THE SYSTEM OF RICE INTENSIFICATION (SRI) AS A CLIMATE CHANGE ADAPTATION STRATEGY: CASE STUDY OF MKINDO AREA IN MOROGORO, TANZANIA

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF
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ABSTRACT

The System of Rice Intensification (SRI) is one way in which farmers practicing irrigation in rice farming can cope with the effects of climate change by reducing water used for paddy rice production while increasing the yields. System of rice intensification, developed in Madagascar, is a system approach to increase rice productivity through proper management of fewer inputs such as irrigation water, transplanting protocol, and seeds. Field experiments using SRI techniques were conducted in Mkindo irrigation scheme in Mvomero District during the wet season (March- July 2011) and dry season (September 2011- January 2012). One rice variety TXD 306 (SARO) was planted on plots in a randomized complete block design with five treatments based on SRI technique and conventional method where effects plant spacing (in cm) of 20x20 for T1 and T2, 25x25 for T3, 30x30 for T4, and 40x40 for T5 were evaluated. Parameters such as plant height, root depth, tillerig, biomass and grain yields, irrigation water use, and wetting and drying interval were evaluated and the results were statistically analyzed using GenStat software. Results revealed that highest grain yield was achieved in T3 and T4. The mean grain yield for two seasons for T3 and T4 were 4.76 tons/ha and 4.68 tons/ha, respectively. The grain yield obtained from SRI on Farmer Field School (FFS) trials during the wet season were 6.30 t/ha for T3, 4.93 t/ha for T4, and 3.37 tons/ha for T5. The percentage yield increase of the treatments with respect to the reference T1 from the mean of two seasons obtained was 24.28% in T3 and 22.19% in T4. With respect to water productivity, SRI method registered the highest water productivity of 0.47kg/m^3 and 0.46 kg/m^3 for T4 and T3 respectively. Statistically at $p<0.05$, water productivity at T1 was significantly different from all other treatments T2, T3, T4 and T5. Under SRI practice, 62.51%, 63.64%, 64.67%, and 64.07% water saving were noticed for T2, T3, T4 and T5 respectively compared to T1. SRI practice for planting space 25x25 and 30x30 cm, wetting and drying interval of three days, and younger seedling (<14days) are recommended as good combination for SRI practice in Mkindo area.

DECLARATION

I, **EBENEZER ELIA KOMBE** do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

24/06/2013

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The declaration is confirmed.

24/06/2013

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DEDICATION

This work is dedicated to my father ELIA KOMBE and my mother TRIZA KOMBE who laid the foundation of my education.

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LIST OF ABBREVIATIONS AND SYMBOLS

AICAD	African Institute for Capacity and Development
ASTM	American Society of Testing Materials
CIIFAD	Cornell International Institute for Food, Agriculture and Development
DAELP	Department of Agricultural Engineering and Land Planning
FAO	Food and Agriculture Organisation
GENSTAT	General Statistic Software
IFAD	International Fund for Agriculture Development
IMAWESA	Improved Management of Agricultural Water in Eastern and Southern Africa
IPCC	Intergovernmental Panel on Climate Change
IRRI	International Rice Research Institute
IWM	Irrigation Water Management
IWMI	International Water Management Institute
JKUAT	Jomo Kenyatta University of Agriculture and Technology
LULUCF	Land Use, Land-use Change and Forestry
MAM	March, April, May rain season (masika)
MIAD	Mwea Irrigation Agricultural Development Centre
NGO	Non Governmental Organisation
NIB	National Irrigation Board
OND	October, November, December rain season (vuli)
PAPSTA	Support Project for the Strategic Transformation of Agriculture
SIWI	Stockholm International Water Institute
SRI	System of Rice Intensification
SUA	Sokoine University of Agriculture

SWMRG	Soil and Water Management Research Group
T1	Treatment one, conventional practice- flooding, planting 20x20cm
T2	Treatment two,-conventional practice- AWD, planting 20x20cm
T3	Treatment three- SRI practice- AWD, planting space25x25cm
T4	Treatment four-SRI practice, AWD, planting space 30x30cm
T5	Treatment five-SRI practice, AWD, planting space 40x40cm
TANESCO	Tanzania Electric Supply Company
UNFCC	United Nations Framework Convention on Climate Change
URT	United Republic of Tanzania
USDA	United States Department of Agriculture
WARDA	West Africa Rice Development Association
WP_{ET}	Water productivity as yield per unit water evapotranspired
WP_{irr}	Water productivity as yield per unit per unit total irrigation water input

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Climate change and variability, population growth, increasing water demand, overexploitation of natural resources and environmental degradation have significantly contributed to depletion of the world's freshwater resources (IWMI, 2007). Climate change threatens agricultural production through higher and more variable temperatures, changes in precipitation patterns and increased occurrences of extreme events like droughts and floods, and reduced fresh water availability. The frequent droughts and floods in most parts of sub Saharan Africa (SSA) that lead to severe food shortages, food insecurity, water scarcity, hunger/famine, and acute shortage of hydropower indicate the region's vulnerability to climate change (Nelson, 2009). The challenges of water resources development in the SSA will be aggravated by resultant climate change, with serious implications on socio-economic development. According to IPCC (2001), water resources challenges will include population pressure, problems associated with land use such as erosion/siltation and possible ecological consequences of land use change on the hydrological cycle. In terms of fresh water, annual run-off and water availability are projected to increase by 10-40 % at high latitudes, but will decrease by 10-30 % over some dry regions in mid-latitudes and in the dry tropics (IPCC, 2007). This means that drought-affected areas will likely increase in extent. Agricultural production is projected to be severely compromised in many regions by these trends (UNFCC, 2008).

Agriculture accounts for more than 70 percent of global fresh water use (FAO, 2008). As irrigation is a highly consumptive water user and has the greatest impact on water resources, the main challenge for irrigated agriculture is to produce more food with less water. In Tanzania, for example, the performance of the agriculture sector, which has historically been the backbone of Tanzania's economy and employs about 80 percent of the total population (URT, 2009), is projected to drop as a result of negative effects of the ongoing global climate change and variability (Levira, 2009).

More than one-half of the world's population depends on rice as their staple source of food (FAO, 2005). Rice plays a critical role in ensuring food security in developing nations in Asia and Africa. For majority of the world's small-scale farmers who live in Asia and sub-Saharan Africa, rice is a major source of calories and the single largest source of income. Rice is rapidly becoming a major staple food in much of SSA and is set to overtake maize, cassava, sorghum, and other cereals in the near future. The demand is driven as much by population growth as by urbanization (Mati *et al.*, 2011).

Rice is the second widely cultivated cereal food crop in Tanzania after maize. Rice is grown in almost all regions of Tanzania by small scale and large scale farmers as a food and cash crop (FAOSTAT, 2008), and it is grown in three agro-ecosystems namely rainfed lowlands, rainfed uplands and irrigated lowlands (Kanyeka, 1994). The popularity of rice is due to the following reasons: population growth and urbanization, consumer preference and diet changes, convenience and ease of storage and cooking, consumption increase by 5% per year and it sustains livelihood for more than 100 million people in sub-Saharan Africa. Despite its importance in SSA, rice production has not kept pace with increased consumption and thus widening domestic deficit, which is met by importation (WARDA, 2005).

Rice is reported to be the greatest consumer of water among all cereal crops and uses about 80% of the total irrigated freshwater resources in Asia (Bouman and Toung, 2001).

According to National Irrigation Policy, Tanzania is encountering a challenge of how to raise crop production with restricted resources of land and water, finance, agricultural inputs and support services. Irrigated agriculture is also constrained by other production practices, storage facilities, marketing, water management, adequate crop protection and adoption of appropriate technologies for irrigation (URT, 2009).

Rice cultivation requires about 3000 - 5000 litres of water to produce one kilogram of rice depending on whether the cultivation methods are flooding or non-flooding (IRRI, 2002). It takes three to five times more water to grow rice than wheat or corn. The higher water demand of irrigated lowland rice mainly arises from the practice of keeping a permanent layer of water on the field. A lot of water is lost from this layer through evaporation, runoff, seepage and deep percolation (Guerra *et al.,* 1998; Nyirenda *et al.*, 2010). It is estimated that 24% to 30% of the world's accessible freshwater resources (rivers, lakes and aquifers) are used to irrigate rice (IWMI, 2007). Worldwide, water scarcity is already a reality for as many as 2 billion people (IWMI, 2007). Water for agriculture is becoming increasingly scarce, and climate change-induced higher temperatures will increase crops' water requirements making the water shortages even more serious. By 2025, it is estimated that 15–20 million of the world's 79 million hectares of irrigated rice lowlands, which provide three-quarters of the world's rice supply, are expected to suffer some degree of water scarcity (IWMI, 2007). It is also estimated that to eliminate hunger and undernourishment for the world's population by 2025, the additional water requirements may be equivalent to all freshwater withdrawn used today for agricultural, industrial and domestic purposes (SIWI, 2005). In the face of growing water scarcity, the key challenges in irrigated areas are to use water more efficiently (WDR, 2008). Water-use efficiency and water productivity are two of the measures of on-farm water management (Mahoo *et al.*, 2007). As the global demand for rice increases, finding ways to grow more rice while preventing environmental degradation and increasing water productivity will be essential to helping ensure food security. One of such ways is the use of System of Rice Intensification (SRI) practices.

SRI developed during the 1980s by a French priest in Madagascar, Father Henri de Laulanie, who spent 20 years learning about rice-growing practices from local farmers (Uphoff, 2007). SRI is a methodology for increasing the productivity of irrigated rice cultivation by changing the management of plants, soil, water, and nutrients, while reducing external inputs. It has been raising yields by 50% to 100%, and sometimes more, with reduced requirements for water, seed, fertilizer, and crop protection. To date, the effects of SRI methodology have been empirically demonstrated in over 30 countries, including most of the rice-producing countries of Asia and many others in Africa and Latin America (Uphoff, 2007). SRI is reported to reduce the amount of water applied to the field by about 40–70% compared with the traditional practice of continuous flooding (Sato and Uphoff, 2007).

Unlike the conventional method of continuous flooding of paddy fields, SRI involves intermittent wetting and drying of paddies as well as specific soil and agronomic management practices. It is based on six principles: (i) transplanting single seedlings (ii) transplanting younger seedlings at the 2–leaf stage (8-12 days old) (iii) wide plant spacing of 25x25cm or wider, planted in lines (iv) minimum water applications during vegetative growth period, keeping soils moist but well-drained and aerated (v) frequent weeding with a simple mechanical hand weeder and (vi) application of organic matter, in preference to chemical fertilizer (Laulani'e, 1993). The combined increase in demand for food and scarcity of water in Tanzania and worldwide necessitates saving water and increasing its productivity of which SRI fits in.

1.2 Justification

With the changing climate, increasing variability of rainfall, growing competition for water, and increasing demand for food, SRI offers a new opportunity for increasing production value per drop of water and reducing agricultural water demand. Actually, farmers and rice scientists have tried many of the SRI elements in many other countries for their effectiveness over the past 50 years (Horie *et al.*, 2005). Although these practices cover important areas of rice crop management such as wider spacing, ponding levels, and alternate wetting and drying (AWD), they lack a combined study using different SRI components to assess SRI as a system. Results of SRI in many tropical and sub-tropical countries have shown significance of SRI methods in increasing grain yield and water savings.

While SRI practices sounds promising, few attempts have been made to evaluate the performance of SRI in Tanzania. In addition, principles of SRI need to be optimized to suit local conditions. Rather than a strict technique, SRI methods present a "menu" of different practices that farmers can adapt to suit local conditions and cropping systems. The Cornell International Institute for Food, Agriculture and Development (CIIFAD, 2010) emphasizes that SRI is a system rather than a technology because it is not a fixed set of practices. The current study, therefore, was undertaken to investigate different SRI components and come out with optimal components for yield, water saving and water productivity that can be adopted for Mkindo smallholder farmers in Mvomero District, Morogoro Region in Tanzania.

1.3 Objectives

1.3.1 Overall objective

The overall objective of this study was to evaluate the performance of the SRI in reducing water use and increasing rice yield as an adaptation strategy to climate change and variability by smallholder rice farmers in Tanzania.

1.3.2 Specific objectives

The specific objectives were to:

i) Assess the SRI components of transplanting age, spacing, and irrigation schedule that will produce maximum productive tillers of paddy rice in Mkindo area, Tanzania.

ii) Evaluate growth and yield parameters, water saving, and water productivity of the SRI against conventional rice growing practices in Mkindo area, Tanzania.

iii) Demonstrate SRI practices through FFS, evaluating the acceptability and its adoption in Mkindo area.

1.4 Research Questions

(i) Producing more food with less water is a challenge to irrigated agriculture due to Climate change and variability.

(ii) In the coming 30 years, 80% of additional food supply needed to serve the growing world population will depend on irrigated land.

(iii) New technologies and practices such as System of Rice Intensification (SRI) are needed to produce more food with less water.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Climate Change and Variability

2.1.1 Preamble

The earth's atmosphere has never been free of change. Its composition, temperature, and self-cleansing ability have all been varying since the planet was first formed. Yet, the changing pace in the past two centuries has been remarkable; the atmosphere's composition in particular, has changed significantly faster than it has at any time in human history. The world is warming; climatic zones are shifting; glaciers are melting; and the sea level is rising. These are not hypothetical events. These changes and others are already taking place, and we expect them to accelerate over the next years to come (Kihupi, 2009). Climate change is any long-term change in the patterns of average weather of a specific region or the earth as a whole. Climate change reflects abnormal variations to the earth's climate and subsequent effects on other parts of the earth, such as in the ice caps over durations ranging from decades to million years (Kihupi, 2009). Climate variability, which includes erratic and unpredictable seasonal rainfall, floods, and cyclones, contributes to the risk of rainfed farming across most of tropical countries.

2.1.2 Climate change factors

Climate change is the result of many factors including the dynamic processes of the earth itself, external forces including variations in sunlight intensity (natural factors) and more recently human activities (anthropogenic activities). Various hypotheses for human-induced climate change have been argued for many years and currently, the scientific debate has moved on from scepticism to a scientific consensus on causes of climate change. It is now agreed that human activity is the probable cause for the rapid changes in world climate in the past several decades (IPCC, 2007a). Of most concern in these anthropogenic factors is the increase in CO_2 levels due to emissions from fossil fuel combustion, methane, nitrous oxide and chloro-fluorocarbons (CFCs). Certain naturally occurring gases, such as carbon dioxide (CO_2) and water vapour (H_2O), trap heat in the atmosphere causing a greenhouse effect. Burning of fossil fuels like oil, coal, and natural gas also add CO_2 to the atmosphere. The current level of CO_2 in the atmosphere is the highest in the past 650 000 years (IPCC, 2007b).

It has been concluded (IPCC, 2007a) that most of the observed increase in the globally averaged temperature since the mid-20th century (Fig. 1) is very likely due to the increased anthropogenic greenhouse gas concentrations (IPCC, 2007) .The sun rays hit the earth, but when they are reflected back out into space, they are trapped in the atmosphere due to such gases.

