lowest soil moisture content and AWC was at 20 cm depth followed by 10 cm depths (Table 8; Fig. 9).
Ogindo & Walker (2005), recorded an increase in DUL and CLL down the soil profile with the highest DUL at 60 cm depth. Mukhala (1998) noted that an increase in DUL down the soil profile was due to an increase in clay content with depth down the profile reaching a maximum within the 60-90 cm layer. Consequently, the water holding capacity for the soil profile increased down the profile with highest AWC in the 20-40 cm layer. The 20-40 cm depth recorded the highest AWC in the soil profile

(Table 8 and 9).The cause of the reduced DUL at 60 cm was not investigated during the study.
The results of our study shows that 20 cm depth had the lowest soil moisture content(Table 5 & 6) as well as the AWC across the two seasons (Table 8 & 9) followed by the 10 cm depth. The 20 cm depth was the least significant on AWC across the field management practices and the seasons. This was perhaps due to the fact that the 20 cm depth had the highest root concentration and was therefore supplying water for ET while the 10 cm depth was the evaporation zone. Somado *et al.* (2008) reported that the 20 cm depth was the lowest in water storage across all field production practices due to highest concentration of roots. Nguyen *et al.* (2013) reported that mulch compost significantly increased soil moisture content at 10 cm depth during the dry and wet periods during the growing season with a resultant increase in grapevine yield.

Application of straw mulch retained higher soil moisture content at 10 cm depth perhaps due to reduced evaporation from this treatment (Table 1& 2). The straw mulch field management practice reduced evaporation from the soil surface by 53% compared to the bare treatments and the conserved soil moisture may have led to the increase in AWC at 10 cm depth as seen in Table 8 & 9.
Creation of soil bunds (FB) on flat fields (FU) cut out soil surface erosion and intercepted all the rainfall which led to enhanced infiltration into the soil horizon and this may have increased the soil moisture content as well as the AWC on this treatment. The low soil moisture content at 10 cm depth may have been due to increased evaporation which was at par with the other treatments (Table 2).
Wolka *et al.*, (2011) and Admissau *et al* (2014) reported similar results with soil bunds in Ethiopia while Hobbs *et al* (2008); Nguyen *et al* (2013) and Lal (1995) reported enhanced soil moisture on fields with crop residues. Crop residues enhance rainfall interception and infiltration reducing surface runoff and increasing the soil moisture and AWC in the soil profile.

The results show that the 10 & 20 cm depths had the lowest SMC and AWC during the two seasons across the field management practices (Table 5& 6; Table 8 & 9). This implies higher water extraction by plants from the 20 cm depths. Moisture content on the FUM treatment was significantly higher than on the FB, FU & SF treatments at 10 cm depth during season one and two. This implies lower water extraction from this treatment compared to the non mulched treatments. At 20 cm depth, the FUM treatment had higher soil moisture content than the FU and SF; however, the FB treatment had the highest SMC than the FUM at 20 cm depth.

The results show that the straw mulch management practice increases the AWC in the top 10 cm depth in rice fields compared to flat level fields (FU), fields with soil bunds (FB) and fields with a slope of 10%.This implies an increase in the water holding capacity of the plant root-zone and an increase in water available for plant uptake during the growing season especially when rainfall does not occur. The plants on the FUM treatment may therefore suffer less moisture stress compared to the plants on FB, FU and SF field management practices.

