EVALUATION OF THE PERFORMANCE OF SYSTEM OF RICE INTENSIFICATION (SRI) IN BUMBWISUDI RICE IRRIGATION SCHEME, ZANZIBAR

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ABSTRACT

Declining water resources, low rice yields and a widening gap between current rice demand and production in Zanzibar necessitates a change from the current rice production system to a more efficient system of production such as the system of rice intensification (SRI). In an attempt to evaluate the efficacy of SRI practice and determining the optimum spacing and transplanting age of seedlings for better grain yield, productive tillers and water productivity, a field experiment in a Randomized Complete Block Design (RCBD) was set with 13 treatments and three replications at Bumbwisudi rice irrigation scheme in Zanzibar. The experiment was conducted during *vuli* season from September 2013 to January 2014. SUPA BC rice variety was transplanted at square spacing (20, 25, 30, 35) cm and 8, 10, 14 and 21 days seedlings ages. Eight days old seedlings, transplanted at 20 x 20 cm spacing (T_1) (SRI plot) recorded significantly higher grain yield (7.38 t/ha) as compared to 21 days old seedlings under continuous flooding at 20 cm x 20 cm (T_{13}) (5.283 t/ha). Lower grain yield of (5.14 t/ha) was in older seedling age of 14 days and spacing 25 x 25 cm (T_{10}). There was 39.8% increase in yield in SRI practice compared to continuous flooding. Treatment T_5 (10 days old seedling) with 20 x 20 cm spacing produced maximum productive tillers per hill (32/hill). High water productivity was obtained in T_5 (0.44 kg/m^3) as compared to (0.24 kg/m^3) in continuous flooding. Highest water use efficiency (WUE) was observed in T_1 (12.06 kg/ha/mm). Amount of water (46.7%) could be saved by using SRI while still producing reasonable yields instead of continuous flooding. Irrigation water analysis in the study area revealed no restriction in its use for rice cultivation. Zanzibar has the potential of increasing yield and water productivity and reducing water use in irrigated rice under SRI.

DECLARATION

I, **RUBEA MOHAMED ALI,** do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and has neither been submitted nor concurrently being submitted for a degree award in any other academic institution.

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DEDICATION

This dissertation is dedicated to my late father Mohamed Ali and my late mother Time Othman who contributed to my academic orientation. May Almighty God keep their souls in paradise.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATION AND ACRONYMS

µS/cm	microsiemens per centimeter
ANOVA	Analysis of Variance
ARC-ILI	Agriculture Research Council
CEC	Cation Exchange Capacity
cmol	Cent mole
DI	Deficit Irrigation
dS/m	deciSiemens per metre
EC	Electrical Conductivity
EDTA	Ethylenediaminetetraacetic acid
ETc	Crop Evapotranspiration
ETo	Reference Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
HI	Harvest Index
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IRRI	International Rice Research Institute
ISO	International Organization of Standards
IWMI	International Water Management Institute
K	Potassium
Kc	Crop Coefficient
LSD	Least Significant Difference
MALE	Ministry of Agriculture Livestock and Environment

me/l	Milliequivalent per litre
N	Nitrogen
Na	Sodium
NARI	National Agricultural Research Institute
NERICA	New Rice for Africa
OECD	Organization for Economic Co-operation and Development
P	Phosphorus
RCBD	Randomized Complete Block Design
SAR	Sodium Adsorption Ratio
SAWQG	South African Water Quality Guidelines
SDWAF	South African Department of Water Affairs and Forestry
SRI	System of Rice Intensification
TDS	Total Dissolved Solids
TWU	Total Water Use
URT	United Republic of Tanzania
USGS	United States Geological Survey
WP	Water Productivity
WUE	Water Use Efficiency
WWF	World Wide Fund for Nature
ZFBS	Zanzibar Food Balance Sheet

CHAPTER ONE

1. INTRODUCTION

In recent years the availability of freshwater for agriculture has been declining and the costs for water resources development have been steadily on the rise. While the demand for agricultural products is becoming high, either more water is needed to produce food to meet the current demand or producing more crops using less water. Rice being a popular grain worldwide is the leading consumer of water (Bouman and Toung, 2001). According to the International Water Management Institute (IWMI) (2007), irrigated rice consumes about 24% - 30% of the freshwater of the world. In India alone for instance, 70% of water used for irrigation is used for rice production (Biswas, 2010).

Rice is the most important staple food worldwide for 2.7 billion people, almost half the world population (Ginigaddara and Ranamukhaarachchi, 2009; Sinha and Talati, 2007). It is estimated that the world demand for rice is projected to increase by up to 70% over the next 30 years (Partha and Samsul, 2011). This projected demand can only be fulfilled by maintaining a steady increase in production over the years through various ways like adoption of hybrid rice, super hybrid rice and judicious utilization of production factors, especially water.

In Zanzibar, it is estimated that 22.3 million cubic metres of water (Mm^3/year) will be required to irrigate 1712 ha of rice by 2015. This is about 40% of total water demand based on estimated irrigation demand of 1300 m^3/ha/year (Halcrow, 1994).

Rice is the main staple food in Zanzibar and accounts for more than 50% of food consumed (ZFBS, 2007). The annual per capita rice consumption is about 120 kg per year implying the current demand is 120 000 tons per year out of which 80% is imported (Mnembuka *et al.,* 2010). This situation indicates insufficient/shortage in terms of food production, particularly, rice. To feed the growing population of more than one million people, the Government of Zanzibar is putting emphasis on irrigated agriculture to narrow down the gap of food supply that has to be imported from outside using foreign currency.

The current irrigated rice production system in Zanzibar is continuous flooding, which in principle exploits more groundwater. In the most intensively cropped areas under rice, where groundwater is often used for irrigation, water tables have been falling at an alarming rate of one meter per year or more (Shymashree and Bisht, 2012). Also, climate change will exacerbate the problem by adversely affecting rice and wheat yields and increasing evapotranspiration (Rosegrant *et al.,* 2008).

With declining trends of water resources and the rising demand for rice, there is need of changing how rice is produced in the country. Rice production under conventional practice of maintaining continuous flooding should no longer be talked about. So we have to keep an eye on the modification of rice cultivation practices using less amount of water. Fortunately a technique has been explored, promising more yield with less water use. This technique is called the System of Rice Intensification (SRI). The System of Rice Intensification is a technique of producing rice with less water and has been proved to increase yields and water productivity in many parts of the world (Geethalakshmi *et al*., 2009; Vijayakumar *et al*., 2006).

In Tanzania the SRI practice is becoming more popular in a number of rice producing areas whereby researches are being conducted to evaluate its suitability and acceptability. A few examples of these areas are Mkindo and Dakawa in Morogoro Region and Lower Moshi in Kilimanjaro Region. There are some parts of the country like Zanzibar where little has been done. In Zanzibar groundwater is the main source for both irrigated agriculture and domestic water supply and therefore need to be carefully abstracted and efficiently utilized. Out of 601 ha of land currently under rice irrigation, about 363 ha (60%) are irrigated using groundwater. In Unguja island alone, out of 475 ha of land under irrigated rice, 363 ha (76%) is irrigated using groundwater sources. The yield of 3.5 t/ha obtained with the existing production system is still low and need to be increased.

This study is therefore designed to assess the performance and suitability of SRI in Zanzibar with special focus on its potential in increasing crop yields and water productivity. Increasing productivity in agriculture is in line with the goal of Zanzibar Poverty Reduction plan (RGoZ, 2010), Agriculture Sector Policy, and Agricultural Sector Strategic Plan (Ministry of Agriculture, Livestock and Environment (MALE) (MALE, 2008).

1.1 Justification

With declining water resources, increased population, low rice yields and water competition with other development activities including domestic uses, farmers need to adopt crop production systems that favour water saving while improving yield in irrigated rice. According to Sharma (1989), the continuous flooding method of rice cultivation is very inefficient as about 50–80% of the total water input is wasted. Thus even small savings of water due to a change in current practice will translate into a significant bearing on reducing the total consumption of water for paddy production. Therefore water saving techniques are absolutely essential for increasing and sustaining future rice production in Zanzibar. SRI offers an opportunity and an alternative method since it has the potential of improving rice crop yields and saving more water for other uses. SRI can also save government foreign currency for rice imports and avoiding expenses for alternative water supply infrastructure and water conflicts as well.