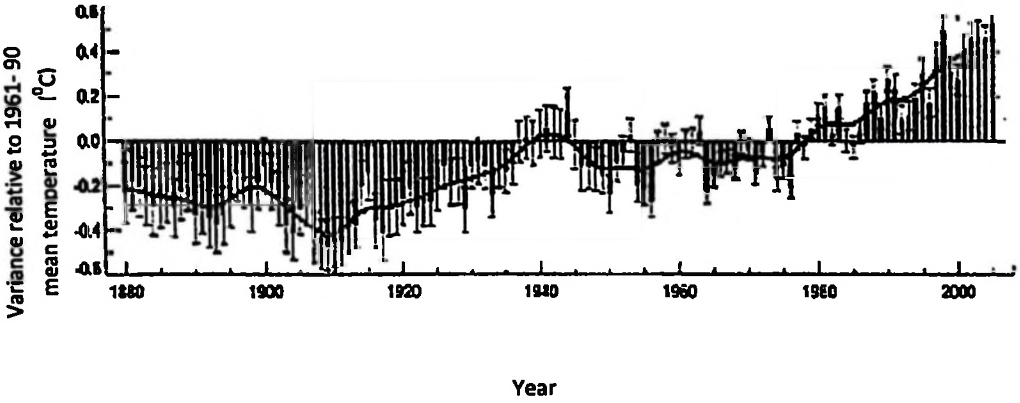

Figure 1: Line plot for mean land-ocean temperature index, 1880 to present

Source: Kihupi (2009)

2.1.3 Climate change adaptation and mitigation

Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. In contrast, climate change mitigation is any action taken to permanently eliminate or reduce the long-term risk and hazards of climate change to human life and property. The International Panel on Climate Change (IPCC) defines mitigation as: “an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases”. In simple words, mitigation is tackling the causes of climate change whereas adaptation is tackling its effect.

The world's primary international agreement on climate change mitigating strategy was the Kyoto protocol, an international agreement linked to the United Nations Framework Convention on Climate Change negotiated in 1997 (UNFCCC, 2008). The Kyoto protocol is a legally binding agreement under which industrialized countries were required to reduce their collective emissions of greenhouse gases (GHG) by 5.2% compared to the year 1990. Projects that are based on land use like land-use change and forestry (LULUCF) activities were considered to be important means of mitigating greenhouse gas emissions. On the other end adaptation measures include water conservation (Boland, 1997), changes to agricultural practices (Ngigi, 2009), construction of flood defences (Nicholls, 2004) and rain water harvesting.

2.1.4 Climate change and water resources for agriculture

In terms of fresh water resources, annual run-off and water availability are projected to increase by 10-40 % at high latitudes but to decrease by 10-30 % over some dry regions at mid-latitudes and in the dry tropics (Falkenmark, 2007). This means that drought-affected areas will likely increase in extent. Agricultural production is projected to be severely compromised in many regions by these trends (UNFCC, 2008). Agriculture accounts for more than 70 % of global water use (FAO 2008, WB, 2006). According to projections, there will be increasing challenges in terms of increased water stress and areas suitable for agriculture along the margins of semi-arid and arid areas are expected to decrease significantly (Falkenmark, 2007).

By mid century, it is projected (IPCC, 2007b) that:

(i) annual average river runoff and water availability will increase by 10-40 percent at high latitudes and in some wet tropical areas, and decrease by 10-30 percent over some dry regions at mid-latitudes and in the dry tropics i.e. dry regions will get drier, and wet regions will get wetter.

(ii) drought-affected areas will become larger and

(iii) Heavy precipitation events will very likely to become more common and increase flood risks.

All these have implications on agricultural production, especially in drier regions where water for irrigation may be an issue and risks of land degradation from erosion and flooding are a real threat. Changes in the length of growing season can result from changes in rainfall patterns. For example, it has been observed from parts of Tanzania that rains are progressively starting later and ending earlier than before, resulting in a shorter growing season (Fig. 2 and 3). Longer dry spells also seem to be increasing with time for some areas reducing the reliability of a growing season (Kihupi, 2009). Climate exacerbates existing environmental challenges for example declining water resources and thus increases urgency of managing natural resources in a suitable and sustainable manner.

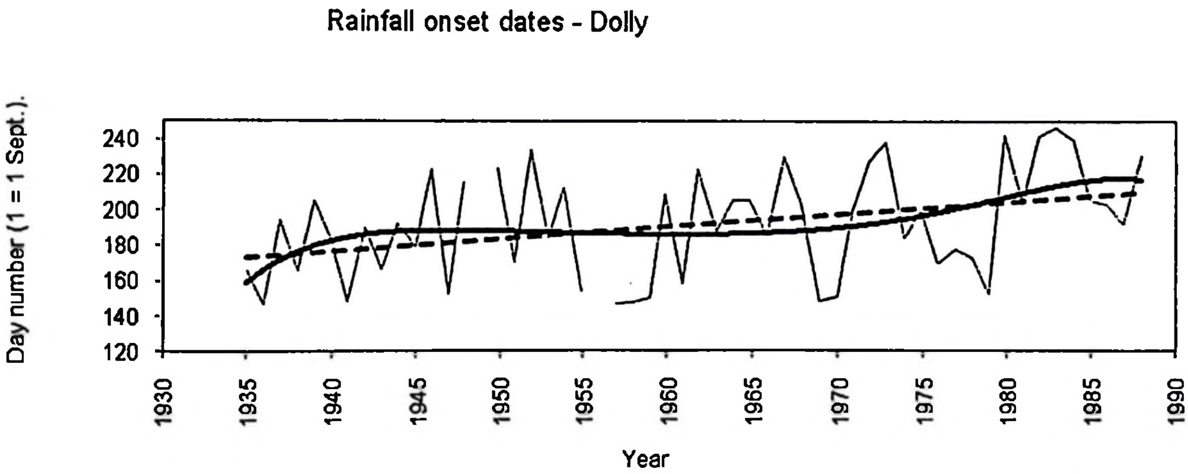

Figure 2: Trend of rainfall onset dates for Dolly Estate in northern Tanzania

Source: Kihupi (2009)

Legend

dotted line	*= linear trend,*
bold line	*= polynomial trend*

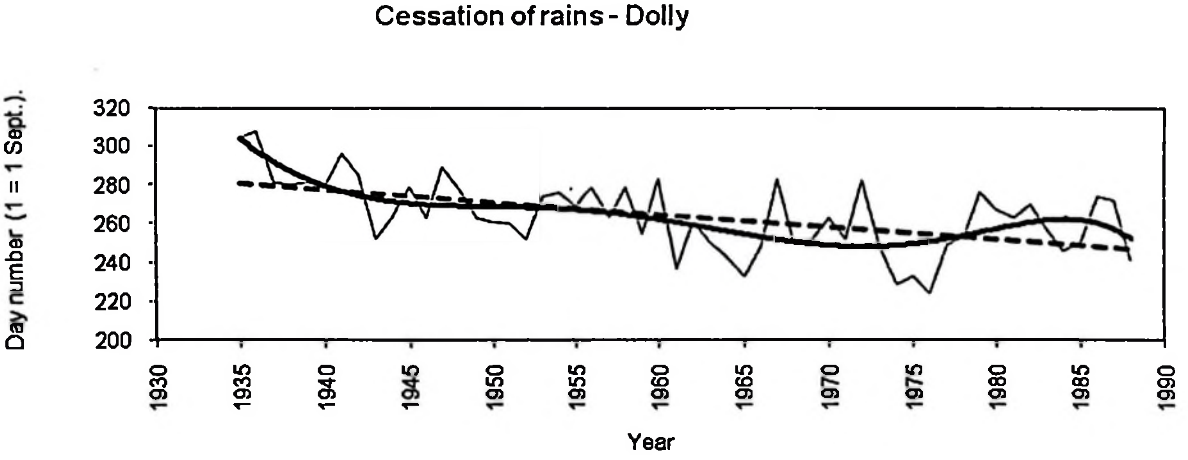

Figure 3: Trend of rainfall cessation dates for Dolly Estate in northern Tanzania

Source: Kihupi (2009)

Legend

dotted line	*= linear trend,*
bold line	*= polynomial trend*

2.1.5 Water productivity

Water productivity (WP), in general can be defined as crop yield per cubic meter of water consumption (Cai and Rosegrant, 2003). Depending on the type of water flows considered, water productivity can be defined as grain yield per unit water evapotranspired (WP_{ET}) or grain yield per unit total irrigation water input (WP_{irr}). Water productivity can be improved by increasing the yield per unit of land area or adopting more efficient irrigation technologies. Thus water productivity, including other determinant factors, is useful in identifying water-saving opportunities of the system under consideration. The terms water-use efficiency and water productivity are used complementarily to assess the impact of water management strategies and practices used to produce more crops with less water. Irrigation water management (IWM) involves the managed allocation of water and related inputs in irrigated crop production so that economic returns are increased relative to available water (USDA, 1997). Farmers may reduce water use by applying less than full crop-consumption requirements (deficit irrigation), shifting to alternative crops or varieties of the same crop that use less water, or adopting more efficient irrigation technologies (USDA, 1997). Many irrigators have responded to water scarcity through the use of improved irrigation technologies – often in combination with other water-saving strategies. Liu and Yang (2009) reported that challenges of availability of irrigation water supply may be influenced by global climate change; although the impacts of climate change on irrigation water demand is still not well studied. At the field level, WP_{ET} values under typical lowland conditions range from 0.4 to 1.6 kg/ m^3 and WP_{irr} values range from 0.20 to 1.1 kg/m^3 (Tuong, 1999; Bouman and Tuong, 2001). The wide range of WP_{ET} reflects the large variation in rice yield as well as in evapo-transpiration caused by differences in environmental conditions under which rice is grown. Furthermore, it has been reported that the average WP in the developed world (0.47 kg/m^3) is higher than that for developing world of 0.39 kg/m^3 indicating the need for improving the WP (Cai and Rosegrand, 2003).

WP$_{irr}$ of rice is less than 50% of that of wheat. The relatively low WP$_{irr}$ of rice is largely due to the high unproductive outflows. A large increase in the productivity of irrigation water use with SRI can make water savings more attractive, compensating farmers well for the extra labor or expenditures involved. The returns to land, labor, capital, and water are all increased by the use of SRI practices (Uphoff and Randriamiharisoa, 2003).

2.2 Irrigated Rice Production in Tanzania

Rice (*Oryza sativa*) is one of the most important cereals grown by small scale and large scale farmers as food and cash crop in almost all regions of Tanzania. Tanzania is the second largest producer of rice in Eastern, Central, and Southern Africa after Madagascar (FAOSTAT, 2008). Rice is second to maize in terms of consumers' preferences. In Tanzania major rice production systems are lowland rainfed and irrigated and upland rainfed. Current average yield is estimated at 1.5-2.1 tons/ha, but yields as high as 5 tons/ha have been obtained in irrigated rice projects (Luzi-Kihupi and Zakayo, 2001). Production and productivity in most irrigation schemes is generally below expectations. For smallholder traditional rice cultivation, yields of 4.0 - 5.0 t/ha are being realized by some smallholder farmers in improved irrigation schemes (URT, 2009). The challenge is how to raise crop production with restricted resources of land and water, finance, agricultural inputs and support services (URT, 2009). It is a common cry in the world that water shortage is increasingly being recognized as a major constraint to improving the lives of the rural poor and is an important component of rural livelihood programs to be established in southern Africa (SWMRG, 2005). Extensive irrigation during the dry season dries up the rivers, thus disturbing ecosystems and wildlife. Rice being a crop having high water requirement, there is a need to search for alternative methods of reducing water requirement of rice without compromising yield. In recent years, with the introduction of new aerobic rice technology in rice cultivation, it has become possible to get reasonably good yields with two to three irrigations, thus resulting into saving of 30%-40% of water. System of Rice Intensification (SRI) is an emerging water saving technology, with several fold increase in crop yields (Laulanı'e, 1993).

2.3 System of Rice Intensification

System of rice intensification (SRI) is a package of practices especially developed to improve the productivity of rice with less water. Unlike the conventional method of continuous flooding of paddy fields, SRI involves intermittent wetting and drying of paddies as well as specific soil and agronomic management practices. The main features of this system as developed in Madagascar through the efforts of Fr. Henri de Laulaniè, are: transplanting of young seedlings at the 2-leaf age (approx 8-11 days), transplanting a single seedling in a square pattern, with wide spacing between plants (25x25 cm but even wider as soil quality improves), using organic rather than chemical fertilizers, hand weeding (preferably with a simple rotating hoe that aerates the soil as it removes weeds), and keeping the paddy soil moist but not flooded during the vegetative growth phase or adoption of intermittent irrigation (Uphoff, 2007; Stoop *et al.,* 2002). The practices under SRI are said to be innovative in nature because they differ from the conventional ways of growing paddy rice. By practicing SRI, rice farmers in countries where the system began noticed that their rice yields increased - some by 50%, some doubled, and even others tripled, while their water use for paddy rice reduced by half (Styger, 2008). Farmers in a number of countries have been able to increase the yields from their current rice varieties with available resources by utilizing SRI (Kabir and Uphoff, 2007; Namara *et al.,* 2008;

Sato and Uphoff, 2007; Sinha and Talati, 2007). The SRI is an innovation in rice a production system that is still evolving and a work in progress (Uphoff *et al.*, 2008).

2.4 Adoption of SRI in the East Africa Region

Among the East African countries, Rwanda was the first country to introduce SRI in 2006. Knowledge of SRI was brought to Rwandan farmers by Malagasy experts working for Association Tefy Saina (NGO) under IFAD project "Support Project for the Strategic Transformation of Agriculture" (PAPSTA) in 2006. Fifty rice farmers and technicians were trained in SRI methods (Reiner, 2009). IFAD supervision team visiting Rwanda in 2008 found that in two project-supported marshland areas there was a wide application of SRI that increased rice yields from 4 t/ha to 6 t/ha in Kibaza and to 7 t/ha in Rwabutazi. The total number of rice farmers in both marshlands together increased 2000 by the end of 2008 (Reiner, 2009).

In Kenya, initiative to introduce SRI commenced in July 2009, through the efforts of diverse partners that included the Jomo Kenyatta University of Agriculture and Technology (JKUAT), the National Irrigation Board (NIB), the African Institute for Capacity and Development (AICAD), Mwea Irrigation Agricultural Development Centre (MIAD), Improved Management of Agricultural Water in Eastern and Southern Africa (IMAWESA) , the Ministry of Water and Irrigation, the Ministry of Agriculture, private consultants, the World Bank office in Nairobi, the World Bank Institute (WBI) in Washington DC and the Central Kenya Dry Areas Project. The initiative started with three main activities: (i) scientific research on SRI, (ii) concurrent trials implemented by volunteer farmers within the Mwea Irrigation scheme and (iii) capacity building and outreach activities for farmers. In addition, training manuals on SRI have been developed, one in English and the other in Kiswahili, and distributed to farmers (Mati and Nyamai, 2009).

Exciting results were reported from the two farmer trials, indicating an increase in paddy yield by the range of 84 to 100%. During the main rice-growing season beginning August 2010, over 100 farmers had planted their rice by SRI method, and the number has steadily been increasing. It is reported that by the 2011 season, over 200 farmers were applying the SRI method in Mwea (Mati *et al.*, 2011).