5.3. Effect of field management practices on AWC for NERICA 4 rice crop

The results from the study showed that field management practices significantly affected soil moisture content (Table 4) and available water capacity (Fig.2) in the 100 cm depth of the soil profile. Significant differences in soil moisture content was observed between the field management practices with the flat fields with soil bunds having the highest soil moisture content and AWC (Table 4). Installation of soil bunds (FB) on flat fields (FU) increased the AWC perhaps due to increased interception of rainfall and infiltration into the soil profile unlike on flat fields that generated significantly higher amounts of surface runoff (Table 3). The soil bunds intercepted and retained 16% of rainfall being the runoff from the flat fields (FU) in our study (Table 3). This may have led to increased soil moisture content by 26.6% and 14.9% during season one and two respectively (Table 4). Further impounding all the seasonal rainfall water and retention on the soil may have perhaps led to increased infiltration into the soil profile increasing the AWC by 25.03% and 20.17% during season one and two respectively (Fig. 2). The increases in soil moisture content and AWC was perhaps due to elimination of overflows of rainfall from the soil bunded fields throughout the rainfall events of the two seasons. The soil bunds in this study significantly increased soil moisture thus corroborating earlier studies (Herweg & Ludi 1999; Tenge *et al.* 2005). For instance, Tenge *et al.,* (2005) reported that bench terraces, fanya juu, and grass strip (forms soil bunds) conserved soil moisture by 26-36% compared to untreated land. Vancamenhout *et al.* (2006) reported higher yield and biomass with stone bunded land and attributed the increase to the moisture conserving role of these structures. Teshome *et al.* (2013) reported that stone bunds and soil bunds reduced soil loss by 72.9 & 83.7% respectively compared to untreated land. The soil bunds impound excess water and enhance the possibility of its infiltration, thus soil moisture can be improved.

The soil bunds constructed across the slope and parallel to fields impounded excess water and enhanced the possibility of its infiltration which otherwise would produce surface runoff enhancing soil moisture within the soil profile (Herweg & Ludi, 1999; Schwab *et al.,* 2002) especially in dry areas. Wolka *et al.,* (2011) reported improved crop performance due to surface runoff reduction and water retention ability of soil bunds in the Ethiopian highlands. The bunds created across fields retained all the runoff water and enhanced infiltration increasing the water available for plant growth while the mulch applied on the fields covers the soil and reduces the runoff velocity (Young, 1997). Odunze *et al.,* (2010) found that creation of bunds across fields' decreases bulk density due to reduced crusting and surface soil hardening which lead to increased soil moisture in the soil profile. Reas *et al.,* (2007) noted a yield increase of rainfed lowland rice on fields with soil bunds. The results of our study implies that that the NERICA 4 rice crop grown on FB management practice had higher available water during the growing seasons compared to the plants on the FUM , FU and SF fields management practices.

At shallower depth of 10 cm, application of straw mulch (FUM) on flat fields (FU) increased soil moisture content more significantly than creation of soil bunds (Table 8 & 9). The straw mulch reduced significantly the evaporation and surface runoff from the soil (Table 2 & 3).The reduction in evaporation and runoff was attributed to increased rainfall interception and infiltration enhanced by straw mulch cover. This led to a significantly greater plant available water (PAW) compared to the FU and SF treatments which may have contributed to a lower percentage of unfilled grains (Fig. 3).This was also reported by (Tolk *et al.*, 1999) and Khan & Pervej ,(2010) on maize.

Surface residue limits the solar energy reaching the upper horizon soil surface, decreasing first-stage evaporation of soil water (Scopel *et al.,* 2004). Mulching with crop residues shields the soil surface from direct solar radiation .This reduces the evaporation rate from a residue-covered surface compared to bare soil (Aiken *et al.*, 1997; Todd *et al.,* (1991). The straw mulch /crop residues at the soil surface shade the soil, serve as a vapor barrier against moisture losses from the soil, slow surface runoff and increase infiltration (Mulumba & Lal, 2008) which significantly increases soil moisture in the top 1.2 m profile (Donk *et al.,* 2010) with a significant effect on plant available water in the soil profile for production of maize (Scopel *et al.,* 2004) improving yields under water-limited growing conditions (Erenstein, 2002). Rao *et al.* (1998) and Findeling *et al.* (2003) reported that a mulch of crop residues enhances water infiltration and protects the soil from sealing and crusting by rainfall increasing the plant available water capacity in the soil. Uwah & Iwo, (2011) reported significant soil moisture contents on maize fields at mulch treatment of 6-8 t/ha.