Despite high yields observed with SRI in other places, the difference in geographical locations, climatic and soil conditions call for SRI components especially spacing and seedling age to be re-established through field trials in order to fit local specific locations. There is a chance of obtaining higher yields at lower spacing in other locations e.g. Zanzibar. Considering Zanzibar is an island with limited land and water resources with respect to its population and food demand especially rice, and little has been done concerning SRI practice under the Zanzibar environment, testing SRI components is the right point of departure towards reduction of irrigation water input for paddy production. This is the essence for the current study.

1.2 Objectives

1.2.1 Overall objective

The overall objective was to evaluate the efficacy of the System of Rice Intensification (SRI) in increasing water productivity and rice yields in Zanzibar.

1.2.2 Specific objectives

The specific objectives includes to:

i) Characterize the soils and water quality for paddy rice production in the project site.

ii) Determine optimum transplanting age of seedlings under SRI practice.

iii) Determine optimum spacing that gives maximum productive tillers and yield under Zanzibar soil conditions.

iv) Evaluate water productivity and water use efficiency under SRI practice and the conventional flooding method.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Irrigation

In the Proceedings of the Consultation on Irrigation in Africa Lome, Togo, irrigation was defined as the application of water supplementary to that supplied directly by precipitation for the production of crops (FAO, 1997). Kay (1983) defined the term irrigation as the artificial method of applying water for supplementing rainfall to improve crop yield. Recently the United States Department of Interior Geological Survey (USGS) defined irrigation as the controlled application of water for agricultural purposes through manmade systems to supply water requirements not satisfied by rainfall. Irrigation is applied to avoid water deficits that reduce crop production. However, when water supply is limited, deficit irrigation is deliberately practiced.

2.2 Deficit Irrigation

The application of water below the crop evapotranspiration (ETc) requirements is termed as deficit irrigation (DI) (Fereres and Soriano, 2007). Owusu-Sekyere (2010) defined DI as a strategy that allows a crop to sustain some degree of water deficit in order to reduce production costs and potentially increase income. Irrigation supply under DI is reduced relative to that needed to meet maximum ET (English, 1990). Therefore, water demand for irrigation can be reduced and the water saved can be diverted for alternative uses. SRI is among the practices of deficit irrigation since it involves suboptimal water applications during the vegetative phase of rice plant.

2.3 Irrigation Methods

There are three commonly used irrigation methods: surface irrigation, sprinkler irrigation and drip irrigation (Brouwer *et al.,* 1988). The selection of an irrigation method is based on technical feasibility and economics. Feasibility in terms of soil type, slope of the land and quality of irrigation water to support particular irrigation type. Economics focus on crops to be grown and investment and operating costs. Surface irrigation methods are generally cheapest to install and where conditions are suitable there is little point to consider other methods (Withers and Vipond, 1974). However, where high value crops are to be grown or land slope is steep or water is saline there may be economic justification for considering other methods of irrigation (sprinkler and drip irrigation). Sprinkler and drip irrigation systems are relatively expensive to install and even their operation and maintenance costs and therefore is uneconomical and not used for paddy production. Paddy rice is grown in basins.

2.3.1 Crop water requirement (ETc)

Crop water requirement (crop water need) is the amount of water required to compensate the evapotranspiration loss from the cropped field (Allen *et al.,* 2006). It refers to the amount of water that needs to be supplied to the crop to meet evapotranspiration demand, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration. It is expressed in millimetres per given duration (mm/day, mm/month or mm/season). The crop water requirement (ETc) is computed by multiplying the reference evapotranspiration ETo and the crop coefficient (kc). The reference evapotranspiration ETo is the evapotranspiration rate from a reference surface not short of water (Allen *et al.,* 2006). The reference surface is a hypothetical grass well watered, completely shading the ground with an assumed height of about 0.12 m above the ground, fixed surface resistance of 70 s m^{-1} and albedo of 0.23. The recommended procedure for computing the ETo is the use of Penman - Monteith method (Allen *et al*., 1998). Nowadays computer software (ETo calculator) has been developed to simplify the computation of ETo because the former method is a long process and involves several computed parameters which somehow are laborious to handle. The parameters required are air temperature in ^{o}C, air humidity, solar radiation and wind speed (m s^{-1}). Values for kc depend on crop development stage of a particular crop. For simplicity, kc values have been determined and can be obtained in Appendix 1.

2.3.2 Crop water requirements for rice

The crop water requirement for rice is determined using same procedure of computing water requirements for other crops by multiplying the reference evapotranspiration and crop coefficient for a particular growth stage (Equation 1).

ETc = ETo x kc…..………………………………………………………………….. (1)

Where:

ETc = crop evapotranspiration (mm/day)

ETo = reference evapotranspiration (mm/day)

kc = crop coefficient (dimensionless)

2.3.3 Irrigation water requirement

Irrigation water requirement (IR) is the crop water requirement less effective rainfall. (Pe).

IR = ETc – Pe (mm) …………………………………….……………………… (2)

Where:

Pe = Effective rainfall (mm/month).

Effective rainfall is that part of rainfall that can be used effectively by the crop. It is normally computed by the following formulae shown in Equations 3 and 4.

Pe = 0.8 P if P > 75 mm/month…………………….…………………..……..... (3)

Pe = 0.6 P if P < 75 mm/month….…………………..………..….….……..… (4)

Where:

Pe = effective rainfall (mm/month)

P = Monthly rainfall (mm)

For paddy rice grown with standing water, is an exceptional case. Not only has the crop water need (ETc) to be supplied by irrigation or rainfall, but also water is needed for saturation of the soil before planting (SAT), percolation and seepage losses (PERC) and establishment of a water layer (WL) (Equation 5)

IR = ETc + SAT + PERC + WL – Pe (mm) ……………………………………… (5)

for heavy clay: PERC = 4 mm/day

for sandy soils: PERC = 8 mm/day

on average: PERC = 6 mm/day

The amount of water layer is not needed in SRI practice.

2.4 Water Quality and Crop Production

Water quality plays a crucial role in successful production of crops. Overtime the quality of groundwater is constantly changing in response to daily, seasonal and climatic factors (Ackah *et al.,* 2011). A thorough water analysis and evaluation is therefore important for any successful crop production operation. Conceptually, water quality refers to the characteristics of a water supply that will influence its suitability for a specific use, i.e. how well the quality meets the needs of the user and is defined by certain physical, chemical and biological characteristics (FAO, 1985).

According to the South African water quality guidelines (SAWQG) (1996), the term water quality describes the physical, chemical, biological and aesthetic properties of water that determine its fitness for a variety of uses and for the protection of aquatic ecosystems. It means water quality for irrigation is described by properties that judge its fitness for irrigation purposes.

The suitability of water for irrigation depends on a variety of factors. Most relevant and important are; (salinity) concentration of Total Dissolved Solids (TDS), expressed in EC unit, (element toxicity) concentration of certain ions, which may be toxic to plants or have unfavourable effects on crops, soils and public health and (sodicity) concentration of cations, which may cause de-flocculation of clays in soils resulting damage to soil structure and permeability (Bauder *et al.,* 2007). Ayers and Westcot, (1985) classified irrigation water into three groups based on salinity, sodicity, toxicity and miscellaneous hazards. These general water quality classification guidelines help to identify potential crop production problems associated with the use of conventional water sources. In 1985 Food and Agriculture Organization of the United Nations (FAO) produced guidelines for evaluation of water quality for irrigation (FAO, 1985). The key parameters include pH, electrical conductivity (EC), Sodium content (Na) measured in sodium adsorption ratio (SAR) and bicarbonate (HCO_3). These parameters are briefly discussed in the following sections.