In Tanzania, SRI methodology has not been reported to be practiced extensively. Norfund and its co-investors Agrica Ltd have redeveloped an obsolete 5000 ha rice farm in the Kilombero Valley. The investment represents the Norfund continuous focus on the development of sustainable agribusiness in the least developed countries in Eastern Africa. In 2010, the company launched a transformative smallholder programme, introducing the System for Rice Intensification to Kilombero farm. The SRI project, which has shown the potential locally to double traditional rice yield, is expected to be expanded to 5000 farmers by 2016 under this programme (Norfund, 2010).

2.5 The Conventional Rice Farming System

From time immemorial, rice has been grown in lowland areas under flooded conditions. The actual amount of water used by farmers for land preparation and during the crop growth period is much higher than the actual field requirement. Farmers often store water in their fields as a back-up safety measure against unreliability in water supply and to suppress weeds. Conventional rice farming involves the use of mature seedlings (>21 days) planted in a clump of 3-5 seedlings per hole, spacing grid of 20 x 20 cm; provided with a continuous irrigation up to 5–7 cm ponding throughout the cropping season. During land preparation, the plots are ploughed, and then flooded for two weeks. Water is then removed and paddling is done ready for transplanting. Fertilization is done mostly using industrial fertilizers depending on preference of the locality. In Mkindo area for example in most cases urea fertilizer is used. Hand weeding is done after draining water from the field 14-20 days after transplanting and repeated around 30-40 days after transplanting. Manual weeding by hand-pulling the weeds is also commonly used, especially by lowland paddy rice growers.

2.6 Rice as a Water Tolerant, Not Aquatic Plant

With rice *(Oryzae sativa L.)* having been grown over centuries under submerged conditions, there is a general belief that rice plants grow better under saturated conditions. Although it can *survive* when its roots are continuously submerged under water, it does not *thrive* in this situation. Rice is a unique crop in that it is adapted to a wide range of climate, soil, and water conditions. It is usually grown under shallow flooding or wet paddy conditions, but it is also cultivated where water may be several meters deep and, in the extreme it can be grown as an upland crop. Although rice appears to have high water requirements, it is not much different from that of other field crops. The water requirements of rice for evapo-transpiration are between 450 and 700 mm depending on climate and length of growing period, as compared to cotton (700-1300mm), sugar cane (1500-2500 mm), and maize (500-850 mm) (Doorenbos and Kassam, 1979). It is evident that rice can be grown under un-flooded conditions and can even be irrigated like any other upland cereal to obtain good yields.

Rice plant does not grow well in standing water compared to when its roots are able to get oxygen from direct contact with air in non saturated soil. Under submerged conditions, some of the roots' cortex disintegrates to form air pockets (aerenchyma) so that oxygen can reach root tissues. But this is not the most efficient way to sustain the roots, and under flooded conditions, up to 75% of roots may die by the time of flowering (panicle initiation). SRI experience tells that the development of aerenchyma is an indication that the plant is unable to survive under flooded conditions (Kabir and Uphoff, 2007). Rice crop when grown under well-oxygenated soil conditions produce vigorous root systems and require 5 to 10 times much force that is required to uproot a similar plant grown under submerged conditions. Profuse growth allows the roots to spread to larger areas to be able to absorb more nutrients compared to one grown under flooded conditions. The grain yield decreases as the water depth increase when the rice crop is grown in submerged conditions. This could be due to impaired tillerig and decreased photosynthetic leaf surface (Matshushima, 1967). Photosynthetic potential yield depends on proper combination of good rice variety, solar radiation, agronomic practices and plant protection. The highest potential yield for rice recorded in winter was 9.5 t/ha while in dry season was 15 t/ha under AWD (IRR1, 1982).

2.7 The Yields under SRI

The effects of reduced irrigation, wider spacing, transplanting age, and number of transplanted seedlings on vegetative and yield-contributing traits have been reported by a number of researchers. Krishna *et al.* (2008), Vijayakumar *et al.* (2001) and Udyakumar (2005) reported an enhanced tillering, early flowering, better yields and grain quality in SRI plots as compared to traditional methods. Rainfed rice yields averaged 7 ton/ha in carefully controlled trials in the Philippines and are now averaging this level for tens of thousands of poor farmers in India. A rice yield of 8.06 t/ha was recorded in the treatment with younger seedlings (14 days old) transplanted singly at wider spacing (30 x 30 cm) under non-flooded conditions. It is also reported an increased conversion of tillers into productive tillers/flowering panicles with the adoption of SRI management

(Gani *et al.,* 2002). The reason for superiority in these yield attributes of rice and consequently increased yield could be due to good root aeration, efficient utilization of resources, and less inter- and intra-space competition under SRI management (Gani *et al.,* 2002). Senthilkumar (2002) reported that younger seedlings were observed to have an increased leaf area and subsequent increase in photosynthetic activity and thus biomass production. Increased biomass as a major portion of photosynthesis accounted for dry matter, and all these factors favored the yield components under SRI practices. Studies done in eastern Indonesia, showed paddy yields of 8.02 t/ha for SRI versus 4.19 t/ha for non-SRI methods, an increase of 91.4% (Sato and Uphoff, 2007). Related studies done in Timbuktu, Mali reported remarkable yield increase using SRI of up to 8.98 t/ha, more than double the regional average of irrigated rice yield of 4.03 t/ha (Styger, 2008).

2.8 Water Saving under SRI

Numerous studies conducted on the manipulation of depth and intervals of irrigation intended to save water have demonstrated that continuous submergence is not essential for obtaining high rice yields (Guerra *et al.,* 1998; Nyirenda *et al.*, 2010). About 40–45% of the water normally used in irrigating the rice crop in the dry season can be saved by applying water in small quantities, only enough to keep the soil saturated throughout the growing season, without sacrificing rice yield (Bhuiyan and Tuong, 1995). There is evidence that farmers in Asia who were confronted with high costs of water adopted SRI methodology. In China, where farmers were charged by the volume of water they use, various forms of alternate wetting and drying (AWD) and reduced floodwater depths have been widely adopted (Li *et al.*, 2009). Farmers in north-central India and in central Luzon, Philippines that operate pumps to irrigate their fields consciously applied some form of AWD to save pumping costs. Similar results were reported by Sato and Uphoff (2007) under SRI management in Eastern Indonesia. Similarly, Tabbal *et al.* (1992) and

Singh *et al.* (1996) have reported that maintaining a very thin water layer, at saturated soil condition, or alternate wetting and drying, can reduce water applied to the field by about 40–70% compared with the traditional practice of continuous shallow submergence, without a significant yield loss. Keisuke *et al.* (2007) also reported the reduction of irrigation water requirement for non-flooded rice by 20–50% compared to flooded rice, with the difference being strongly dependent on soil type, rainfall, and water management practices. According to Kassam *et al.* (2011), water reductions in other countries have reached as high as 78% under SRI (Table 1).

Table 1: Summary of reported irrigation water reduction with SRI management

Country	Irrigation water reduction (%)
China	26
Indonesia	40
India	52
Pakistan	70
Iraq	37
Mali	10
Panama	78

Source: Kassam *et al.* (2011)

2.9 Irrigation Water Management under SRI Practice

The recommended irrigation method for SRI is intermittent irrigation with a wet-dry cycle that does not maintain standing water (maximum depth of 2 cm). The length of the dry period for SRI paddy fields differs from location to location according to soil conditions such as permeability, water-holding capacity, plot size and shape, availability of irrigation water, and rainfall condition. The indicator for restarting irrigation delivery is the point of surface cracking of soil in the paddy fields, especially for clay or loamy soils. The importance of keeping the soil unsaturated to get more air to plant roots is evident.

But how long can a field be left without water? How dry can they become? What is the role of rainfall in providing water for the field? The differences in practice will be necessary with different kinds of soil and climate. Not much systematic research has yet been done on water management options and optimization within the framework of SRI management. The trials reported by Mishra and Uphoff (2011) showed the importance of maintaining sufficient water available in the soil for plants during their reproductive phase. Some SRI practitioners, however, have reported good results from extending alternate wetting and drying (AWD) throughout the whole crop cycle (Zhang and Yang, 2010). AWD has been commonly used as a water-saving practice in many parts of the world for more than a decade (Gani *et al.*, 2002). In the SRI, the soil is allowed to dry for a few days within irrigation events depending on plant developmental stages. Some successes have been reported as far as yield and water demands are concerned (Gani *et al.*, 2002). However, unproductive water losses could not be totally avoided by AWD. Hence, the water consumption is still high in AWD since the soils need to be submerged at least during the irrigation period.

2.10 Plant Growth Performance under SRI Practice

SRI method provides better root aeration, wider plant spacing, and less competition, which enables the plants to grow vigorously. SRI rice plants exhibit stronger root systems that grow deeper into the soil profile. Kabir and Uphoff (2007) reported that transplanting young seedlings carefully and at a wider spacing gave rice plants more time and space for tillering and root growth. Ceesay *et al.* (2006) reported that SRI plots had about five times greater root-length density, seven times more root volume, and ten times more root mass and length of roots in the surface soil profile. SRI practices produce stronger straw (tillers) and larger, deeper root systems that make rice plants less susceptible to being blown down or pushed over by storms. At greater root depth they can access deeper reserves of soil moisture (and nutrients) and this is particularly important given the increasing risk of rainfall variation during the growing season.

2.11 Challenges Associated with SRI

Management measures such as transplanting, handling, weeds and keeping soil moist (not saturated) are too complex, and it was thought more labour is needed with SRI. It is reported that, after the first year or two, the labour requirements with SRI decline as farmers learn the techniques and get comfortable and skilled , doing everything faster and more confidently. Many farmers by the 3rd or 4th year find SRI becoming labor-saving. In a survey of SRI farmers in Cambodia, 70% said that SRI requires less labour for them (Stoop *et al.*, 2002). There are always some start-up costs with new methods. Efforts are ongoing to develop labour-saving methods and equipment. Farmers in Cuba have designed a simple seeder that transplants younger seedling onto the surface of a prepared field at 40x40cm spacing. Saving labour time was considered worthwhile.

The main requirement for SRI success is a sufficient degree of water control, to be able to apply small amounts of water regularly and reliably, or to be able to flood the field and then drain it after a few days, being sure to be able to re-flood it after a few more days. In this case SRI requires a different irrigation schedule than conventional practice, which is difficult to implement within the predetermined irrigation schedules of a conventional irrigation (Styger, 2008).

When fields are not kept continuously flooded, weed growth becomes one of the major problems. Under conventional method and farmers use excess water to reduce labor requirements for weed control. Weeding can be quite labor demanding, but its timing is more flexible than in transplanting. So, weeding is a restriction to SRI adoption

(Satyanarayana *et al.*, 2007). Also it is reported that AWD irrigation method under SRI practice in salt-effected soils will aggravate salinity toxicity.

Cultural changes such as AWD may help improve grain production; however, these very same practices have also tended to make SRI more weed-prone and thus require more laborious weeding operations (Latif *et al.*, 2005). Although hand weeding is effective in controlling weeds, it is faced with high labor cost, labor scarcity during peak periods and sometimes unfavorable weather condition at weeding time. In most rice growing areas, increasing cost of labor and its scarcity during the critical period of crop-weed competition are the major reasons that rice farmers use hand weeding only as a supplement to mechanical weeding or to herbicides (Soe, 2010). It is reported by Soe (2010) that rotary weeding followed by hand weeding gave superior yield and high weed control efficiency. Planting in a square pattern allows farmers to weed their fields using rotary weeder in perpendicular directions, which achieves effective weed control (Soe, 2010).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

The study was conducted at Mkindo Farmer-Managed Irrigation Scheme located in Mvomero District in Morogoro region, Tanzania (Fig. 4). The district is located between latitudes 6^0 16' and 6^0 18' South and longitudes 37^0 32' and 37^0 36' East and its altitude ranges from 345 to 365 metres above mean sea level. Mkindo village is situated about 85 km North of Morogoro Municipality.

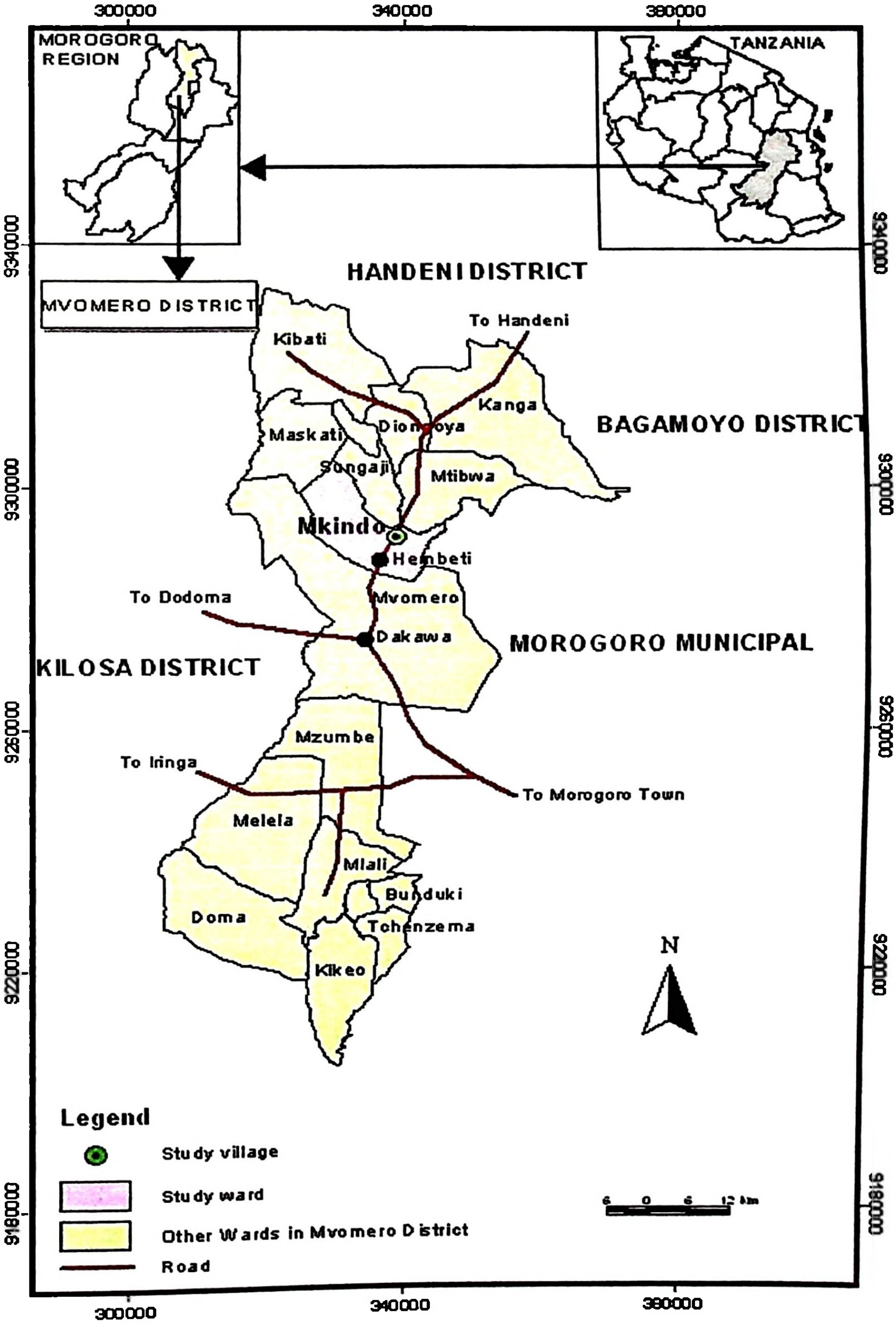

Figure 4: Location of Mkindo ward in Mvomero District, Morogoro Region.