Khan & Parvej (2010) noted that the rice straw mulch treatment retained maximum soil moisture probably due to reduced evaporation (Cui *et al,* 1998) , transmissivity (Mbagwu, 1990), plant transpiration (Shekour, *et al.,* 1987) and increased hydraulic conductivity (Schoningh ,1985), water infiltration (Arifandi, *et al.,* 1995) and water holding capacity (Gicheru *et al.,* 1998). Somado *et al.* (2008) reported that the 20 cm depth was the lowest in water storage across all field production practices due to highest concentration of roots.

The implication of this is that applying straw mulch on flat fields reduces soil surface evaporation which increases AWC at 10 cm depth availing more soil moisture for plant uptake for longer periods when rainfall does not occur. This implies that the NERICA 4 rice crop grown on FUM treatment had higher available water during the growing seasons compared to the plants on the FU and SF treatments. Further, the straw mulch production practice increased the AWC in the top 100 cm depth in rice fields compared to flat level fields (FU) and fields with a slope of ≤ 10%. This implied an increase in the water holding capacity of the plant root-zone and an increase in water available for plant uptake during the growing season especially when rainfall failed to occur. The plants on the FUM treatment therefore suffered less moisture stress compared to the plants on FU and SF field management practices.

Flattening fields with 10% slope (SF) had a significant increase on soil moisture content (Table 4) across the two seasons. By flattening the land, water from precipitation is more uniformly stored in soil, erosion is minimized and crop production is more uniform on the entire field (Seck *et al*., 2012).

Available water capacity(AWC) showed significant differences amoung field management practices (Fig. 2) and especially at 10 cm depth (Table 8 & 9)) during the two growth seasons. Creation of soil bunds (FB) on flat fields (FU) significantly increased AWC by 20-25% (Fig. 2) in the top 100 cm of the soil profile while application of straw mulch (FUM) on flat fields(FU) increased AWC by 12- 16 % during season one and two respectively. The effects of the soil bunds is attributed to its ability to reduce water loss by creating barrier against surface runoff and reducing slope length and gradient(Rao *et al.,* 1998; Nyssen *et al.,* 2005) in the long-term which aides in collection surface run-off, increase water infiltration and prevent soil erosion. This leads to increased soil moisture and AWC within the 100 cm soil profile. The implication of this is that installation of soil bunds on flat fields increases AWC more than applying mulch on flat fields.

The increase in soil moisture content in the upper 0-120 cm depth has been reported by similar studies for soil physical properties (Mulumba & Lal., 2008) soil water content (Scopel *et al.,* 2004; Nguyen *et al.,* 2013) however soil chemical properties (Wolka *et al* ., 2011) on fields with bunds was not significantly different from non bunded/terraced fields. The soil moisture content significantly increased after installation of soil bunds (FB) on flat fields as well as straw mulch cover across the two seasons. The NERICA rice crop grown on the FB and FUM treatments had a higher available water and suffered less moisture stress leading higher biomass (Table 11), few unfilled grains(Fig. 3) and higher RUE based on grain(Fig. 4).

Any soil modification that obstruct the movement of the runoff, slowing it down, giving more time for infiltration thereby reducing the volume of runoff will affect the soil moisture and AWC in the soil profile. The effects of mulching is attributed to protection of the soil from water erosion by reducing the rain drop impact. A partial covering of mulch residue on the soil can strongly affect runoff dynamics, and reduce runoff amount (Findeling *et al.,* 2003; Rees *et al.,* 2002) which increases soil moisture storage (Ji & Unger, 2011).