2.4.1 Water pH

The pH is an indicator of the acidity or basicity of water, but is seldom a problem by itself. The main use of pH in a water analysis is for detecting abnormal water. The normal pH range for irrigation water is from 6.5 to 8.4. Irrigation water with a pH outside the normal range may cause a nutritional imbalance or may contain toxic ions (FAO, 1985). An abnormal value is a warning that the water needs further evaluation. Water with a pH below 7 is acid and water with a pH above 7 is alkaline (Brunton and Ourimbah, 2011). Most natural waters have pH of between 5 and 8. High values of pH above 8.5 are often caused by high carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) concentrations (Ayers and Westcot, 1985).

2.4.2 Electrical conductivity (EC)

Electrical conductivity (EC) is a measure of the ability of water to conduct an electric current, which is carried by various ions in solution such as chloride, sodium, sulphate, nitrate, carbonate, bicarbonate, calcium and magnesium. Electrical conductivity is commonly used as an estimate of the concentration of total dissolved salts (TDS) or total salinity in irrigation water. The instrument used to measure EC is the EC- meter and the standard unit used to express electrical conductivity is deciSiemens per metre (dS/m) or microSiemens per centimeter (μS/cm). One dS/m is equivalent to one thousand microsiemens per centimeter μS/cm. The readings in the instrument are proportional to the concentration of dissolved salts. This implies that lower units of EC indicate low concentration of dissolved salts and vice versa. FAO, 1985 indicated the values of EC less than 3 dS/m as free from salinity (Ayers and Westcot, 1985). Plants take up water through a process of osmo-regulation, wherein elevated salt concentration within plants causes water to move from the soil surrounding root tissue into the plant root. Saline conditions restrict or inhibit the ability of plants to take up water and nutrients, regardless of whether the salinity is caused by irrigation water or soil water which has become saline because of additions of salty water (Bauder *et al.*, 2006).

2.4.3 Sodium content (Na)

The effect of sodium ions in irrigation water is its tendency of reducing infiltration rate and soil permeability (Ayers and Westcot, 1985). Sodium causes soils to disperse or lose soil structure (Akoto, *et al.,* 2010). As soil structure deteriorates soil compaction or tightness will increase and water infiltration, water percolation and root growth are all decreased. If irrigation water contains greater than 50 ppm sodium, it can begin to adversely affect soil structure (Misstear *et al*., 2006). Sodium adsorption ratio (SAR) is the most commonly used parameter for evaluating groundwater suitability for irrigation purposes (Ayers and Westcot, 1985). SAR is calculated using the following formula (Equation 6).

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \quad \text{...} \quad (6)$$

Where: Na, Ca and Mg are sodium, calcium, and magnesium contents in milliequivalent per litre (me/l) respectively. Irrigation water having SAR less than 3 me/l, there is no restriction on use as irrigation water source, 3-9 me/l have slightly to moderate restrictions on use while those having SAR greater than 9 me/l have severe restriction on use as it destroys soil structure and reduce permeability of soil.

2.4.4 Bicarbonate (HCO_3)

Bicarbonates (HCO_3^-) concentration in irrigation waters is primarily important in its relation to calcium (Ca^{2+}) and Magnesium (Mg^{2+}). There is a tendency for both calcium and magnesium to react with bicarbonate in the water and /or soil, precipitating as either calcium carbonate ($CaCO_3$) or magnesium carbonate ($MgCO_3$). Since magnesium carbonate is more soluble, it has a less tendency to precipitate. The precipitation of either calcium or magnesium from water as carbonate salts increases the relative proportion of sodium which directly raises the sodium hazard rating. The acceptable range of HCO_3^- content in irrigation water is from 1.5 to 8.5 me/l. Values greater than 8.5 me/l can severely affect irrigation equipments (Ayers and Westcot, 1985).

2.5 Rice Plant

Rice (*Oryza sativa L.*) is a plant belonging to the family of grasses, Gramineae/Poaceae. There are 12 genera within the *oryzae* tribe (Vaughan, 1994).

The genus *Oryzae* contain approximately 22 species of which 20 are wild and only two (*O. sativa* and *O. glaberrima*) are cultivated (Vaughan, 1994). Chatterjee and Maiti (1985) describe rice plant as an annual grass with round, hollow and jointed culm, flat leaves and terminal inflorescence called panicle.

2.5.1 Morphology of rice

Rice is a typical grass forming fibrous root system, bearing erect culm and developing long flat leaves and multiple tillers which bear panicles that emerges on the uppermost node of a culm from within a flag leaf sheath (Yoshida, 1981; OECD, 1999). The culm consists of a number of nodes and hollow internodes that increase in length and decrease in diameter up the length of the culm. Plant height varies by variety and environment conditions, ranging from approximately 0.4 m to over 5 m in some floating rice varieties (NARI, 2001; IRRI, 2013). Cultivars can vary widely in the length, width, colour and pubescence of the leaves. Grain length varies with cultivar and is between 5 and 7 mm. With SRI practices individual plants may reach, if not complete, the 12th phyllochron and produce more than 80 tillers (Stoop *et al*., 2002). The term phyllochron is used to describe the growth dynamics of cereals. It is defined as the interval of leaf emergence (Nemoto *et al*., 1995).

Rice yield is determined by the grain weight in tonnes/hectare (t/ha). In Tanzania yields of up to 9.91 t/ha has been recorded at Mkindo Irrigation Scheme (Katambara *et al*., 2013). In Madagascar yields of up to 15t/ha have been obtained (Stoop *et al.*, 2002).

2.5.2 Origin of rice

The origin and centres of diversity of two cultivated species *O. sativa* and *O. glaberrima* have been identified using genetic diversity, historical and archaeological evidences and geographical distribution. It is generally agreed that river valleys of Yangtze, Mekon Rivers could be the primary centre of origin of *O. sativa* while delta of Niger River in Africa as the primary centre of origin of *O.glaberrima* (OECD, 1999; Vaughan *et al*., 2003). The foothills of the Himalayas, Chhattisgarh, Jeypore Tract of Orissa, north eastern India, northern parts of Myanmar and Thailand, Yunnan Province of China etc., are some of the centres of diversity for Asian cultigens. The inner delta of Niger River and some areas around Guinean coast of Africa are considered to be centres of diversity of African species of *O. glaberrima* (Chang, 2003).

O. sativa is the most widely grown rice of the two cultivated species. It is grown worldwide, including Asia, North and South America, Europe, Middle East and African countries (Linares, 2002).

2.5.3 Rice ecology

Rice has a semi aquatic life style requiring water particularly during reproductive growth phase. Unlike other crops, rice has the ability to grow in various environments and is also productive in situations where other crops cannot survive. Maclean *et al.* (2002) classified the environments in which rice is grown depending on their hydrological characteristics. These can be classified as irrigated lowland, rainfed lowland, upland and flood prone. Irrigated lowland rice has enough water supplies in the entire growing season. Farmers generally try to maintain ponded water of 5–10 cm in their fields. Rainfed lowland rice is grown in fields that are sometimes flooded with rainwater. In lowland rainfed rice fields there is no assurance of ponded water since rainfall is the only source of water. Flood prone rice is grown in areas where the fields suffer periodically from floods. Deepwater rice and floating rice are common types of flood prone rice. Upland rice is grown under dry land conditions where the only source of water is rainfall (Bouman *et al.*, 2007).

2.6 Rice Growth and Development

The growth of the rice plant is divided into three phases; viz. vegetative, reproductive, and ripening phases (IRRI, 2002). These growth stages are based on data and characteristics of IR64 rice variety, a modern, a high yielding and semi dwarf variety. It has been indicated that in the tropical countries, the reproductive phase is about 35 days and the ripening phase is about 30 days. The differences in growth duration are determined by changes in the length of the vegetative phase. For example, IR64 rice variety, which matures in 110 days, has a 45-days vegetative phase, whereas IR8 which matures in 130 days has a 65-days vegetative phase (IRR, 2002).