3.1.2 Climate

The average annual temperature of Mkindo is 24.4°C with a minimum of 15.1°C in July and a maximum of 32.1°C in February. The mean relative humidity is 67.5%. The rainfall pattern is bimodal, characterized by two rainfall peaks with short rains from October to December (OND) and long rains from March to May (MAM). Table 2 shows a summary of mean monthly climatic parameters for Morogoro Region as obtained from FAO CLIMWAT (2006).

Table 2: Mean monthly climatic data of Morogoro Region for the period of 1971 – 2000

Month	Max. Temperature [°C]	Min. Temperature [°C]	Relative Humidity [%]	Wind Speed [km/ day]	Sunshine Hours [h/day]	Solar (Global) Radiation [MJ/m^2/ day]	ET0 (mm/day)	Precipitation (mm)
January	31.5	21	71.4	129.6	5.73	18.62	4.23	105
February	31.7	20.8	72.7	121	5.9	19.1	4.24	97
March	31.5	20.8	76.3	121	5.96	18.83	4.09	133
April	29.6	20.4	83	103	4.58	15.64	3.28	198
May	28.2	18.8	82.3	112.3	4.22	13.92	2.88	79
June	27.3	15.9	78	129.6	4.46	13.55	2.75	19
July	27.2	15	74.1	129.6	4.36	13.67	2.79	13
August	28.3	15.8	69.2	129.6	4.41	14.77	3.17	11
September	29.8	16.6	66.9	155.5	4.89	16.61	3.75	20
October	31.2	18	65.1	190.1	5.77	18.63	4.42	43
November	31.8	19.5	67.8	172.8	6.14	19.23	4.48	98
December	31.8	21	69.2	172.8	5.74	18.46	4.43	119

Source: FAO CLIMWAT (2006)

3.2 Soils

The soil textural class at the research area as obtained from laboratory test results done at Soil Science laboratory – SUA was predominantly clay loam (Appendix 9). It is composed of sand 44%, clay 37%, and silt 19%. The mean soil field capacity (FC) was 35.1%, permanent wilting point of was 23% and saturation point was 45.5% by volume. The recorded infiltration rate was 12 cm/day or 0.5 cm/hour. The average bulk density was 1.4 g/cm^3.

3.3 Methods

3.3.1 Experimental design

The experiments were laid out in a randomised complete block design (RCBD) with three replications. The treatments were: i) transplanting using 21 days (conventional) and14 days (SRI) old rice seedlings (SRI); ii) planting spacing at 20 × 20 cm, 25 × 25 cm, 30 × 30 cm, and 40 × 40cm; and iii) irrigation at 5.0 cm depth (conventional) and 2.0 cm depth on development of hair-line crack (SRI). The experiments were conducted for two seasons, wet season between March and July, 2011 and for dry season between September, 2011 and January 2012.

The following factors were considered: irrigation method, age of transplanting, spacing, and number of seedling per hill. The treatments were selected based on different SRI components already tested in other counties while conventional rice growing practices of Mkindo area was taken as a control. There were two sites, on station experimentation and concurrent set of on farm trials that acted as farmer's field school (FFS). The treatment combinations were as shown in Table 3 and the layout is shown in Fig. 5 and Plate 1.

Table 3: Treatment details

Treatment	Cultivation practice	Irrigation method	Transplanting age (days)	Seedling /hill (nos)	Spacing (cm)
T1	Conventional	flooding	21	3	20 x 20
T2	Conventional	AWD	21	3	20 x 20
T3	SRI	AWD	13	1	25 × 25
T4	SRI	AWD	13	1	30 × 30
T5	SRI	AWD	13	1	40 × 40

AWD = Alternate Wetting and Drying

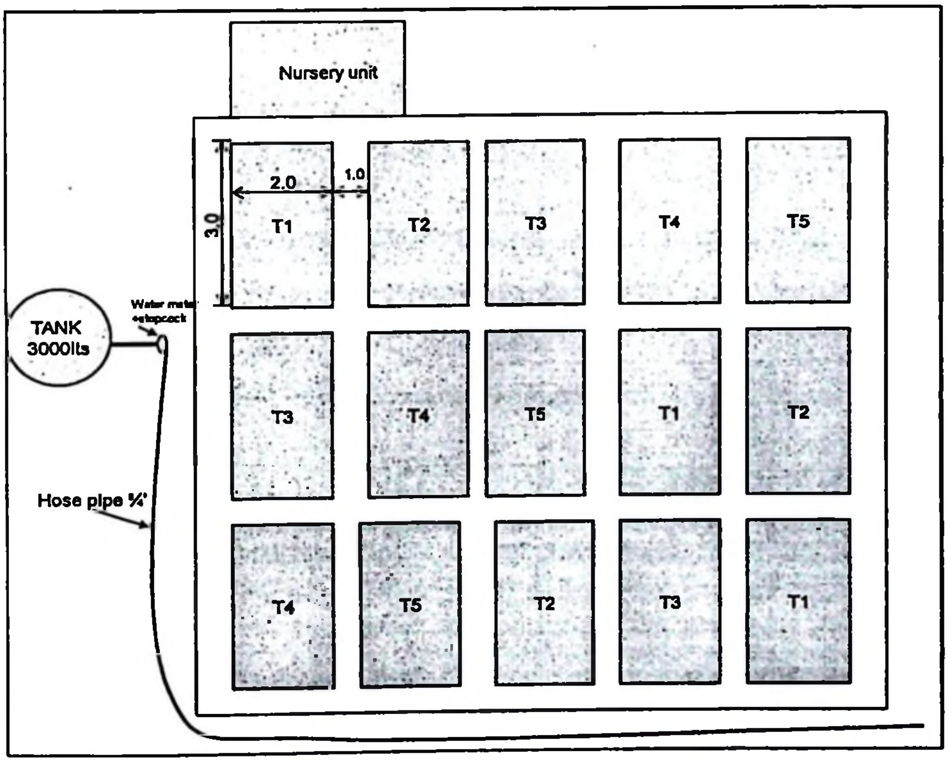

Figure 5: Experimental layout

Plate 1: Treatment layout –On station site

3.3.2 Agronomic practices

Soils for experimental plots were well worked and well-levelled to produce a good seed bed. Correct levelling helped to achieve uniform wetting of the soil through irrigation with a minimum application of water. Adequate drainage channels were maintained for proper water control. Saro (TXD 306) rice variety was chosen as it was well-suited to local conditions of Mkindo. Only the best seed, with good density and formation were used. Light and inferior seeds were separated and discarded by submerging the seed in a container of water with enough salt dissolved in it to make a salt solution in which an egg will float. Then the seeds were soaked in water for 48 hours (seed priming). The practice of soaking seed before planting enhances the rate of germination and seedling emergence.

Seedlings for transplanting were grown in an un-flooded, garden-like nursery, watered by a watering can, with a fairly low seeding rate to avail the seedling roots plenty of room to grow. Taking seedlings out of the nursery for transplanting was done very carefully. The seedlings were lifted with a trowel to ensure the seed sac remained attached to the root.

Soil was not knocked off from the roots. Seedlings were transplanted quickly after being removed from the nursery and they were placed in the shallow soil of depth of 1-2 cm deep. The sowing dates for wet and dry season were 15th March 2011 and 29th September 2011, respectively. Urea fertilizer was applied 14 and 60 days after transplanting at the rate of 50 kg/ha. Liquid fertilizer Byfolan was also sprayed 70 and 90 days after transplanting (DAT).

3.4 Data Collection

3.4.1 Soil moisture data

The HH2 Soil Moisture Meter Version 2.3 and tension meters were used to monitor the volumetric moisture content of the soil. The Moisture Meter type HH2 used was a versatile readout unit that reads instantly soil moisture from the ThetaProbe. Tensiometers were used to get estimates of the soil matric potential in each plot and then transformed to volumetric moisture content by using moisture release curve developed prior to experiment on site. The matric potentials at the development of hair-line cracks of the soil were monitored.

3.4.2 Water table depth

The ground water level was measured using a pvc standpipe 12.5mm (½ inch) diameter consisting of an open-ended tube. The piezometer pipe was then perforated near the base by punching holes in the lower 30 cm of PVC pipe and wrapped with two layers of geo-fabric to cover the holes. The geo- fabric was fixed by adhesive tape then a wooden cap over was fixed at the end. The pipe was inserted in a borehole drilled by using hand auger at depth of 1.5 m. The process of installation followed that outlined by USGS (2008). Water level readings were taken at a site relative to an arbitrary benchmark. For this case, top of the piezometer casing was taken as arbitrary level and all top of piezometers were set on the same level. Measurements of water level in the standpipe were made by lowering a flexible 5 mm horse pipe which acted as a dip stick. The head difference (*h)* between the water level in the piezometer and the ground surface level was measured by a graduated dipstick.

3.4.3 Crop and yield parameters

Growth and yield parameters were taken at regular intervals. Several key parameters like plant height, number of tillers per plant (and per m^2), days to flowering and maturity, and grain and straw yield were used to assess the treatment effects on crop growth and performance. The tillers per hill were taken from a random sample of 10 plants/hills for each plot. The average value of 10 plants/hills was taken as number of tillers per hill for each treatment.

3.4.4 Above ground biomass

The above ground biomass was taken during harvest time. For determination of aboveground biomass, plants from a 1 x 1m quadrants. The flux collars were cut at ground level and the samples were oven dried for 48 hrs to attain constant weight at 70°C. The dry mass of each sample was obtained by weighing with a digital scale balance with accuracy of 5g. The total biomass was divided into leaves, stems and grain yield (after harvesting). A comparative analysis was done to observe if there existed any significant difference in biomass production among different treatments.

3.4.5 Irrigation management

Irrigation management was a prominent feature of the experiment. Treatments T2, T3, T4, and T5 plots were designed for intermittent irrigation (1–2 cm) with alternate wetting and drying periods, whereas T1 (control) was continuously flooded (up to 5–cm depth) throughout the rice-growing season. Continuous flooding is the irrigation method commonly used by conventional rice growers in Mkindo area. In determining the irrigation schedule, major emphasis was laid on the wet-dry cycle. Usually wet-dry cycle differs by location, reflecting differences in soil type, shape and size of plot, rainfall pattern, temperature and availability of irrigation water. For SRI practice, the importance of keeping the soil unsaturated to get more air to plant roots is evident. But how long can a field be left without water? How dry can they become? What is the role of rainfall in providing water for the paddy field? The difference in practice was necessary with different kinds of soil and climate. The indicator for restarting irrigation delivery was after development of hairline cracks appearing on the soil surface of paddy fields. This method was used to establish frequency of wetting and drying periods for SRI in Indonesia (Sato and Uphoff, 2007; Keisuke *et al.*, 2007). In addition, a tensiometer in conjunction with moisture release curve developed on site was used to measure and establish the soil moisture content at development hairline cracks on the soil.

3.4.6 Water saving and productivity

The quantity of water required to maintain appropriate water level in the treatment plots and control during each irrigation was noted and summed up to calculate the total amount of water applied to a plot throughout the cropping season. In all the treatment plots, the total amount of water used was quantified by using flow meter. Water saving percentage was calculated by using the following formula:

$$\text{Water saving (\%)} = \frac{\text{Water used in flooded plot} - \text{Water used in SRI plot}}{\text{Water used in flooded plot (control)}} \text{X100} \ldots\ldots\ldots\ldots(1)$$

Water productivity, defined as crop productivity per unit of water consumed, was calculated as:

$$WP = \frac{Y}{I_{rr}} \qquad (2)$$

Where WP = water productivity (kg/m^3)

Y = yield (kg/ha)

I_{rr} = irrigation water applied (m^3/ha)

3.4.7 Infiltration tests

Field infiltration tests were conducted in triplicates at representative points within the experimental plot. The double ring infiltrometer was used in which two concentric rings of diameters 28 cm for the inner ring and 53 cm for the outer ring were driven vertically into the soil surface to approximately 8 cm depth to prevent lateral movement of water. Both rings were filled with water to the depth of 15 cm to 20 cm recording the time and height of water in the inner cylinder using a floating scale in the stilling water. The levels of water were measured after 1, 5, 10, 20, 30, 45 minutes and thereafter each hour depending on the rate of infiltration until a steady state was reached. The levels were recorded before and after every refill. Water levels in the outer ring were maintained at the same level as the inner ring to control lateral movement of water. In each complete test three replications were made (ASTM, 2003).

3.4.8 Grain yield and harvest index

A quadrant of 1x1 m^2 was harvested in each plot for yield measurement. The grain was weighed fresh unhusked and a crop moisture meter was used to measure the moisture content of the grain at harvest. The grain moisture meter used was Dole 400 Moisture

Tester. The fresh weight was standardized by adjusting to 12.5% moisture content by calculating the equivalent mass at standard moisture using the Equation (3)

$$M_{std} = m\frac{100 - M\%}{100 - 12.5\%} \quad \ldots\ldots(3)$$

Where M_{std} = the grain mass (kg) at 12.5% moisture content

m = the measured mass of grain (kg) at harvest

M = moisture content wet basis at harvest

The harvest index was calculated as the ratio of standardized grain yield per unit area to the total dry aboveground biomass at harvest per unit area (ratio between grain yield and total biomass).

3.4.9 Maximum effective rooting depth (Zr)

Maximum effective rooting depth (Zr) was estimated by visual inspection of 1.0 m deep pits dug in the plots to expose the roots at maturity. Washing of the profile with water facilitated clarity in identifying the roots and the lowest level where roots of the rice crop could be observed was considered the maximum effective rooting depth. Measurements were taken by using a measuring tape.

3.4.10 Adoption of SRI

To raise awareness of SRI principle, village/community-level meetings for selected farmers and village and ward officials were conducted. Meetings and group discussions were organized with FFS members who started learning SRI practices in the first season from demonstration farm and trial plots done by the researcher. During the second season, farmers themselves started using SRI practice on FFS group field. Communication strategies involving video were used for raising wider awareness of SRI and for further scaling up program impacts. Farmers' own findings through FFS pilot and experiments and their messages were powerful in understanding the SRI practice and scaling up.