The presence of crop residues slows the movement of water, increase the infiltration rate and decrease the potential for runoff by creating an uneven surface. Crop residues protect the soil by absorbing energy carried by the falling rain water droplets. This limits soil crust development, resulting in a more consistent infiltration rate throughout the rainfall events during the growing season. The volume of water soaking into the soil may have been increased by giving more time for infiltration by slowing down runoff, through construction of soil bunds across the slope and parallel to the contour. Soil bunds created on flat fields across the slope and parallel to the contours impound excess water and enhance the possibility of its infiltration which otherwise takes surface runoff (Wolka 2014). Although soil bunds can increase soil moisture, Reas *et al* . (2007) and Adimassu *et al.* (2014) reported reduced crop yield due to reduction of cropped area that is occupied by the soil bunds.

Similar results on effect of soil bunds (Wolka *et al.,* 2011) and crop residues (Mulumba &Lal, 2008; Uwah & Iwo , 2011) have been reported for increased soil moisture content in the 0-120 cm depth for maize production in the Ethiopian highlands and Nigeria. The effect of increased soil moisture content on flat fields with soil bunds and straw mulch cover was attributed to reduced surface runoff (Glab & Kulig, 2008; Scopel *et al.,* 2004; Wolka *et al.,* 2011) reduced evaporation (Scopel *et al.,* 2004) and increased infiltration (Khurshid *et al.,* (2006) of incoming rainfall. Soil bunds promote rainwater infiltration (Critchley *et al.,* 1994) increasing soil moisture storage.

5.3.1 Effect of field management practices on Soil moisture extraction patterns by NERICA 4 rice

The total soil water depletion was minimum under the mulch treatment (Table 8& 9). Grain yield and rainfall water use efficiency was however maximum under the mulch treatment (*Table* 11). So grain yield and RUE were positively correlated (Table 11), whereas water use efficiency(Table 11) and total soil moisture depletion(Table 5 & 6) were negatively correlated. Application of mulch improved the productivity as well as water retention on the rootzone due to reduced evapotranspiration in the mulched plots. Masanta & Mallik (2009) reported improved wheat productivity by 85.5% under mulch over the farmers practice, Similar findings were also observed by Khera & Singh (1998) in case of maize yield in Punjab. Masanta & Mallik (2009) also reported minimum total soil moisture depletion under mulch. Saha & Ghoshi (2010) recorded maximum soil moisture extraction at 0-15 cm depth of 32.2-44.5%. Increased water uptake by the crop from under the surface layers of the mulch treatment was due to increased availability of soil moisture on this treatment(Table 4).

Most of the moisture was extracted by the crop from the top 40 cm depth on all the treatments. Saha & Ghoshi (2010) found similar results.

This study has demonstrated that the FUM treatment reduced water extraction by the NERICA 4 rice crop compared to the fields with a slope of up to 10% however the NERICA 4 rice crop grown on fields with bunds (FB) extracted less and less water at similar depths of 10-40 cm(Table 5 & 6). Compared to the NERICA rice crop grown on the flat without bunds (FB) fields, the water extraction by crop on the FUM fields was higher in both seasons (Table 4).

Smika & Unger (1986) reported that use of mulch increased infiltration, reduced runoff rates and decrease evaporation resulting in more water storage. The evaporation component was reduced to more 50-55% on the mulched fields (Table 2) compared to the bare fields and much of the ET was perhaps transpiration which is useful to plant growth. The bare treatments are characterized by high evaporation rates ranging from 50-75% (Bennie & Hensley 2001). Singh *et al.* (2006) demonstrated that organic mulches improve the hydrothermal regime in the root zone as well as vegetative growth and development. Saha & Ghoshi (2010) recorded maximum soil moisture extraction at 0-15 cm depth of 32.2-44.5%. Increased water uptake by the crop from the surface layers of the mulch treatment was due to increased availability of soil moisture on this treatment .Most of the moisture was extracted by the crop from the top 40 cm depth on all the treatments. Saha & Ghoshi (2010) found similar results.