2.6.1 Vegetative phase

Vegetative phase is the period from germination to panicle initiation (IRRI, 2002). Germination begins with the emergency of coleorhiza and coleoptile (primary shoot) from the pericarp (seed coat). The radicle gives rise to the seminal root system (Moldenhauer and Gibbons, 2003). The coleoptile elongates along with epicotyle and when coleoptyle reaches the soil or water surface, it split opens and the primary leaf emerges (Mc Donald, 1979). During this early phase of development, the rice plant can produce a leaf every four to five days as the primary culm develops. As the rice plant grows, primary tillers begins to emerge from axial nodes of lower leaves, this gives rise to secondary tillers from which tertiary tillers can develop. When the fifth leaf of the main culm emerges, the first leaf of the tiller comes from the axial of the secondary leaf on that culm (Yoshida, 1981).

2.6.2 Reproductive phase

Reproductive stage begins with panicle initiation. The panicle initiation occurs at the growing tip of the tiller. As the panicle grows inside the flag leaf sheath, senescence of the lower leaves begins. A further three leaves develop before the heading or emergency of the panicle. Flowering typically begins one day after heading and continues down the panicle for approximately up to seven days until all the florets have opened (IRRI, 2002).

2.6.3 Ripening phase

Once the florets were fertilized, ovaries begin to develop into grains. They start filling with white milky fluid as the starch deposit begin to form. The panicle remains green at this stage and begins to bend downwards (IRRI, 2002). Leaves senescence continue from the base of the tillers but the flag leaf and the next two lower leaves remain photosynthetically active. The grain then begins to harden, the husk turn from green into yellow and senescence of the remaining leaves and tillers, then grain become full matured and ready to harvest.

2.6.4 Rice plant and water environment adaptation

Rice is one of the few crops able to withstand periods of partial or even complete submergence. One of the adaptive traits of rice is the constitutive presence and further development of aerenchyma which enables oxygen to be transported to submerged organs (Parlanti *et al*., 2011). Aerenchyma comprises gas filled spaces within plant tissue and is considered anatomical adaptive traits for survival under flood conditions. This adaptation limits the plant's ability to absorb nutrients (Shymashree and Bisht, 2012). Aerenchyma tissues facilitate oxygen diffusion through continuous air spaces from shoot to root.

However, complete submergence due to frequent flooding can adversely affect plant growth (IRRI, 2006).

There was a notion that rice can grow better and produce higher yields when grown under flooded conditions with high investment in higher doses of fertilizer application. Contrary to this popular view, when rice is grown under alternate wetting and drying conditions, (SRI) better crop performance and higher yields were observed. Standing water, in fact, suppresses yield by limiting the ability of roots to respire and slows down the plant's metabolism (Shymashree and Bisht, 2012). Moist conditions as opposed to flooding increases soil aeration and therefore helps in improving soil biology and thus helps in better nutrient availability (WWF-ICRISAT, 2010). Roots of the rice plant can grow deeper and better able to explore more nutrients and better performance.

2.7 Rice Varieties in Zanzibar

Rice (*Oryza sativa L.*) is thought to have been brought to Zanzibar and Kilwa by traders from the far East about 2000 years ago (Carpenter, 1978; Lu and Chang, 1980). According to Koenders, (1992) some rice varieties that were available by then included: - *Ringa*, which was a late maturing variety of up to 150 days. Others were *Kidowa*, *Supa*, *Kidimu*, *Kaniki*, *Malikora*, *Mzurihajipambi*, *Hakuwawiki*. Some of these varieties are rare and others rarely exist. Through introduction of modern varieties mostly from IRRI, a number of improved varieties are now available and include IR64, BKN, BKN-Supa, SUPA INDIA, TXD88, SUBANG, and TXD306 or SARO 5 (the variety introduced from Tanzania Mainland) (Hamima Mzee, field officer, Irrigation Department Zanzibar; personal communication). NERICA varieties, some of which are still under trials include: line IR 08M110, lines IR 07A 166 and IR 77379-33-3-7-19-B (Khatib *et al*., 2013). SUPA BC is a lowland rice cultivar developed through mutation breeding and was recently released in Zanzibar with high performance in grain yield (Khatib *et al*., 2013).

2.8 Conventional Method of Irrigated Rice Cultivation

Most of irrigated rice worldwide is grown under flooded conditions. According to De Datta, (1981), most of the irrigated rice in central Luzon and in other parts of Asia is grown under flooded conditions. Land preparation of fields consists of soaking, plowing and puddling (i.e. harrowing under shallow submerged conditions). Puddling is mainly done for weed control, but also increases water retention and reduces soil permeability, and eases field leveling and transplanting (De Datta, 1981).

The same field preparation applies in Zanzibar. However the actual water requirements for rice are much smaller than the amounts applied by farmers in their fields. In practice under traditional methods, farmers prepare their nurseries and start transplanting when they feel that it is easy to uproot and handle the seedlings, (about 21 days to more than 30 days). There is no specific number of seedlings per hill but normally about three seedlings are used per hill. Flooding rice fields is considered an easy way of weed control coupled by hand weeding. Terminal drainage might sometimes be done during fertilizer application and few days before harvesting just to allow field to dry for ease of harvesting.

2.9 System of Rice Intensification (SRI)

The System of Rice Intensification (popularly known as SRI) is an alternative methodology of rice cultivation instead of traditional flooded cultivation practice. The methodology developed in the 1980s in Madagascar by Fr. Henri de Laulanié (Uphoff, 2006). It is a set of agronomic management practices for rice cultivation that can enhance yield (Kabir and Uphoff, 2007; Namara *et al*., 2008; Senthilkumar *et al.,* 2008) while reducing water requirements (Satyanarayana *et al.,* 2007). SRI rice cultivation involves agronomic changes which include the use of much younger seedlings (8-14 days) than are normally transplanted, planting them singly and carefully in a square pattern with wide spacing in soil that is kept moist but not continuously flooded, and with increased soil amendments of organic matter and active aeration of top soil during weed control operation preferably with a mechanical weeder (Kabir and Uphoff, 2007; Shymashree and Bisht, 2012).

2.9.1 Seedling age under SRI

The key to success with SRI is early transplanting, i.e., before seedlings are 15 days old (before the fourth phyllochron), and as early as 8 to 10 days (Uphoff, 2000). The growing conditions under SRI facilitate an optimum environment for tillering expression by early transplanting. Early transplantation in conjunction with other practices allows a greater realization of the tillering potential of rice plants (Association Tefy Saina, 1992). When rice seedlings are transplanted at the right time in terms of age, tillering and growth proceed normally, only fewer tillers are produced during vegetative period leading to poor yield if transplanting is delayed (Mobasser *et al.*, 2007).

SRI uses much younger seedlings (8-14 days old) compared to 3 to 4 weeks old seedlings in the traditional flooded system. Transplantation of young seedlings at shallow depth of water results in quick recovery and establishment and production of more effective tillers (Biswas, 2010). Manjunatha, *et al.* (2010) observed that 9 days old seedlings produced significant higher grain yield than aged seedlings viz. 15 days. Partha and Samsul (2011) observed higher grain yield in 10 days old seedlings transplanted at 30 cm x 30 cm compared to 12, 14, 16 and 18 days old seedlings in Ultra Pradesh.

Ali *et al.* (2013) conducted experiment in Bangladesh to observe the effect of seedling age and water management on the performance of Boro rice variety BRRID han 28 and found out that transplanting of younger seedlings in combination with intermittent irrigation produced the best results in tiller production, growth dynamics, yield and yield contributing factors. Adoption of younger seedlings, shallow irrigation and mechanical weeder recorded a higher number of tillers at tillering stage (Surya *et al.,* 2011).

2.9.2 Plant spacing under SRI

SRI is a practice which uses agronomic modifications which includes manipulations of plant spacing. Plant spacing is an important production factor in transplanted rice (Gorgy, 2010). Plants largely depend on temperature, solar radiation, moisture and soil fertility for their growth and nutrition requirements. It is necessary to determine appropriate plant population for obtaining maximum yield. Baloch *et al.* (2002).