Plate 2: FFS members participating in observation of growth parameters under SRI practice

3.5 Data Analysis

The biomass, grain yield and harvest index, irrigation water use, tillering, plant height and 1000 grains weight data obtained in all the treatments were analyzed using Microsoft Excel and GenStat 13th Edition statistical software following data analysis procedures for agricultural research (Gomez and Gomez, 1984). Analysis of variance was run in which treatment means were separated using Duncun's Multiple Range Test to determine if there exist a significant difference among the treatments based on p-value of 0.05.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

41 Rainfall and Soil Properties of Mkindo

4.1.1 Rainfall during the experimental period

Rainfall that was recorded at Mkindo site indicated the peak rains during the month of December contrary to normal trend. The month of December 2011 received extraordinary high rainfall. The normal trend shows that rains start in October with peak rainfall in March. From March the rains start to decrease until cessation at the end of May. From mid June to early September during the study period 2011, Mkindo experienced no rains as shown in Figure 6. In comparison, there were some differences between the recorded rainfalls during the experiment to the values from CLIMWAT database. This is because the CLIMWAT database uses the average values of rainfall of more than 30 years while in the experiment the exact rainfall values were recorded using a raingauge for each rainfall event. The pattern was the same as the values were increasing from October to December with peak rainfall in April against December recorded on site. On average 2011 was wetter than the mean monthly precipitations for Morogoro. The annual precipitation in 2011 was 1076.7 mm, while the mean annual precipitation for Morogoro is 935mm.

The growing period for wet season which started on 15 March received moderate rainfall from day 1 to 60 days after seeding, while the remaining days received no rain. For the growing period during the dry season which started on 29th September rainfall events were recorded between 21-46, 71-88, 96-102, and 110-120 days after planting. Figure 7 shows higher rainfall events between 110-120 days after seeding. The dry season received more rains than wet season under this study period.

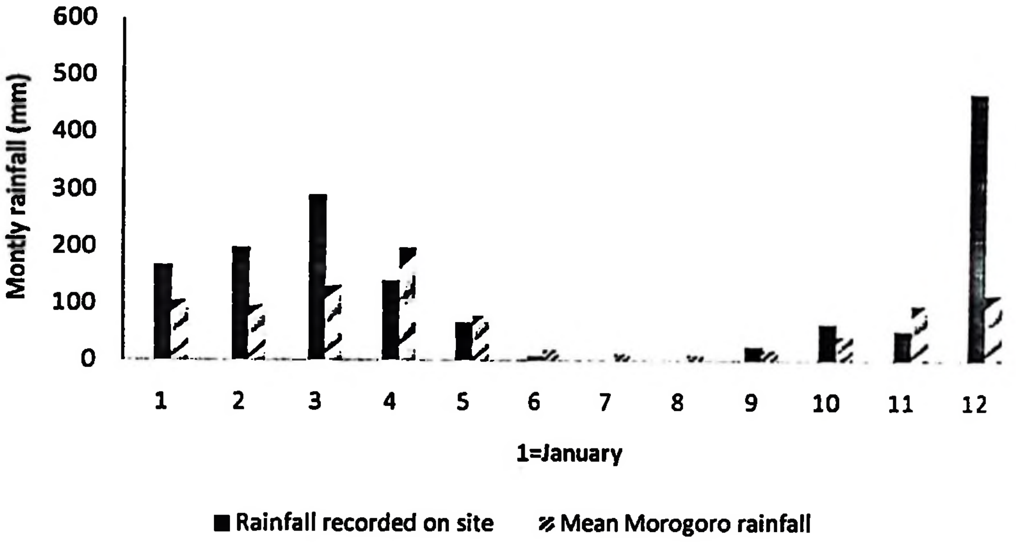

Figure 6: Site monthly rainfall in 2011 and mean monthly rainfall for Morogoro region

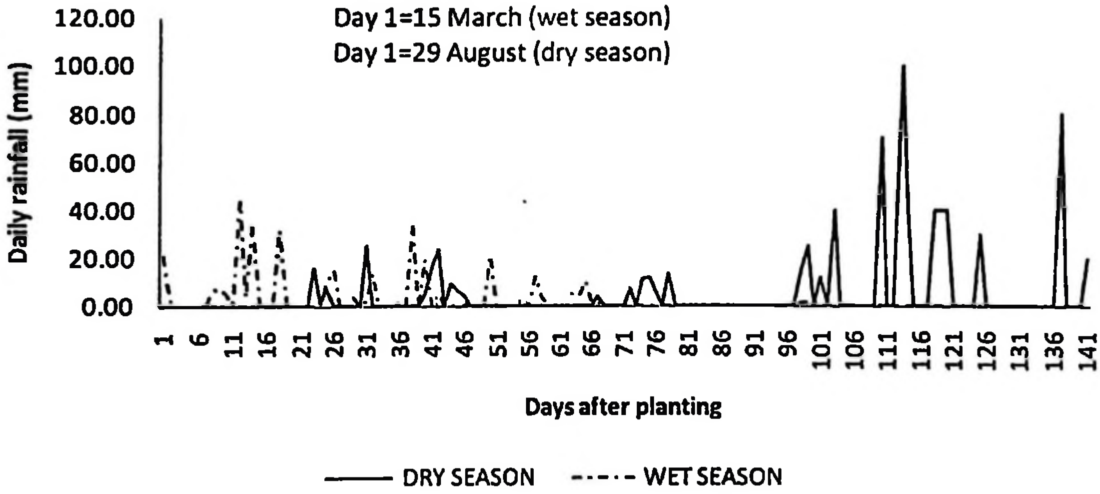

Figure 7: Observed rainfall trends during the two growing periods at Mkindo

4.1.2 Soil physical and chemical properties

The soil texture for Mkindo is clay loam with sand 44%, clay 37% and silt 19% with average bulk density of 1.4 g/cm^3. The mean soil field capacity (FC) 35.1% by volume, permanent wilting point is 23%, and saturation point 45.5% by volume. The infiltration rate recorded was 12 cm/day or 0.5 cm/hr. (Fig. 8). The Mkindo soils have also the following properties: ph - 6.2, K - 12.75 mg/kg, P - 0.532mg/kg and N (%) 1.00.

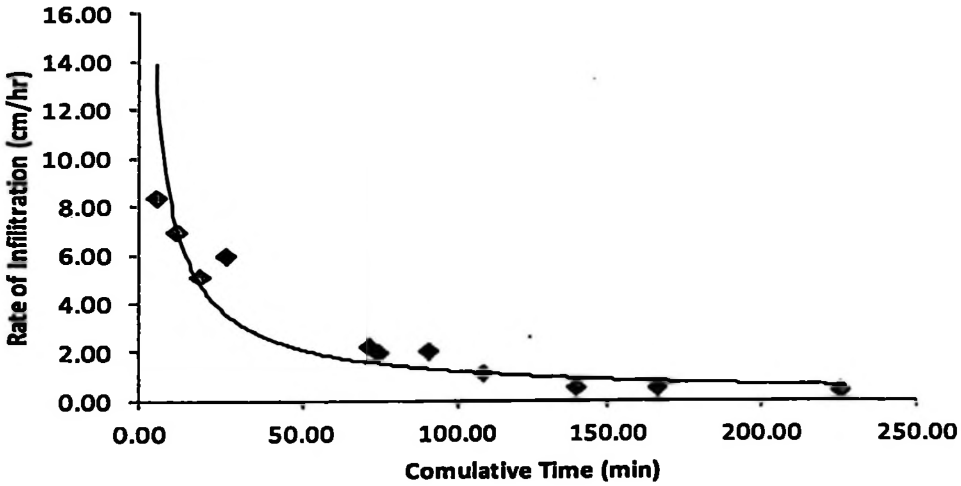

Figure 8: Soil infiltration capacity for Mkindo

4.1.3 Soil moisture characteristic curve

The on-site calibration that required matching water content determined by HH2 moisture meter over range of soil water contents with the readings of the tensiometer were done to develop the graph (Fig. 9) that indicates the relationship values of tensiometer readings in relative to readings obtained using HH2 moisture meter. The Moisture Meter type HH2 was a versatile readout unit that reads instantly soil moisture from the ThetaProbe.

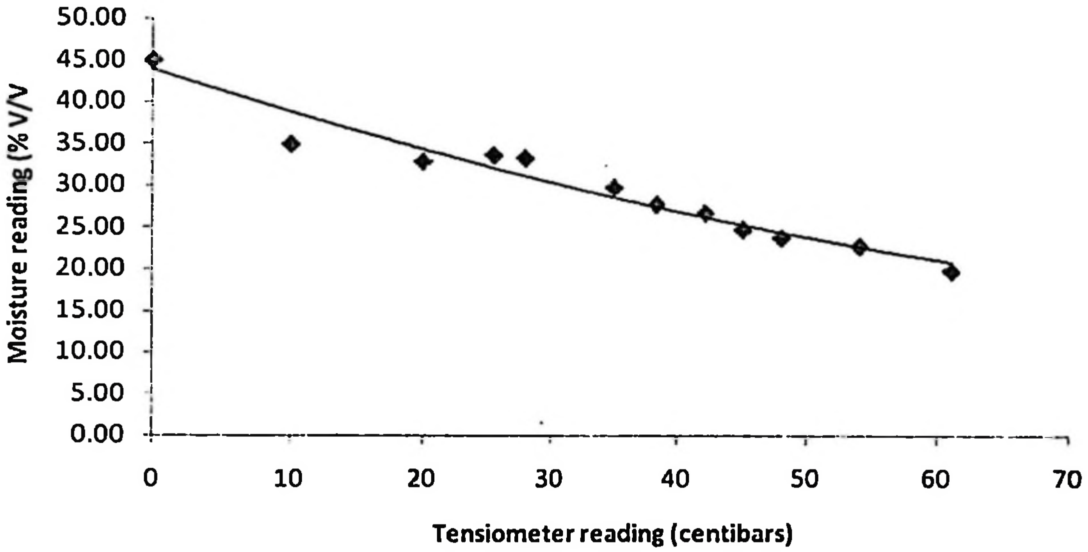

Figure 9: Relation between relative water content and soil water potential for Mkindo

4.2 Plant Growth Parameters

4.2.1 Mean number of tillers per hill

Wider planting spacing of 40 x 40 cm appeared to improve the number of tillers per hill compared to rest. A statistical comparison of the number of tillers per hill among treatments showed that there were significant differences at P = 0.05 (Fig. 10 and Table 4). The mean ranking based on the Duncan Multiple Range Test showed that the number tillers per hill for T1 was significantly different from that of the rest of treatments, but the two treatments T2 and T3 were not significantly different from each other. Significantly higher number of tillers per hill (43.83 tillers per hill, mean for wet and dry season) was recorded under SRI practice in wider spacing of 40x40). cm .There were differences among the seasonal tillering performance where dry season realized more tillering (50.9 tillers per hill) compared to wet season (36.8 tillers per hill) for T5. Planting in square pattern with wider spacing could have resulted in profuse tillering under SRI cultivation, due to better utilization of the resources like light and soil nutrients and water (Gaini *et al*., 2002).

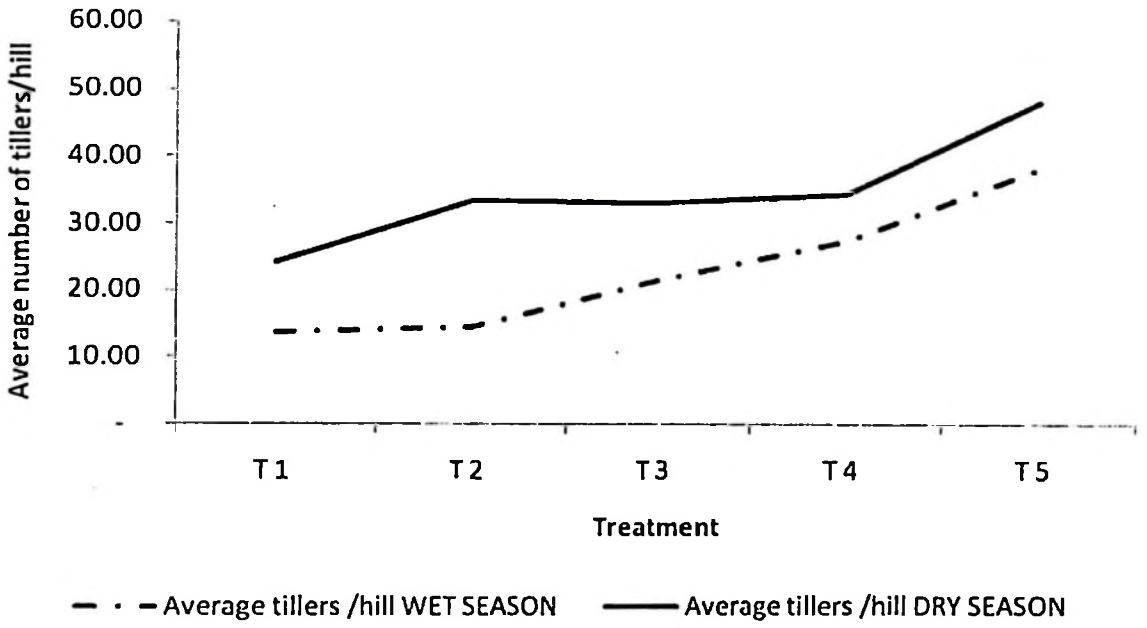

Figure 10: Average number of tillers per hill at flowering stage

Table 4: Mean plant performance parameters

Treatment	Tillers / m^2 (no)	Max number Tillers / hill (no)	Average number tillers /hill (no)	Average Height (cm)
T1	478.8 bc	24.5 a	19.15 a	77.18 b
T2	604.4 c	32.83 ab	24.21 ab	64.22 a
T3	441.3 abc	36.83 b	27.58 ab	77.69 b
T4	382.9 ab	41.33 b	31.42 b	79.76 b
T5	275.6 a	56.17 c	43.83 c	76.83 b

Different letters within column indicate significant difference at $P<0.05$

4.2.2 Maximum number of tillers per hill

Treatment T5 (spacing of 40 x 40 cm, intermittent irrigation and younger seedling planted singly) recoded significantly higher number of tillers per hill (56.7) compared to T1 (24.5 tillers per hill) for the two seasons. The maximum number of tillers per hill from T3 and T4 were not significantly different (Table 4). For both seasons there was an increasing trend of number of tillers per hill as wider planting space was applied (Fig. 11).