5.4. Effects of field management practices on Rainfall use efficiency of NERICA 4 rice crop

The results of our study indicate that field management practices had a significant effect on rainfall use efficiency based on biomass (RUEb) and rainfall use efficiency based on grain (RUEg) (Table 11; Fig. 4). The % of unfilled grains (Fig. 3) was reduced to < 20% with increased soil moisture levels in FB and FUM treatments (Table 4; Fig. 2) while the FU and SF treatments increased development of unfilled grains to > 40% (Fig. 3).

The results of this study indicate that application of straw mulch (FUM) on flat fields (FU) increased above ground biomass yield as well as RUEb of NERICA 4 rice crop (Table 11). The straw mulch management practice increased RUE based on biomass perhaps due to reduced evaporation and surface runoff (Table 3) as well as increased rainfall water infiltration which in turn may have increased transpiration by the NERICA 4 rice plants. This may have led to increased growth (Table 10) especially in plant height with a corresponding high tiller count at harvest.

Water conserved in the 10 cm soil profile (Table 5 & 6; Table 8 & 9) may have been taken up by the plants through transpiration at the expense of water losses through evaporation and surface runoff unlike on the flat fields (FU) and fields with 10% slope (SF). This may have resulted to higher biomass and grain yield with corresponding significant increases in RUE based on biomass and RUE based on grain compared to RUE on the FU plots.

Similar results have been observed on mulched fields for instance, Deng *et al.*, (2004) reported improved WUE by 10-20% through reduced soil evaporation and increased plant transpiration. Tolk *et al* (1999) ; Klocke *et al.*, (2009) and van Donk *et al.*, 2010 reported a significantly higher corn yield in residue covered plots compared to bare plots due to more soil water being used in transpiration at the expense of evaporation. The low RUEg on SF fields may perhaps be attributed to a higher % of unfilled grains (Fig. 3). Increased % unfilled grains in SF treatments was attributed to increased rainfall water losses to surface runoff and evaporation(Table 3) causing low soil moisture and AWC (Table 4 & Fig. 2) on this treatment. The reduced SMC and AWC (Fig 2) on the SF and FU fields may have contributed to the reduction in fertility of the panicles. Fageria *et al* (1997) reported low fertility due to low night temperatures during the flowering stage that affected pollination and fertilization of the panicles increasing sterility. Nutrient application had no significant effect on increased sterility of NERICA 4 (Getachew, & Birhan, 2015).

The RUEb and RUEg on the FU plots (Table 11) were lower than on the FUM plots; however, the reduction in RUE was not significant. The FU field management practice had the highest tiller count (Table 10) and this may have resulted in increased biomass and a corresponding increase in RUEb. The reduction in RUEb compared to the FUM management practice may be due to the increased rainfall water losses via surface runoff and surface evaporation on this treatment (Table 3).

Zubaer *et al.* (2007) ; Fofana *et al.*(2010) and Atera *et al.* (2011) reported similar results. An increase in % unfilled grain per panicle under lower soil moisture level was perhaps due to inactive pollen grain due to dryness, incomplete development of pollen tube; insufficient assimilates production and its distribution to grains (Atera et al., 2011) causing increased sterility. Grain yield loss (Table 11) with moisture stress on FU and SF plots may be as result of decrease in the number of filled grain per panicle. The reduced soil moisture and AWC (Table 4; Fig.2) on SF reduced the biomass, grain yields as well as RUEb and RUEg on these treatments.

There are two broad strategies for increasing yields in rainfed agriculture when water availability in the root zone constrains crop growth: (1) capturing more water and allowing it to infiltrate into the root zone; and (2) using the available water more efficiently (increasing water productivity) by increasing the plant water uptake capacity and/or reducing non-productive soil evaporation. Mulching achieves both strategies while creation of soil bunds achieves the first strategy. Evaporation management through mulching shifts non-beneficial soil evaporation to beneficial transpiration increasing crop yields and water use efficiency (Rockstro¨m *et al* 2010). In rainfed agriculture systems, strategies that reduce evaporation and increase transpiration will increase water productivity per unit of rainfall. These strategies must have the capacity to reduce water losses to surface runoff and surface evaporation but increase infiltration into the plant root zone and transpiration by plants (Hatfield *et al.,* 2001).