Densely populated crops have limitations in maximum availability of these requirements. Wider spacing is one of the aspects of agronomic manipulations. Khem and Ram, (2012) observed higher number of tillers in 25 cm x 25 cm spacing and produced higher grain yield compared to 15 cm x 15 cm, 20 cm x 20 cm and 25 cm x 25 cm spacing. Mohamedian *et al.* (2011) in their study on yield and yield components in different plant spacings, recorded high rice yield in plant spacing of 20 cm by 20 cm. Seedlings planted widely spaced, in a square pattern facilitate weeding as well as to give more space between plants, more sunshine and air and can produce more tillers (Shymashree and Bisht, 2012). More of these tillers will become fertile and produce grains of rice. Tripathi *et al.* (2004) reported that the yields obtained under SRI system from the spacing 20 cm x 20 cm produced significantly higher grain yields (8821 kg/ha) compared to 30 cm x 30 cm (7627 kg/ha) and 40 cm x 40 cm (5747 kg/ha).

With more space in which to grow, rice plants roots become larger and are better able to draw nutrients from the soil. This enables rice plants to produce more grains (Association Tefy saina, 1992). From the above explanation it is evident that beside cultivar's potential, the optimum spacing for a particular location has to be determined through field experimentation.

2.9.3 Water use under SRI

Water saving potential is one among the attractive features of SRI. Water requirement under SRI method is considerably low compared to conventional flooded systems Hameed *et al.* (2013). Mohammed and Shuichi (2007) conducted experiment to assess water saving for paddy cultivation under SRI in Indonesia and observed that SRI can achieve significant high output of rice with reduction in inputs, enchasing simultaneously the productivity of resources (land, water and capital) used in irrigated rice production. With SRI practice, water use for irrigated rice cultivation is reduced by 25-50% (Shymashree and Bisht, 2012). On average, 31% and 37% of irrigation water were saved with SRI methods of rice cultivation in Andhra Pradesh compared to the best management practice under continuous flooding (Gopalakrishnan *et al*., 2013).

Yuan (2002) reported that the water applications could be reduced by as much as 65% in SRI plots compared with conventional irrigated ones and at the same time yield was 16 t/ha in trials with a Super-1 hybrid variety grown under SRI methods. The yield was 35.6% higher than the 11.8 t/ha achieved with the same hybrid in conventional water intensive methods.

Using less water for rice production can increase water availability for other crops, promoting diversification of crops and for other sectors such as domestic and industrial uses. One social benefit, hard to quantify, is the advantage of reducing the amount of conflict over water (Uphoff, 2003).

2.9.4 Yield levels under SRI

The System of rice intensification (SRI) is an innovation in rice production systems that are still evolving and ramifying, but already it is raising productivity. In areas where SRI has been practiced there is an increase in yields. Nyamai *et al.* (2012) observed overall SRI production system gave better yield and productivity results than the conventional flooded system in Kenya. Experiment conducted in West Bengal indicated that paddy yields with SRI were higher than those under conventional paddy cultivation by 32% (Sinha and Talati, 2007). Khem and Ram, (2012) observed similar results in India. Partha and Samsul (2011) observed highest yield with 10 days old seedlings in West Bengal.

2.9.5 Water productivity and water use efficiency under SRI

2.9.5.1 Water productivity

According to Molden and Sakthivadivel (1999) water productivity (WP) is defined as the physical mass of production or the economic value of production measured against gross inflows, net inflow, depleted water, process depleted water, or available water. Water productivity denotes the amount or value of product (in this case, rice grains) over volume or value of water used, in other words, crop per drop (Jianxin *et al.*, 2008).Water productivity is also defined as the ratio of the net benefits from crop, forestry, fishery, livestock, and mixed agricultural systems to the amount of water required to produce those benefits (Steduto *et al*., 2007). Water productivity (kg/m^3) is defined as crop yield (kg) per accumulated actual evapotranspiration for the growing season (m^3).

Humphreys *et al.* (2006) emphasise that in computing WP, it is important to specify which water is being considered to produce that amount of grain (rice); water consumed as evapotranspiration (WP_{ET}), or supplied as irrigation (WP_I), or the total input of irrigation and rainfall (WP_{I+R}).

Fonteh *et al.* (2013) conducted experiment in Cameroon on effective water management practices in irrigated rice to ensure food security and mitigate climate change in a tropical climate and found that there was significant variation in crop water productivity between continuous flooding regime (0.285 kg/m^3) and intermittent irrigation (0.537 kg/m^3).

Similar results were observed by Kombe (2012) at Mkindo irrigation scheme (Morogoro, Tanzania) in his experiment to evaluate the performance of SRI in Tanzania on saving water and increasing rice yield as an adaptation strategy to climate change and variability by smallholder rice farmers. Kombe (2012) observed SRI method registered the highest water productivity of 0.47 kg/m^3 as compared to 0.136 kg/m^3 in continuous flooding conditions. In this study WP as described by Humphreys *et al.* (2006) will be adopted.

2.9.5.2 Water use efficiency

Water use efficiency is a term commonly used to describe the relationship between water (input) and agriculture product (output) (Fairweather *et al.,* 1999). Barrett and Associates (1999) correctly point out that efficiency is in fact a dimensionless term obtained by dividing figures with the same units e.g. volume of water used (output) divided by a volume of water supplied (input). Consequently, the tones of produce per megalitre of water used is an index, not efficiency. This common miss-use of the term “water use efficiency” has created great confusion. In this study the definition by Barrett and Associates, (1999) will be adopted. Water use efficiency (WUE) can be defined as the grain yield of irrigated crop in kg/ha divided by actual evapotranspiration, (mm) (Barrett and Associates, 1999) (Equation 7).

$$WUE = \frac{\text{grain yield (kg/ha)}}{\text{Evapotranspiration (mm)}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots\ldots(7)$$

2.10 Performance of SRI in East Africa

SRI was introduced in Tanzania in 2006 in Kilombero rice plantation in Morogoro region (SRI-RICE, 2014). Until 2012 more than 100 SRI demonstration plots have been established by USAID – funded NAFAKA project. The aim was to scale up and reach 5000 small-scale farmers. Other areas that have adopted SRI practice include Mkindo irrigation scheme and Dakawa in the eastern zone of Tanzania. The practice has spread up to the northern regions of Kilimanjaro and Mwanza (Katambara *et al*., 2013). Through SRI practice, farmers in Mkindo managed to raise their rice yield from 3.83 t/ha in conventional method to 6.3 t/ha and reduction by 76% of water use in SRI (Kombe, 2012).

On the other hand, the System of Rice Intensification (SRI) was introduced in Kenya to farmers of Mwea irrigation scheme through a multi-institutional collaborative research project in 2009 (Mati *et al*., 2011). In the same location, SRI gave higher average grain yield (14.85 t/ha) than the conventional flooded system (8.66 t/ha) (Nyamai *et al*., 2012). Besides the high yields obtained in SRI, amount of seeds used was little since seedlings were transplanted singly at a wide spacing. By virtue of using very young seedlings and quick transplanting time, many farmers viewed the practice as a tedious undertaking as very small seedlings need extra care to handle. Moist condition is the preferred moisture regime in SRI and necessitate good drainage network in order to drain excess water.

2.11 Summary of Literature Review

Rice crop is the leading consumer of irrigation water however, by using SRI water use has been reduced by considerable amount contrary to the conventional method of continuous flooding (Biswas, 2010; Bouman and Toung,2001; IWMI, 2007). Grain yield and water productivity has been raised by using SRI principles. Water quality is the most important concern in irrigated agriculture since it can adversely affect the soil properties and finally the yields and therefore call for regular irrigation water quality monitoring. SRI practice besides its basic principles of using young seedlings, wider square spacing, single seedlings, organic fertilizers amendments and maintaining moist conditions during parts of the growing period to enhance productivity, is an innovation in rice production systems that is still evolving and ramifying, creating the need for more diversified research (Katambara *et al*., 2013).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Study location

The research was conducted at Bumbwisudi rice irrigation scheme in Zanzibar Island. The site is situated at 06^0 03′ 32″ S and 39^0 15′ 37″ E and 40 m above mean sea level, about 13 km North West of Zanzibar town Figure 1.