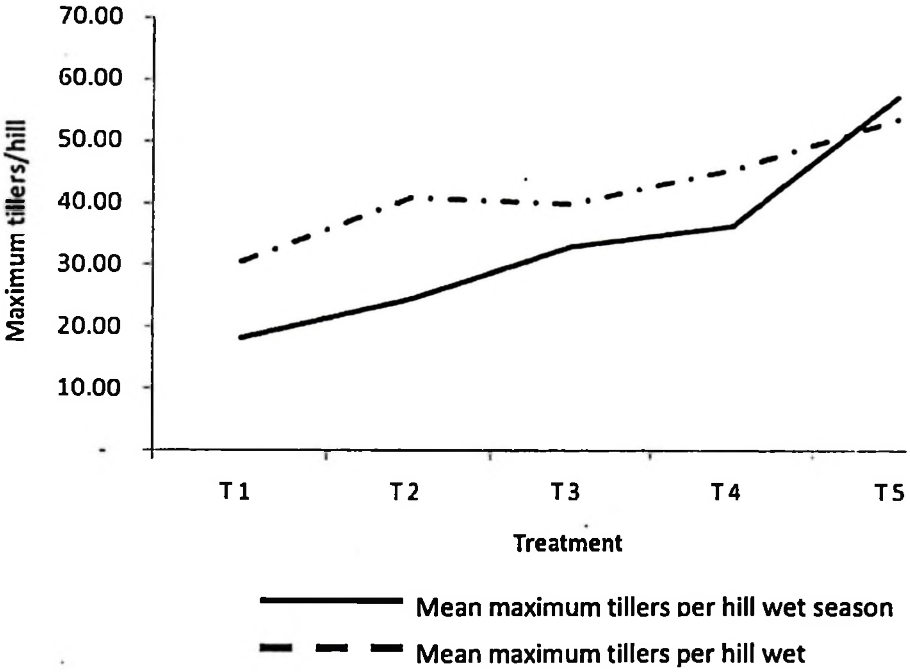

Figure 11: Mean maximum number of tillers per hill at flowering stage for dry and wet season

4.2.3 Number of tillers per unit area

The average number of tillers per unit area showed a decreasing trend as plant spacing was increased. Fig. 12 indicates that there were fewer tillers per unit area for T5 (average number of 275.6 tillers/m^2) although the number of tillers per hill for the same plant spacing was higher. Wider spacing (T5) recorded the lowest number of tillers/m^2 due to less plant population despite improved tillering. A statistical comparison (P = 0.05) based on the Duncan Multiple Range Test showed that the number of tillers per unit area of the reference treatment T1 was statistically different from all other treatment T2,T3, T4 and T5 but the significantly different from the among each other (Table 4).

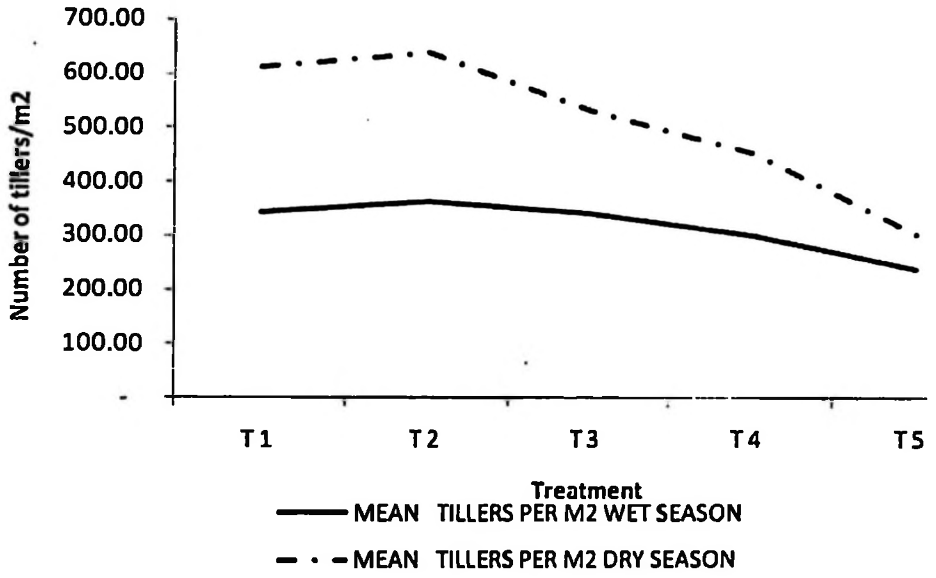

Figure 12: Average number of tillers per unit area at flowering stage under different treatment for wet and dry season

4.2.4 Productive tillers per unit area

Treatment T2 showed maximum total tillering per unit area among all treatments, but with less percentage of productive tillers. Productive tillers are tillers which had more than three leaves at the jointing stage and produce a panicle whereas unproductive had less than three leaves at the jointing stage and could not produce a panicle. The percentage of productive tillers increased with wider plant spacing. Treatments T3, T4 and T5 had productive tillers approaching the number of available tillers. For Mkindo, these results revealed that SRI procedure under treatment T3 and T4 were found to give higher percentage of productive tillers i.e. 92% and 94% (Fig. 13).

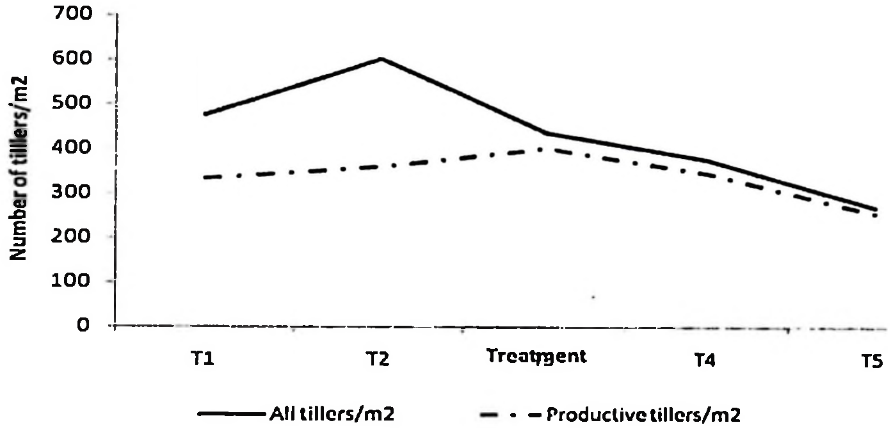

Figure 13: Number of productive tillers/m^2 and total number oftillers/m^2 for different treatments

4.2.5 Plant height

As more water stress was imposed to T2 (closer spacing 20x20 cm, older seedling planted in clump of three, and AWD irrigation) reduction in plant height was found to be greater than conventional and SRI practice. Statistically, no significant differences were observed for treatments T1, T3, T4 and T5 (Table 4 and Fig.14).

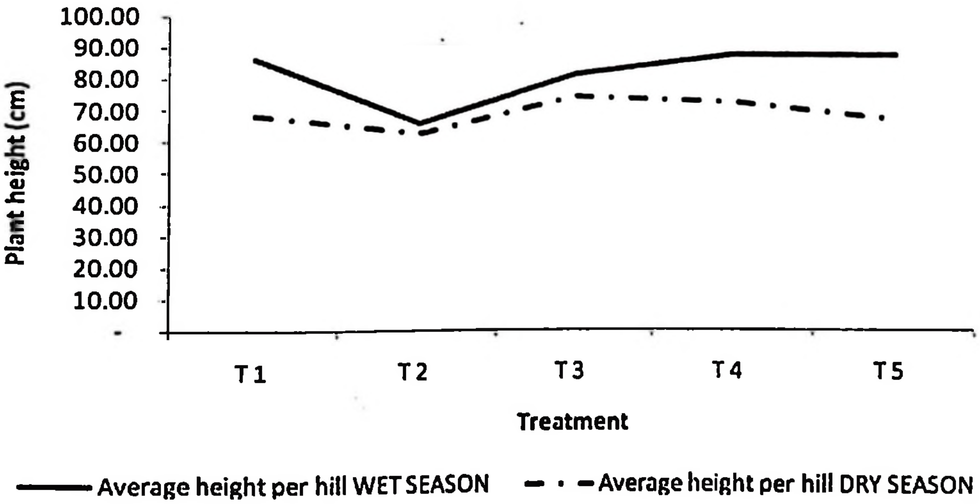

Figure 14: Plant height at flowering stage

4.2.6 Root length density

The mean root length obtained for conventional treatment was between 10 and 14 cm whereas that of SRI was between 20 and 25cm. It appears that SRI plants had greater root development (Plate 3). The appearance of nodal roots with every newly formed tiller led to more developed root system in AWD water management. The effect of soil aeration under AWD, early transplantation and wider spacing mad the rice plant to exploit a greater volume of soil and potentially access greater amounts of nutrients. These results are in agreement with those reported by Ceesay *et al.*, 2006; Kabir and Uphoff, 2007. Rupela *et al.* (2006) also reported that SRI plots had about five times greater root-length density, seven times more root volume, and ten times more root mass and length in the surface soil profile (top 15 cm).

Plate 3: Root growth of conventionally grown rice plant (left) vs. root growth of an SRI grown plant (right)

4.3 Yield parameters

4.3.1 Grain yield

As seen in Fig. 15, the lowest grain yield was obtained from T2 for both seasons. The highest grain yield was achieved in T3 and T4 with mean grain yield for two seasons of 4.76 tons/ha and 4.68 tons/ha respectively. The grain yield obtained from on farm trials during the wet season were 6.30 t/ha for FFS1 (spacing 25x25 cm), 4.93 tons/ha for FFS2 (spacing 30x30 cm) and 3.37 tons/ha for FFS3 (spacing 40x40 cm). However in the dry season the grain yield for T3 was higher with 5.6 tons/ha compared to 4.14 tons/ha in the wet season for treatment T3 (Table 5). The percentage yield increase of the treatments with respect to the control T1 from the mean of two seasons obtained was 24.3 % in T3 and 22.2% in T4. There was also a decrease in yield by 27.7% in T2 and 22.7 % in T5 compared to T1. It was noted that at wide planting spacing more than optimal, there was reduction in the rice yields due to low plant population per unit area despite enhanced tillering per plant. The statistical analysis of two seasons's pooled data showed significant difference in grain yield (Table 6). These results are in agreement with those found by other researchers (Krishna *et al.*, 2008; Vijayakumar *et al.*, 2001; Gani *et al.*, 2002, and Udyakumar, 2005) that higher grain yields are achieved under SRI practice i.e. planting younger seedlings (<14 days old), transplanted singly at wider spacing (25 x 25 cm or wider) and under non flooded conditions.

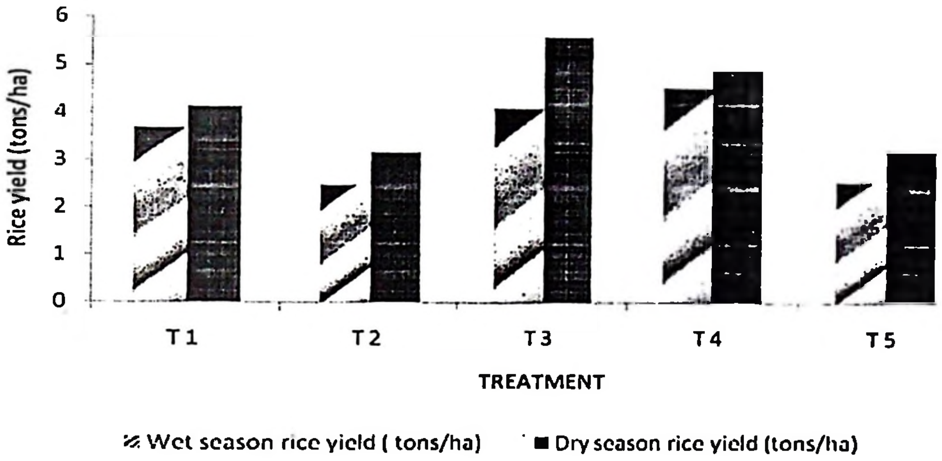

Figure 15: Average grain yield (tons/ha) for different treatments during wet and dry season at Mkindo

Table 5: Rice grain yield for wet and dry season

Treatment	Wet season rice yield (tons/ha)	Dry season rice yield (tons/ha)
T 1	3.7	4.15
T 2	2.5	3.2
T 3	4.14	5.67
T 4	4.6	5.01
T 5	2.6	3.3

4.3.2 Above ground biomass

The mean above ground biomass yield (10.8tons/ha) was significant in T3 under SRI practice with planting space of 30x30 cm. The lowest above ground biomass was recorded in T5 (6.5 tons/ha) due to less plant population despite improved tillering (Table 6). The above ground biomass for treatment T1 (conventional) was higher than T5 (SRI). A statistically at $P < 0.05$ based on Duncan Multiple Range Test showed that the above ground biomass yield of the control treatment T1 was significantly different from all other treatment T2,T3, T4 and T5. For the two seasons, dry season recorded less biomass compared to wet season (Fig. 17). The larger above ground biomass in wet season resulted normally due to higher non-harvestable biomass (more leaves and stem).

Table 6: Mean yield and yield parameters for both seasons

Treatment	Grain yield (tons/ha)	Above ground biomass (tons/ha)	Harvest Index (HI)	1000 grains weight (g)
T1	3.83 a b	8.923 b	0.4301 a	25.42 b
T2	2.77 b	8.002 a b	0.3554 a	23.17 a
T3	4.76 b	10.771 c	0.4357 a	23.77 ab
T4	4.68 b	9.365 bc	0.5014 a	23.85 ab
T5	2.96 a	6.492 a	0.4445 a	23.83 ab

Different letters within column indicate significant difference at P<0.05

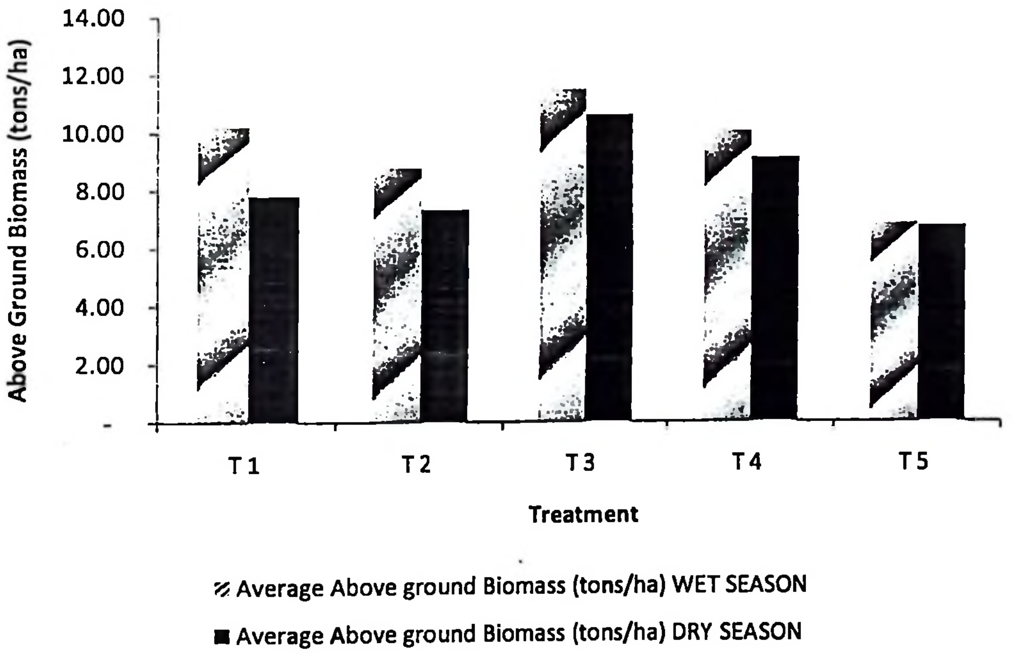

Figure 16: Average above ground biomass (tons/ha) for different treatments during for wet and dry season at Mkindo

4.3.3 Harvest index

There was no significant difference for Harvest Index between conventional and SRI practice at P = 0.05. The effect of flooding and AWD on harvest index was similar to grain and total dry aboveground biomass at harvest per unit area. While the Harvest Index with conventional methods T1 averaged 0.43 that with SRI methods recorded 0.435, 0.501 and 0.444 for T3, T5 and T5, respectively (Table 6 and Fig. 17).