Results of our study show a reduction in RUE_b and an increase in RUE_g when soil bunds (FB) were created around flat fields (FU) (Table 11) though the increase in RUEg was not significant. The increase in RUEg was perhaps due to increased grain yield (Table 11), water conservation through stoppage of surface runoff (Table 3) and increased soil moisture and AWC (Table 4 & Fig. 2).

Soil bunds are embankments of soil built along the contour to reduce or stop the velocity of overland flow and consequently to reduce soil erosion (Morgan, 1995) and promote rainwater infiltration (Critchley *et al*., 1994). Construction of soil bunds at regular intervals reduces the rate of the downward water flow on slopes (runoff), which prolongs the time for water to infiltrate into the soil, and thus, improves water availability for crop production (Adimassu *et al*., 2014).Soil bunds stopped surface runoff of 16% of rainfall and associated loss of soil nutrients through soil erosion increasing rainfall infiltration by 16% (Table 3) which may have contributed to increased grain yield with a corresponding increase in RUEg though the increase was not significant. NERICA 4 produced less dry matter and developed fewer tillers on flat fields with soil bunds (Table 10).This may have resulted into low biomass production and low RUEb.

Tao *et al* (2007) reported reduced tiller count in rice produced under high soil moisture due to a reduction in tiller number reducing biomass yield and RUEb however tillers produced longer productive panicles in our study (Table 10) increasing the grain yield with a resultant increase in RUEg (Table 11).

Similar results were reported in high-rainfall areas in Ethiopia (Shiferaw & Holden, 1999; Kato *et al.,* 2011) on barley, wheat and teff , Adimassu *et al.,* (2014) on barley and maize in Thailand (Pansak *et al.,* 2008) where the difference in mean crop yield on plots with soil bunds and plots without soil bunds was not significant. However, results of our study contrasts with the research findings in Tigray (Northern Ethiopia) where stone bunds increased crop yield per hectare (Gebremedhin *et al.,*1999; Vancampenhout *et al.,* 2006; Kato *et al.,* 2011).The positive effect was found in moisture-deficit areas in which stone bunds contributed to moisture conservation (Kato *et al.,* 2011) whereas our study was in dry humid areas with high rainfall in western Kenya installed with soil bunds.

Soil bunds in our study occupied 8% of the cultivatable land area and this reduces land for NERICA rice grown on fields with soil bunds. This may further have caused a reduction in plant population and grain yield. Similar results were posted by Adimassu *et al.(*2014) and Teshome *et al.,* (2013) where stone/soil bunds installed on flat land occupied significantly high proportion of cultivable area depending on slope. Soil bunds occupy 2-20% of land for a slope of 3-30% (Teshome *et al.,* 2013) and on experimental plots established in central highlands of Ethiopia, soil bunds occupied

8.6% of cultivable land area (Adimassu *et al.,* 2014) while in Northern Ethiopia soil bunds occupied 8% of farmland(Vancampenhout *et al.,* 2006). The reduction in cultivable area may significantly have reduced NERICA 4 rice crop yield and rainfall use efficiency in our study compared to the results from the FU fueld management practice.

There was an increase in RUEg of NERICA 4 rice grown under the flat fields with straw mulch field management practice (FUM) compared to flat fields without straw mulch without bunds (FU), however, the increase was not statistically significant across the two seasons. The RUEb and RUEg of NERICA 4 rice variety produced under flat fields with straw mulch (FUM) and flat fields without straw mulch (FU) showed no significant differences.