3.1.2 Climate

Temperature of the experimental site fluctuates between the coldest and hottest months and ranges from around 21^0C to around 34^0C. Relative humidity ranges from 73% to 88% between the hot and coldest months respectively. Rainfall is bimodal; there is a long rain season from March to June and a short rain season from October to December. The bimodal distribution of rainfall determines two growing seasons. Mean annual rainfall is 1517 mm. Mean daily sunshine hours ranges from 6.6 hrs to 8.8 hrs during the cloudy and the clear months respectively. Mean monthly solar radiation ranges from 16.2 $MJm^{-2}day^{-1}$ in July (the coldest month) to18.8 $MJm^{-2}day^{-1}$ in January (the hottest month) respectively. Evaporation ranges from 119.8 mm in April to 174.7 mm. Wind run ranges from 2.3 m s^{-1} to 3.6 m s^{-1} in the calm and the windy months respectively (Table 1). During 2013 when the research was conducted, the annual rainfall was 1414.1 mm and its monthly distribution is shown in Table 2. For the growing period September to December 2013, total rainfall was 535 mm and its distribution is shown in Table 3.

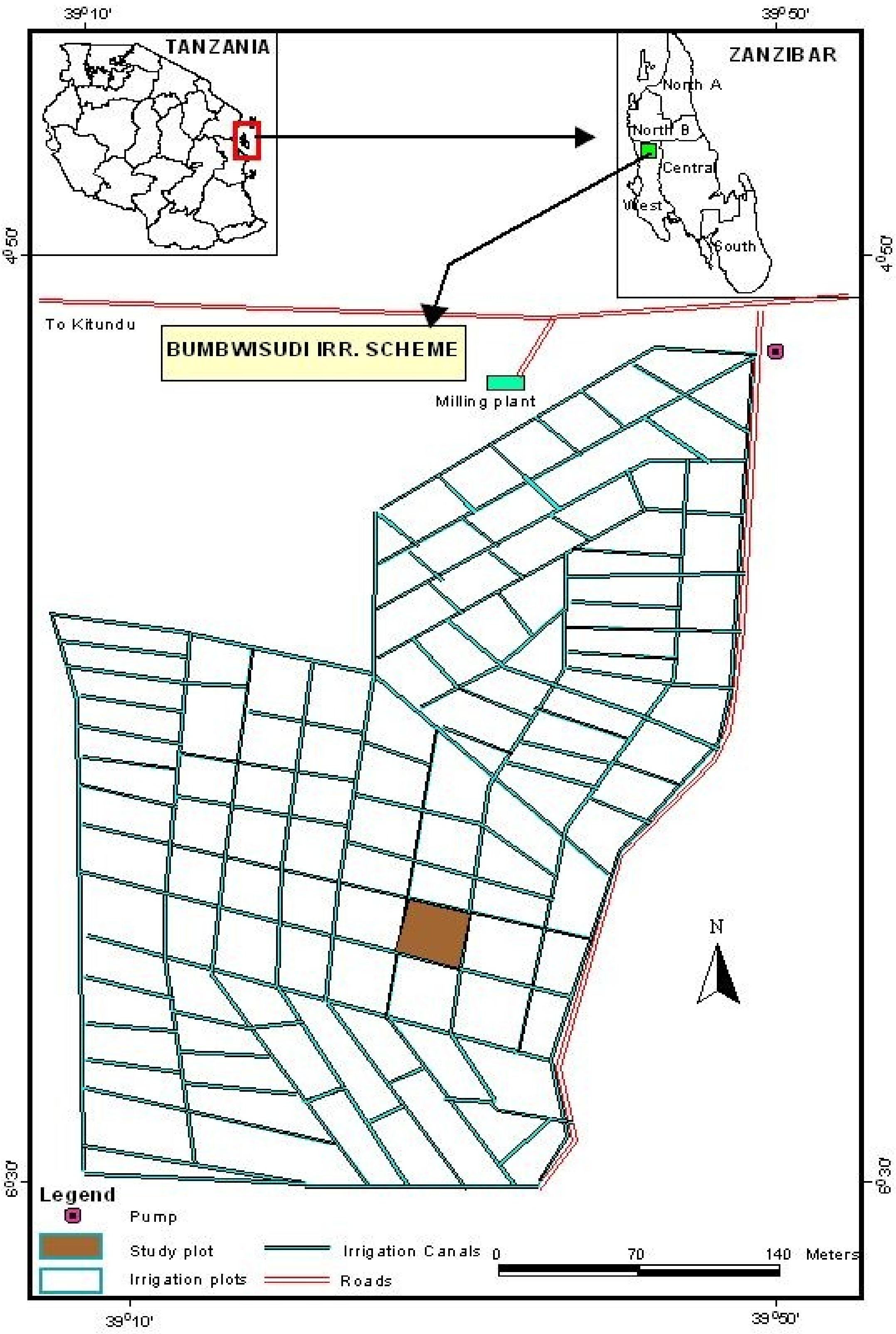

Figure 1: Location of the study area

Source: URT, 2008

Table 1: Climatic parameters from Kisauni meteorological station-Zanzibar (1987-2012)

Month	January	February	March	April	May	June	July	August	September	October	November	December
T_{max} (^{0}C)	32.7	32.8	32.5	30.8	30.0	29.3	29.2	29.6	30.7	31.2	31.0	31.8
T_{min}(^{0}C)	24.5	24.3	24.6	24.5	23.9	23.0	22.2	21.2	21.3	22.3	23.2	24.1
RH (%)	77	77	81.0	84	82	80	76	76	77	79	84	82
Sunshine (hrs)	8.6	8.5	7.5	6.6	6.9	7.9	8.1	8.3	8.5	8.8	8.0	8.5
Solar Radiation (MJ/m^2/day)	18.8	18.7	18.0	16.3	15.6	16.2	16.7	17.0	18.5	18.3	16.3	17.4
Windrun (m/s)	3.4	2.9	2.3	2.9	2.9	3.0	3.6	3.6	3.4	3.1	2.4	2.5

Table 2: Monthly Rainfall distribution (mm) at experimental site for 2013

Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Rainfall	11.8	0.0	334.0	300.2	131.7	36.4	9.9	55.1	44.1	124.0	170.9	196.0

Table 3: Weekly rainfall distribution (mm) recorded at the experimental site from September to December 2013

Month/Weeks	1st week	2nd week	3rd week	4th week	Total
September	7.0	7.4	28.7	1.0	44.1
October	31.5	37.7	5.3	49.5	124.0
November	129.0	1.4	3.8	36.7	170.9
December	112.0	81.4	0.0	2.1	196.0

3.1.3 Soil

The soil of Bumbwisudi in general is good, through observations of good crop stands and vegetation cover. It is dark in colour and has fairly good drainage to support diversity of crops. Considering the geological map of Zanzibar, Bumbwisudi soils originated from Miocene sediments of shallow marine type mainly marls, clays and clayey sands. The underlying strata consist of poorly consolidated but well-bedded calcareous sandstones and detritallimestones, (Johnson, 1983).

3.2 Experimental Design

The experiment was laid out in a Randomized Complete Block Design (RCBD) with 13 treatment combinations replicated three times during the dry (*vuli*) season from September 2013 to January 2014. Treatments were (i) 8 days old seedling transplanted at 20 cm x 20 cm spacing, (2) 8 days old seedlings transplanted at 25 cm x 25 cm spacing, (3) 8 days old seedlings transplanted at 30 cm x 30 cm spacing, (4) 8 days old seedlings transplanted at 35 cm x 35 cm spacing, (5) 10 days old seedling transplanted at 20 cm x 20 cm spacing, (6) 10 days old seedling transplanted at 25 cm x 25 cm spacing, (7) 10 days old seedling transplanted at 30 cm x 30 cm spacing, (8) 10 days old seedling transplanted at 35 cm x 35 cm spacing, (9) 14 days old seedling transplanted at 20 cm x 20 cm spacing, (10) 14 days old seedling transplanted at 25 cm x 25 cm spacing, (11) 14 days old seedling transplanted at 30 cm x 30 cm spacing, (12) 14 days old seedlings transplanted at 35 cm x 35 cm spacing, and (13) 21 days old seedlings transplanted at spacing of 20 cm x 20 cm with two seedlings per hill under continuous flooding (conventional) or control. The individual plot size was 2 m x 4 m (or 8 m^2) and the replications were separated using a 1 m buffer zone and 40 cm between plots. The treatments details and layout are shown in Figure 2 and Table 4 respectively.