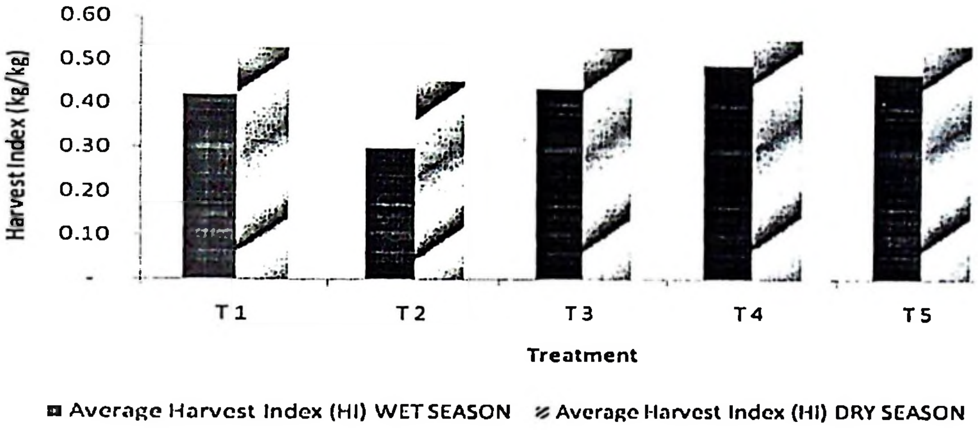

Figure 17: Harvest index under different treatments

4.4 Irrigation Water Use and Water Productivity

4.4.1 Irrigation water use and water savings

The control treatment (T1), which was continuously flooded throughout the crop growing season, had the highest mean irrigation water use of 2.882 m^3 per m^2 for the two seasons. Other treatments T2, T3, T4 and T5, which involved alternate wetting and drying cycle, indicated mean irrigation water use of 1.06, 1.03, 1.0 and 1.01 m^3 per m^2 respectively (Table 7). No significant differences were observed for irrigation water use between two seasons because both growing periods received considerable rainfall events (Fig. 18). The mean ranking based on the Duncan Multiple Range Test at $p<0.05$ showed that irrigation water use of the reference treatment T1 was statistically different from that of treatment T2, T3, T4 and T5 (Table 7). Irrigation water saving of 62.5%, 63.6%, 64.7%, and 64.1% for T2, T3, T4, and T5 respectively was noted compared to T1.

These results agree with findings reported by Sato and Uphoff (2007) under SRI management in eastern Indonesia. Similarly Tabbal *et al.* (1992), and Singh *et al.* (1996) reported that maintaining a very thin water layer, at saturated soil condition, or alternate wetting and drying, reduced water applied to the field by about 40–70% compared with the traditional practice of continuous shallow submergence. Keisuke *et al.* (2007) also reported a reduction of irrigation water requirement for non-flooded rice by 20–50% compared to flooded rice, with the difference being strongly dependent on soil type, rainfall, and water management practices.

Table 7 : Cumulative irrigation water use, water productivity and water saving

Treatment	Cumulative irrigation water use (cu.m/m^2)	Water Productivity (kg/m^3)	Irrigation Water saving (%)
T1	2.822 a	0.1361 a	
T2	1.058 b	0.2693 b	62.51
T3	1.026 b	0.4689 c	63.64
T4	0.997 b	0.4726 c	64.67
T5	1.014 b	0.2903 b	64.07

Different letters within column indicate significant difference at P<0.05

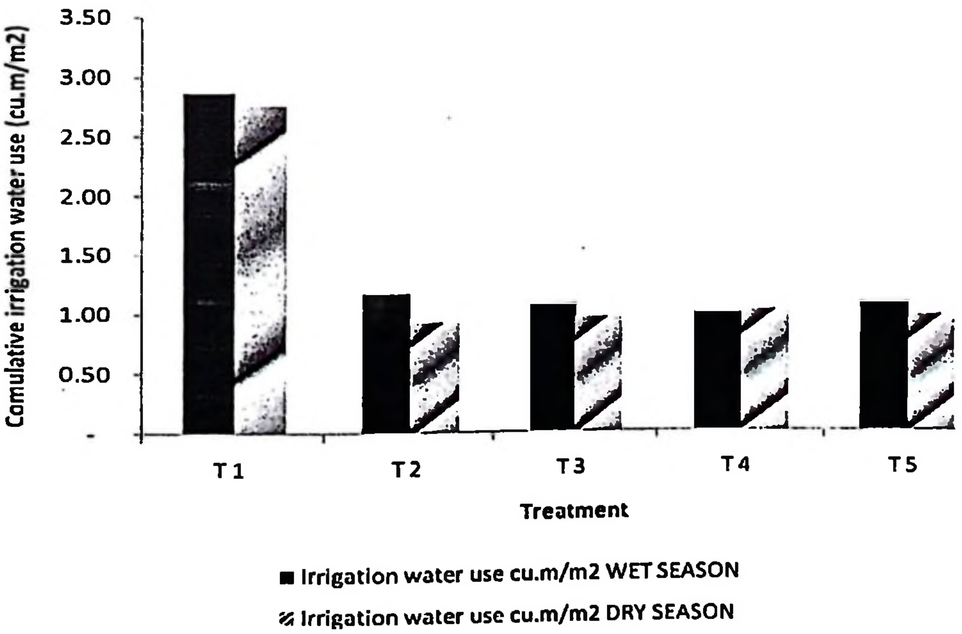

Figure 18: Irrigation water use under different treatments at Mkindo

4.4.2 Water productivity

Water productivity was highest (0.47 kg/m3) in treatment T4 where SRI practice was applied with wider spacing of 30x30 cm, followed by 0.46 kg/m3 in T3 with spacing of 25X25 cm. Water productivity was lowest (0.136 kg/m^3) in continuously flooded plots with normal seedlings and 25x 25 cm spacing (Fig. 19).Water productivity under T1 was significantly different at $p<0.05$ from all other treatments (Table 7). For T1 with WP of 0.136 kg/m^3 it is equivalent to the use of 7347 litres of water to produce 1 kg of rice, but for T4 with WP of 0.47 kg/m^3 it is equivalent to o the use of 2132 litres to produce 1 kg of rice (Table 8). The quantity of water used for T4 is far below the recorded values of 3000-5000 litres of water currently used to produce 1 kilogram of rice (IRRI, 2002).

Table 8: Amount of water required to produce 1 kg of rice

Treatment	Water Productivity (kg/m3)	Equivalent amount of water used to produce 1kg of rice (lts/kg)
T1	0.14	7347.54
T2	0.27	3713.33
T3	0.47	2132.65
T4	0.47	2115.95
T5	0.29	3444.71

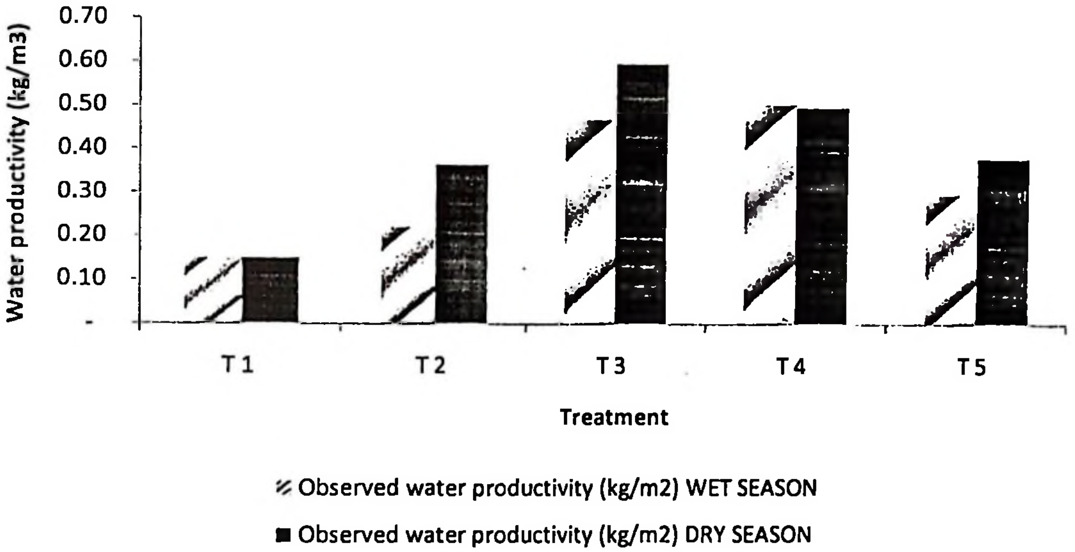

Figure 19: **Water productivity under different treatments during wet and dry season at Mkindo**

4.5 Irrigation Scheduling

The indicator for restarting irrigation delivery was the point of surface cracking of soil in the paddy fields. The soil surface was observed to crack after three continuous days of no surface water in AWD plots. In case of rainfall events, more than three days interval was observed. For Mkindo soils the moisture content at soil surface crack was determined to be 20 centbars be (soil matric tension) measured by tension meter. By using moisture retention curve developed on site, the moisture content at this juncture was equivalent to 35% by volume which was the field capacity at the experimental site.

4.6 Adoption and Up-scaling of SRI at Mkindo

The goal was to facilitate adoption and up-scaling of SRI in Mkindo, and hopefully, in Tanzania. This study was therefore designed to implement pilot trials of SRI by farmers at Mkindo irrigation scheme. A group of fourteen farmers, whom seven were women participated in farmer field school (FFS) managed by the farmers as part of learning exercises. In Mkindo, where farmers were used to transplanting techniques in rows as opposed to direct seeding, SRI planting techniques were easily picked. The presence of Mkindo Farmers Training Centre was a motive behind fast of adoption of SRI and other best practices of rice production in the area.

At the beginning farmers were skeptical about the possibility of one younger seedling to produce more rice than four or five seedlings together. During the early developmental stages of SRI seedlings, soon after transplanting and before the young seedlings had gained strength, the crop looked very poor. Many neighboring farmers mocked the SRI practice. This could be due to younger seedlings (13 days old) with wider plant spacing and planted singly. Four weeks after transplanting, however, the SRI rice plant crop outperformed the conventionally planted rice (average of 25 tillers against 7).

In the second month, tillering was very good up to 52 tillers per hill (Table 9).The neighboring rice fields practicing conventional method could achieve the maximum of 12 number of tillers/hill with the average of 9 tillers/hill from the random sampling. Seeing the better results from SRI practice, the other farmers acknowledged that SRI tillering was superior.

Certain technical issues have also arisen. It was noted that young, newly transplanted SRI seedlings were vulnerable to bird and rat damage, being very delicate. A higher incidence of weeds had also been observed. Mkindo farmers had and were used to cono-weeders (Mechanical weeding tool) and this was an added advantage for weed control. SRI efforts had been relying on volunteers, and sometimes these farmers were not available all the time during farmer training and field days.

Table 9: FFS results

Treatment	Planting space (cm x cm)	Rice yield tons/ ha	HI	Number of tillers/m2	Average max. tillers per hill
FFS 1	25 x 25	6.30	0.46	276.39	44.00
FFS 2	30 x 30	4.93	0.44	223.48	47.33
FFS 3	40 x 40	3.37	0.46	193.95	51.33

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study has showed the potential of SRI practice to enhance rice performance and increase water productivity without reducing yield per unit of land compared to traditional cultivation methods. Results from this study are in line with experiments and field testing of SRI practice of cultivating rice from different countries, which have confirmed the value of alternate wet and drying, raised seedling in an un-flooded nurseries with seed priming and wider spacing, and use of young seedlings transplanted singly in achieving water saving, better crop performance, and higher productivity. Based on results from the field experiment in Mkindo, the following conclusions can be made:

a) Planting space

Plant spacing of 25x25 cm and 30x30 cm gave the best results compared to the other combinations. It was clear that wider spacing have significant influence on the growth pattern and tillering of transplanted rice. Planting spacing of 25x25 cm and 30x30 cm can be adopted for Mkindo area.

b) Irrigation method and interval of wetting

Intermittent irrigation with alternate wetting and drying intervals of three days was observed to be a suitable irrigation scheduling for Mkindo soils in the absence of rainfall. The indicator for restarting irrigation delivery was after development of hairline cracks appearing on the soil surface of paddy fields, which was equivalent to soil matric tension of 20 centbars measured by tensionmeter or moisture content of 35% by volume.

c) Water saving

On average SRI demonstrated water saving of 63.72% for Mkindo. This implies that there is a possibility for reducing the amount of water diverted to rice in the study site. SRI's lower water requirements also mean that farmers can continue to grow rice in regions experiencing diminishing water availability due to population growth, competition for water with other sectors, and challenges of climate change and variability. However, these results are site specific and care must be taken in extrapolating the findings to other geographic locations.

d) Water productivity

Water productivity was significantly higher (0.47 kg/m^3) in the T4 where SRI practice was applied with wider spacing of 30x30 cm followed by 0.46 kg/m^3 in T3 with spacing of 25x25 cm. Water productivity was lowest (0.136 kg/m^3) in continuously flooded plots with normal seedlings and closer spacing. The increased productivity of water and its resource-saving aspects are likely to be the critical factors that will make farmers and other stakeholders adopt AWD in water-scarce environment, which is becoming increasingly common due to the effects of climate change and variability.

e) Rice yield

The highest grain yield was achieved with T3 (25x25 cm) and T4 (30x30 cm) spacings, with mean grain yield for two seasons of 4.76 tons/ha and 4.68 tons/ha, respectively. This represented % increase in the grain yield per ha of 24.28% in T3 and 22.19% in T4 as compared to T1 (control treatment).

5.2 Recommendations

1. The plant spacing of 25x25 cm and 30x30 cm can thus be recommended for Mkindo area using SARO rice variety.

2. In view of the great diversity in rice production systems that operate under varied local biophysical and socio-economic conditions, SRI methods will not be applicable consistently everywhere. Each situation will require research and validation of the various SRI components depending on soil conditions and other biophysical factors. Therefore, on-farm participatory research will be required to introduce site-specific adaptations and to expose farmers and extension agents to the SRI perspectives.

3. As SRI techniques emphasise the use of organic fertilizers, availability of sufficient animal manure may become a constraint as SRI becomes widely adopted, and it will be necessary to develop composting in order to obtain sufficient organic matter to add to the soil. It is recommended to start on-site composting comprising of compost pits, rice straw, animal manure, and other organic matter (plant biomass of all sorts) as components.

4. The extension of SRI should be particularly attractive with pump irrigation as pumped water is relatively more expensive. The reduction in irrigation water requirements that SRI practices will be more significant economically by reducing pumping costs. At the same time pump irrigation technology allows for more precise water control and application.

5. Irrigation schemes that depend on dams as a source of water, SRI practice is highly recommended. The main requirement for the success of SRI practice is a sufficient

degree of water control, to be able to apply small amounts of water regularly and reliably, or to be able to flood the field and then drain it after a few days, being sure to be able to re-flood it after a few more days.