The results indicate additional benefits of increased grain yield of NERICA 4 when grown on flat fields applied with straw mulch; however, using the criteria of RUEg, the additional benefits were not significant. Similarly additional benefits of increased grain yields from the installation of soil bunds have been demonstrated though again using the criteria of RUEg, the additional benefits were not significant.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The FUM soil management practice reduced seasonal soil surface evaporation to half compared to the other treatments in the study. Mulching flat fields for NERICA 4 rice production could reduce seasonal soil surface evaporation water losses from the bare fields by over 50% .The extra 50% water could considerably improve the rainfall use efficiency in a rainfed cropping situation especially in seasons with less rainfall and ensure farmers achieve a good harvest ≥ 1.5t/Ha.
Crop residues consisting of straw mulch have the capacity to modify the radiant energy reaching the soil surface and reduce the soil water evaporation during the "energy" limited phase of evaporation. With high frequency of rainfall events, the soil may remain in the "energy" limited phase and this presents an opportunity for crop residues to impact soil evaporation rates and retain water in the soil to be used by the crop through transpiration relating directly to grain yield and increased rainfall use efficiency by the NERICA 4 rice crop.

Construction of bunds at regular intervals reduces the rate of the downward water flow on slopes (runoff), which prolongs the time for water to infiltrate into the soil, and thus, improves water availability for NERICA 4 rice production, however, the benefits of improved water availability may be offset by the reduction in cultivated area taken up by the soil bunds .Construction of soil bunds requires much land that may not be adequately compensated for by the increased productivity of the remaining area in the AEZ of western Kenya.

Straw mulch tillage increased water content in the shallower plant root zone with a corresponding increase in AWC which lead to increased yields and with a corresponding increase in RUE however, the increase in grain yield and rainfall use efficiency was not statistically different from the grain yield and rainfall use efficiency on the flat fields without straw mulch.

6.2 Conclusions

The following conclusions can be drawn from this study

a) Rice straw mulch has the potential of improving crop growth and yield as well as reducing rainfall water losses through surface evaporation and runoff thereby increasing PAWC in the soil profile for NERICA rice growth leading to increased grain yield and higher RUE.

b) From the present experiment, it was concluded that straw mulch on flat tilled fields increases the NERICA grain and stover yield but also helped in increase RUE. Application of straw mulch (FUM) to flat tilled fields without bunds (FU) could increase the RUE_b by 14.29% with a resultant increase in RUE_g by 20.89%.

c) Creation of bunds on flat fields significantly increased soil moisture and PAWC in the top 100 cm of the soil profile. However, the benefit of increased available water capacity did not result into increased productivity and RUE perhaps due to reduction in cultivated area that was occupied by the soil bunds and water logging due to increased rainfall capture that may have affected tiller development and resultant grain and RUE.

6.3 Recommendations

The following recommendations are inferred from this study

a) Mulching with rice straw should be applied at 6-7.5 t/ha to the soil 42 days after transplanting of NERICA rice plants since this contributes to reduced water loss via evaporation and surface erosion, increased soil moisture and PAWC in the plant rootzone with a resultant increase in grain yields and RUE.

b) Creation of soil bunds on flat fields reduces cultivated area and should only be installed where the benefits of increased available soil water outweigh the reduction in cultivated area usually in drier areas with erratic rainfall.

6.3.2 Suggestions for future research

a) Transpiration use efficiency and nutrient use efficiency studies should be conducted for the straw mulch and soil bunds field management practices to further understand the water nutrient interactions for increased rainfall use efficiency. Such research should further investigate the partitioning of nitrogen (N), phosphorous (P) and potassium (K) in the biomass and grain to understand most limiting nutrients affecting RUE in the mulch (FUM) and soil bund (FB) treatments.

b) Determination of water extraction limits should be conducted under various field management practices with the NERICA 4 rice crop to quantify the plant available water capacity per soil management practice

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