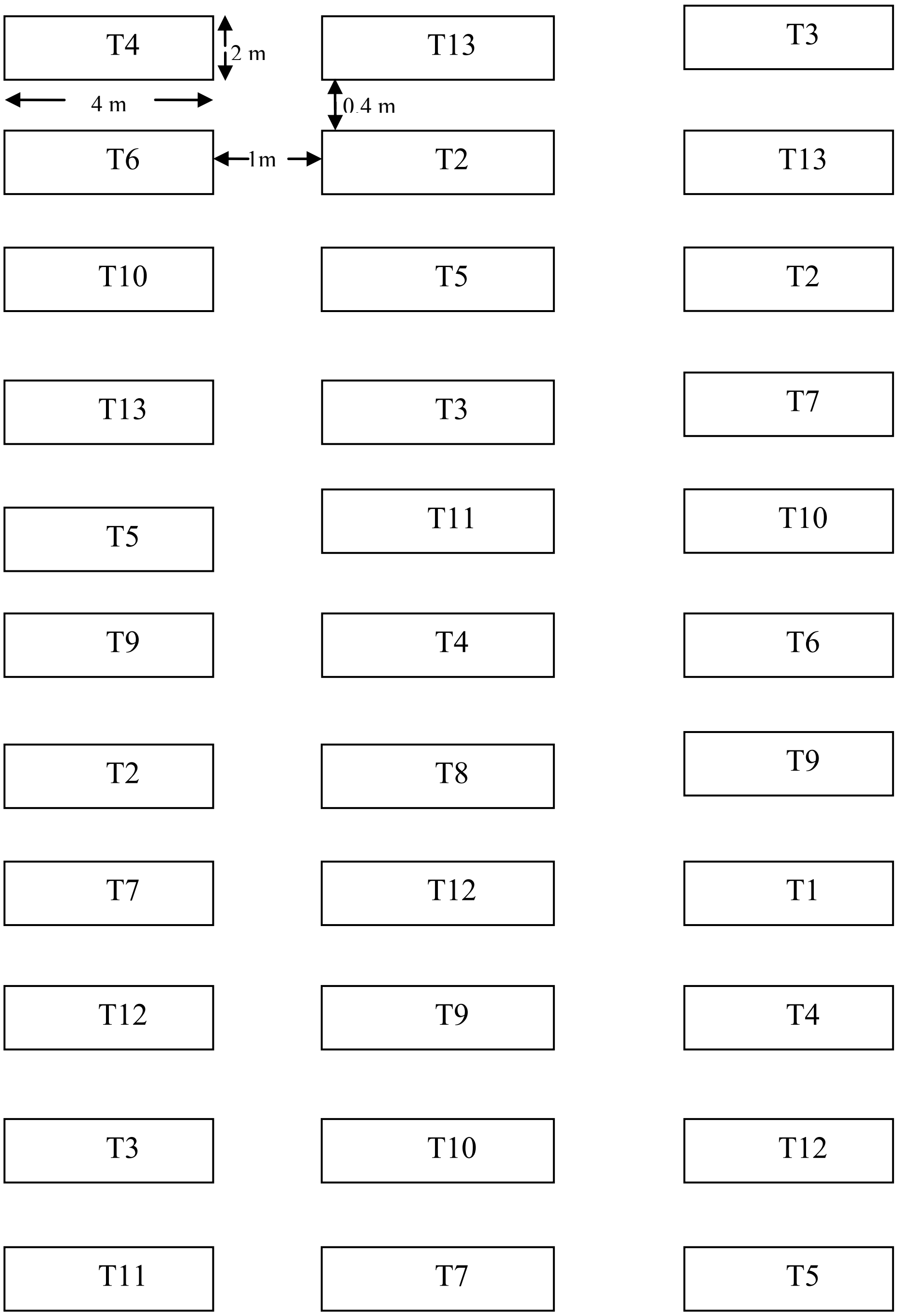

Figure 2: Experimental layout (Randomized Complete Block Design)

Table 4: Treatments details

Treatment	Practice	Transplanting age (days)	No of Seedling (No.)	Spacing (cm)
T_1	SRI	8	1	20 x 20
T_2	SRI	8	1	25 x 25
T_3	SRI	8	1	30 x 30
T_4	SRI	8	1	35 x 35
T_5	SRI	10	1	20 x 20
T_6	SRI	10	1	25 x 25
T_7	SRI	10	1	30 x 30
T_8	SRI	10	1	35 x 35
T_9	SRI	14	1	20 x 20
T_{10}	SRI	14	1	25 x 25
T_{11}	SRI	14	1	30 x 30
T_{12}	SRI	14	1	35 x 35
T_{13}	Control	21	2	20 x 20

3.3 Methodology

The methodology to achieve each of the stated specific objectives is described in the following sections.

3.3.1 Characterization of soil and water quality for paddy rice production

Since crop performance is influenced by fertility status of the soil and quality of water used to irrigate the crop, soil characterization was conducted at the experimental site. Soil samples were collected from four locations in the experimental plot during the month of September 2013. These samples were then mixed thoroughly to obtain composite sample which was sent to the Sokoine University soil laboratory for analysis. Parameters used to define soil fertility status were determined (Landon, 1991). The following parameters were analysed: - soil pH, cation exchange capacity (CEC), total nitrogen (N), available phosphorous (P) and exchangeable bases; calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na).

The pH was measured potentiometrically using glass electrode pH meter in 1: 2.5 soil suspension as described by Maclean (1982). Total nitrogen (N) was determined by Semi-microkjeldahl procedure as described by Bremmer and Malvaney (1982). Available phosphorous (P) was determined by Olsen method, exchangeable bases (Ca) and (Mg) were determined by ammonium acetate extract, potassium (K) was determined by flame photometer and sodium (Na) by atomic absorption spectrophotometer according to Hesse (1971). Results obtained were judged according to Landon (1991).

Water quality analysis was conducted at Sokoine University Soil Science laboratory and the national water laboratory in Saateni Zanzibar, while physical analysis was done through physical observation. The laboratory analysis includes pH, electrical conductivity (EC), sodium (Na), calcium (Ca), magnesium (Mg) and bicarbonate (HCO_3). Soluble salts in irrigation water are measured using the same basic methods as soil samples (Camberato, 2001).

The pH was measured potentiometrically using glass electrode pH meter as described by Maclean (1982). EC was measured by conductivity meter. Na was measured by atomic absorption spectrophotometer according to Hesse (1971). Ca and Mg content were determined by EDTA titration (Jackson, 1958). Bicarbonate was determined titrimetrically as outlined in Black (1965). The above mentioned chemical characteristics are the most commonly used parameter for evaluation of groundwater suitability for irrigation purposes (FAO, 1985).

3.3.2 Determination of optimum transplanting age of seedlings under SRI practice

In determination of optimum transplanting age of seedlings under SRI the following activities were conducted.

a) Land preparation

The experimental field was prepared using ox-plough during the month of September 2013 and then it was subdivided into 39 sub plots of 2 m x 4 m. Plots were then levelled for even distribution of water and nutrients. Super BC rice variety which is preferred by most farmers in the scheme (because of its palatability and promising yield) was used in the experiment.

b) Nursery preparation

Nursery was prepared on 2 September 2013 on another plot and rice seeds were sown on 6 September for all the treatments. Chick liter was applied as organic fertilizer in nursery preparation.

c) Transplanting

Transplanting was done manually when the seedling ages was 8 days, 10 days, 14 days and 21 days respectively. First transplanting was done on 14 September, the second transplanting was on 16 September, the third transplanting was on 20 September and for the control it was done on 26 September 2013. Transplanting of SRI was done using a single seedling per hill on a square pattern at different spacing ranging from 20 cm x 20 cm to 35 cm x 35 cm as described in (Table 4). Seedlings were removed from nursery with the help of stick during uprooting because they were small and to avoid root trauma.