5.3 Suggested Further Research

This study has dealt with SRI experimentation in three different plant spacing of 25x25 cm, 30x30 cm and 40x40 cm; younger seedling 14 days old, single variety of rice and intermittent irrigation of AWD particularly for Mkindo soils and climate. However the following are gaps that need to be researched:

1. Different rice varieties and fertilizing levels in the same area with the same SRI methodology but keeping in mind the optimal combination of this study.
2. Effect of different transplanting ages e.g. 8, 12, 15 and 20 days.
3. Effect of using organic manure visa-a-vie industrial fertilizer on SRI practice.
4. Because of the wide range of variability in topography, soil and climatic conditions across the location, it is important that comparative studies be done in different environments by using the same methodology to verify the wetting interval. It is expected that for clayey soils (unlike clay loam of the study area) where infiltration rate is much less, wetting interval may increase to seven days or more.

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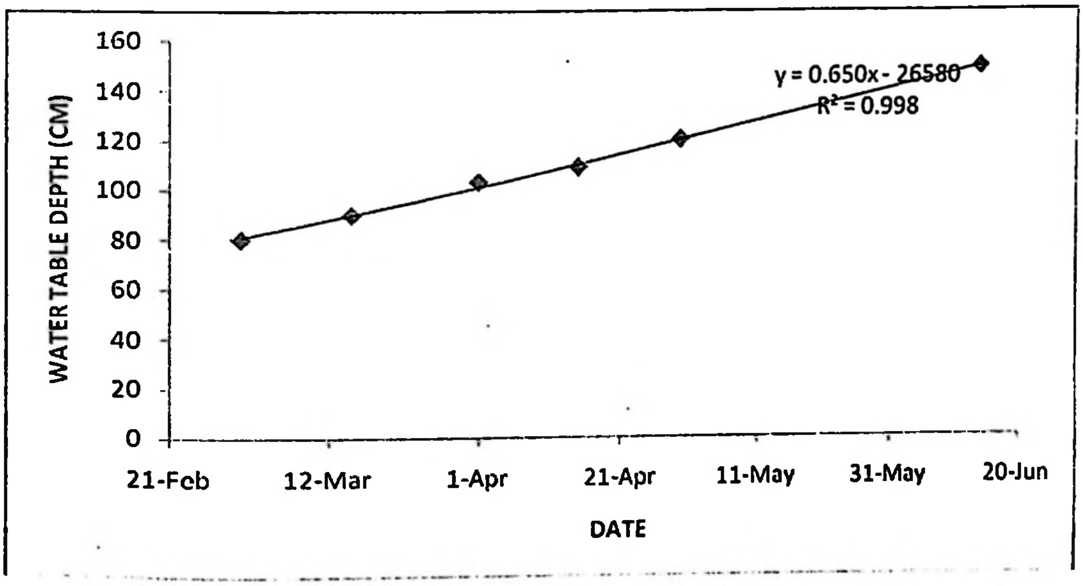
APPENDECES

Appendix 1: Data collected during Tensiometer calibration

DATE	Tensiometer Readings (cent bars)	soil moisture by soil meter (%)
1-Mar	0	45.00
5-Mar	10.00	35.00
10-Mar	20.00	33.00
15-Mar	25.50	33.90
20-Mar	28.00	33.50
25-Mar	35.00	30.00
30-Mar	38.30	28.00
4-Apr	42.10	27.00
9-Apr	45.00	25.00
14-Apr	48.00	24.00
13-Apr	54.00	23.00
17-Apr	61.00	20.00

Appendix 2: Water table depth different periods during growing season



Appendix 3 : Mean root length and width.

TREATMENT	root length	root width
T1	[illegible]	7.00
T2	13.00	15.33
T3	17.33	19.67
T4	13.33	20.00
T5	13.67	21.00

Appendix 4: Field Data collected during measurement of infiltration

Time Hr-min	point gauge reading (cm)	Time diff (min)	cumulative time (min)	Infiltration depth (cm) Difference	Cumulative depth (cm)	Rate of infiltration (cm/h)
9.17	17.00					
9.22	17.70	5.00	5.00	0.70	0.70	8.40
9.28	18.40	6.00	11.00	0.70	1.40	7.00
9.15	19.00	7.00	18.00	0.60	2.00	5.14
9.23	20.30	8.00	26.00	0.80	2.80	6.00
10.08	22.00	45.00	71.00	1.70	4.50	2.27
10.11	22.10/16.50	3.00	74.00	0.10	4.60	2.00
10.27	17.05	16.00	90.00	0.55	5.15	2.06
10.45	17.40	18.00	108.00	0.35	5.50	1.17
11.16	17.70	31.00	139.00	0.30	5.80	0.58
11.43	17.90	27.00	166.00	0.25	6.05	0.56
12.42	18.30	59.00	225.00	0.45	6.50	0.46

Appendix 5: Observed plant performance parameters

	SEASON ONE (WET)					SEASON TWO (DRY)				
Treatment label	Average tillers/m^2	Max tillers per hill	Min tillers per hill	Average tillers /hill	Average height	Average tillers/m^2	Max tillers per hill	Min tillers per hill	Average tillers/hill	Average height
T 1- A	312.50	18	9	12.50	85.80	627.50	31.00	18.00	25.10	69.90
T 1- B	331.25	18	9	13.25	85.80	610.00	31.00	19.00	24.40	69.40
T 1 - C	388.75	19	11	15.55	87.20	602.50	30.00	18.00	24.10	65.00
T 2- A	352.50	21	9	14.10	66.20	827.50	42.00	29.00	33.30	68.90
T 2- B	398.75	28	10	15.95	65.80	827.50	39.00	29.00	33.10	62.20
T 2 - C	347.50	25	6	13.90	65.80	872.50	42.00	29.00	34.90	56.40
T 3- A	329.60	30	13	20.60	80.55	552.00	43.00	23.00	34.50	73.60
T 3- B	356.80	38	14	22.30	82.35	571.20	43.00	31.00	35.70	70.10
T 3 - C	350.40	32	11	21.90	81.17	488.00	35.00	25.00	30.50	78.40
T 4- A	309.10	33	19	28.10	86.30	492.22	42.00	35.00	38.50	70.10
T 4- B	314.05	39	21	28.55	85.45	487.78	68.00	38.00	43.90	71.70
T 4 - C	295.35	38	19	26.85	90.30	398.89	28.00	18.00	22.60	74.70
T 5- A	291.56	57	36	46.65	93.20	280.00	49.00	36.00	44.80	67.80
T 5- B	233.13	56	22	37.30	84.55	323.13	57.00	48.00	50.10	67.70
T 5 - C	202.81	61	21	32.45	83.35	323.13	57.00	48.00	51.70	64.40

Appendix 6: Mean plant performance

	SEASON ONE (WET)					SEASON TWO (DRY)				
Treatment lebel	Mean tillers/m^2	Max tillers per hill	Min tillers per hill	Average tillers /hill	Average height	Mean tillers/m^2	Max tillers per hill	Min tillers per hill	Average tillers /hill	Average height
T 1	344.17	18.33	9.67	13.77	86.27	613.33	30.67	18.33	24.53	68.10
T 2	366.25	24.67	8.33	14.65	65.93	642.50	41.00	29.00	33.77	62.50
T 3	345.60	33.33	12.67	21.60	81.36	537.07	40.33	26.33	33.57	74.03
T 4	306.17	36.67	19.67	27.83	87.35	459.63	46.00	30.33	35.00	72.17
T 5	242.50	58.00	26.33	38.80	87.03	308.75	54.33	44.00	48.87	66.63

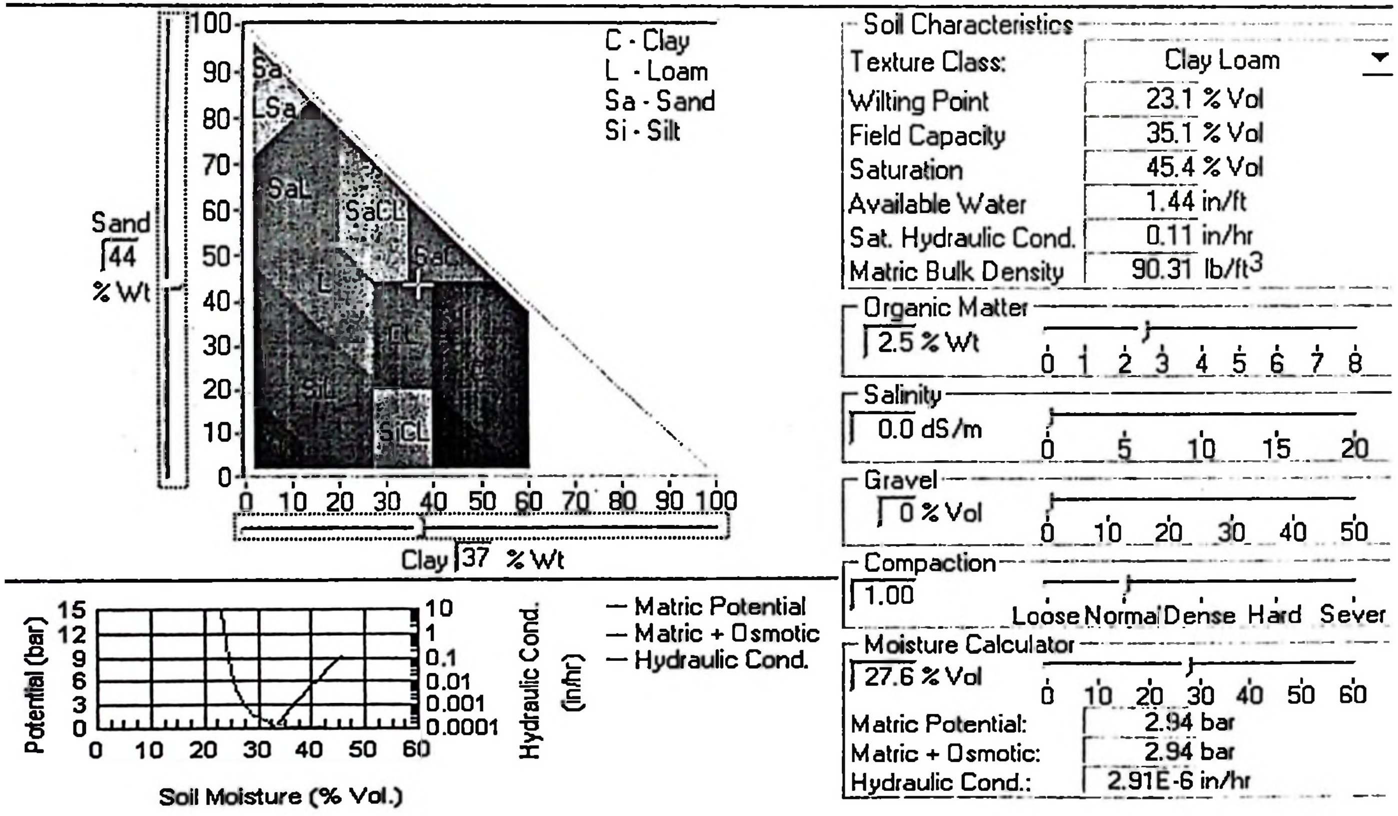
Appendix 7 : Observed grain and irrigation water performance parameters

TREATMENT	SEASON ONE (WET)					SEASON TWO (DRY)				
	Grain yield (g/m^2)	Leaves& stem(g/m2)	Harvest Index	Irr. Water use ($cu.m/m^2$)	WP kg/m^3	Grain yield (g/m^2)	Leaves& stem(g/m^2)	Harvest Index	Irr. Water use ($cu.m/m^2$)	WP kg/m^3
T 1- A	421.10	571.90	0.42	2.78	0.15	182.64	538.90	0.25	2.83	0.06
T 1- B	437.89	709.50	0.38	2.76	0.16	441.41	360.90	0.55	2.73	0.16
T 1 - C	427.77	500.00	0.46	3.06	0.14	389.00	372.90	0.51	2.78	0.14
T 2- A	261.76	452.00	0.37	1.24	0.21	222.36	463.90	0.32	1.02	0.22
T 2- B	280.83	808.80	0.26	1.24	0.23	329.75	354.40	0.48	0.83	0.40
T 2 - C	231.18	609.30	0.28	1.01	0.23	336.00	451.20	0.43	1.00	0.34
T 3- A	446.86	697.40	0.39	1.12	0.40	201.10	654.50	0.24	1.02	0.20
T 3- B	543.09	602.30	0.47	1.03	0.53	569.67	579.20	0.50	0.86	0.66
T 3 - C	527.20	652.80	0.45	1.07	0.49	565.05	423.30	0.57	1.05	0.54
T 4- A	501.07	593.10	0.46	0.91	0.55	310.95	438.30	0.42	1.02	0.30
T 4- B	526.18	486.10	0.52	1.01	0.52	497.23	294.80	0.63	0.91	0.55
T 4 - C	467.10	460.70	0.50	1.04	0.45	505.29	538.10	0.48	1.10	0.46
T 5- A	308.53	510.30	0.38	1.10	0.28	66.68	400.00	0.14	0.94	0.07
T 5- B	288.79	337.60	0.46	0.99	0.29	364.73	315.60	0.54	0.94	0.39
T 5 - C	370.17	252.00	0.59	1.12	0.33	377.85	302.80	0.56	0.99	0.38

Appendix 8: Mean grain and irrigation water use performances

TREATMENT	SEASON ONE (WET)					SEASON TWO (DRY)				
	Grain weight (g/m^2)	Leaves and stem (g/m^2)	Harvest Index	Irr. Water use ($cu.m/m^2$)	WP kg/m^3	Grain weight (g/m^2)	Leaves and stem (g/m^2)	Harvest Index	Irr. Water use ($cu.m/m^2$)	WP kg/m^3
T 1	428.92	593.80	0.42	2.86	0.15	415.21	366.90	0.53	2.76	0.15
T 2	257.92	623.37	0.30	1.17	0.22	332.88	402.80	0.45	0.92	0.37
T 3	505.72	650.83	0.44	1.08	0.47	567.36	501.25	0.53	0.96	0.60
T 4	498.12	513.30	0.49	0.98	0.51	501.26	416.45	0.56	1.01	0.50
T 5	322.49	366.63	0.48	1.07	0.30	371.29	309.20	0.55	0.97	0.38

Appendix 9: Soil water characteristic for Mkindo



Sand 44 % Wt

Clay 37 % Wt

Soil Characteristics

Texture Class:	Clay Loam
Wilting Point	23.1 % Vol
Field Capacity	35.1 % Vol
Saturation	45.4 % Vol
Available Water	1.44 in/ft
Sat. Hydraulic Cond.	0.11 in/hr
Matric Bulk Density	90.31 lb/ft^3

Organic Matter 2.5 % Wt

Salinity 0.0 dS/m

Gravel 0 % Vol

Compaction 1.00

Moisture Calculator 27.6 % Vol

Matric Potential:	2.94 bar
Matric + Osmotic:	2.94 bar
Hydraulic Cond.:	2.91E-6 in/hr