3.3.3 Determination of optimum spacing that gives maximum productive tillers and yield

Spacing that gives maximum productive tillers was obtained by transplanting single seedling per hill on a square pattern at different spacing ranging from 20 cm x 20 cm, 25 cm x 25 cm, 30 cm x 30 cm and 35 cm x 35 cm as described in (Table 4). Optimum spacing was determined by counting the number of productive tillers

(tillers that bear grains) in each treatment. The treatment in which the number of productive tillers produced high grain yield was considered as optimum.

3.3.4 Evaluation of water productivity and water use efficiency under SRI practice and conventional method

In order to be able to determine crop water productivity the cumulative amount of irrigation water applied to the treatments and yields were determined. The amount of water input was measured using a V-notch weir by measuring depths of flow above the weir for each irrigation application and duration of irrigation was recorded. The crop water productivity was determined by dividing the grain yield by accumulated irrigation water. Water use efficiency was determined by dividing the grain yield by accumulated water evapotranspirated by the crop to produce that yield. The computation of discharge and irrigation water input were determined using the equation from the International Organization of Standards publication 4371 (ISO, 1984) (Equation 8).

$$Q = \sqrt{\frac{g}{2}}\left(h/0.795\right)^{5/2} \tan\frac{\theta}{2} \quad \text{...} (8)$$

Where: h = measured water depth in m

Q = discharge in m^3/s

θ = apex angle in degrees

g = Acceleration due to gravity = 9.8066 m/s^2

Discharges were multiplied by irrigation time to obtain volume of water applied.

The following agronomic interventions were implemented;

a) Fertilizer application

The above mentioned objectives were successfully achieved with proper crop husbandry which includes fertilizer application and regular weeding. Organic and inorganic fertilizers were applied in combination. For the organic fertilizer chick litter was applied at a rate of 6000 kg/ha applied 2 days before first transplanting while Triple Super Phosphate (TSP) was applied during transplanting at a rate of 25 kg/ha. Urea 46% N was applied at a rate of 125 kg/ha in two splits; one at two weeks after transplanting just after first weeding and the other at eight weeks after transplanting.

b) Weeding

First weeding was done two weeks after transplanting using hand hoe and subsequent weeding was done at 10 days intervals using a push weeder. Weeding was done five times during the experimental period. This frequent weeding was a result of vigorous weed development favoured by alternate wetting and drying; the key component of SRI.

3.4 Data Collection

3.4.1 Climatic data

Climate data were collected from Kisauni meteorological station about 6 km from the study area (Table 1). The data included average maximum and minimum temperatures in (°C), average rainfall and evaporation in (mm), mean relative humidity in (%), mean solar radiation in ($MJ/m^2/day$), mean sunshine hours in (hrs) and wind run in knots. Rainfall data for the study year 2013 were collected from

Kizimbani agricultural station about 3 km from the study area and they are summarized in (Table 2).

3.4.2 Crop performance

Crop performance was monitored through observation and field measurements of the following growth parameters: number of tillers per plant on a weekly basis and plant heights (from soil surface to the tip of epical leaf). In each plot three plants were randomly selected by zig-zag walking and marked for crop performance monitoring and the average figure was taken and recorded. Number of tillers was recorded on a weekly basis starting from the second week after transplanting.

3.4.3 Yield and yield components

Total number of tillers and productive tillers per hill were taken at maximum tillering time and during harvesting. Grain yield and total biomass were measured after harvesting by digital electronic balance when rice grain moisture content was at 16%. Yields of all treatments were then compared. Quadrants of 1 m x 1 m located at the centre of each plot (to avoid edge effect) were harvested for the yield measurements. Entire plants above the ground in the quadrant were harvested.

3.4.4 Irrigation water monitoring

Irrigation water management was monitored under two scenarios. One was continuous ponding in the control plots throughout the entire growing period up to two weeks before harvesting time where irrigation was stopped. The second one was alternate wetting and drying (SRI). The time for the next irrigation was determined through physical observation. The appearance of fine cracks in the soil determined subsequent irrigation.

3.4.5 Crop water productivity

The amount of water used during the entire period of crop development was measured as described in section 3.3.4 and cumulative amount were determined and used together with grain yield to determine the crop water productivity and land productivity.

Water productivity (WP) was calculated as the ratio of grain yield to total water used (TWU) through irrigation and rainfall, expressed in kg/m^3 (Pereira, *et al.,* 2012; Humphreys *et al.,* 2006). Beldera *et al*. (2004) in a study on the effect of water-saving irrigation on rice yield and water use in typical lowland conditions in Asia, also expressed water productivity as the grain yield by total water input.

3.4.6 Crop water use efficiency

Crop water use efficiency is defined by agronomists as crop production (kg) divided by evapotranspiration (mm) (Barrett and Associates, 1999) equation (7). Water use efficiency (WUE) was determined by dividing the grain yield of irrigated crop in (kg/ha) divided by actual evapotranspiration, ETc (mm)

$$WUE = \frac{\text{grain yield (kg/ha)}}{\text{Evapotranspiration (mm)}} \quad \text{...(7)}$$

Crop evapotranspiration (ETc) was computed by the product of reference evapotranspiration (ETo) and crop coefficient (kc) values for the respective growth stages of a crop. ETo was computed using ETo calculator software (Raes, 2009).

ETc = ETo x kc……………………………………………………………………. (1)

Where:

ETc = crop evapotranspiration (mm)

kc = Crop coefficient of a crop depends on the growth stage (Table 5).

ETo = Reference evapotranspiration (mm/day).

Monthly ETc was determined by multiplying daily ETc by number of days in a month and seasonal crop evapotranspiration was computed by addition of monthly ETc's.

Seasonal crop water requirements for rice during dry (*vuli*) season is about 612 mm. (Table 6). The value was obtained by multiplying reference evapotranspiration data by crop coefficient (kc) values starting the initial stage of rice crop in the month of September.

Table 5: Kc values for paddy rice

Climate	Little wind		Strong wind	
Growth stage (days)	Dry	Humid	Dry	Humid
0-60 days after transplant or direct sowing	1.1	1.1	1.1	1.1
Mid-season	1.2	1.05	1.35	1.3
last 30 days before harvest	1.0	1.0	1.0	1.0

FAO, 1986

Table 6: Seasonal crop water requirements ETc (mm) for paddy rice

Months	September	October	November	December	January	Total
ETo (mm/day)	4.4	4.3	4.0	4.1	4.7	
Kc	1.1	1.1	1.06	1.03	0.5	
ETc (mm/day)	4.8	4.7	4.2	4.2	2.4	
ETc (mm/month)	144	141	126	126	75	612

3.4.7 Water quality analysis

Irrigation water quality was assessed in terms of its quality parameters by laboratory determination of most important water quality parameters; the pH, total dissolved solids measured in electrical conductivity (EC), sodium content measured in sodium adsorption ratio (SAR) and bicarbonate. Results were compared with the ones in the guidelines for evaluation of water quality for irrigation (Table 11).

3.5 Data Analysis

Data for paddy growth and yield parameters, (plant height, number of tillers, productive tillers, grain yield, total biomass water productivity, irrigation water, and water use efficiency) all were subjected to an analysis of variance (ANOVA) according to Gomez and Gomez (1984) using Genstat computer software. Treatment means separation was done by using Tukey's studentized range test at 95% confidence limit (Stern *et al*., 2001).

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 Soil Physical and Chemical Properties

Results for soil physical and chemical properties are summarized in (Table 7) and the description is as follows.

4.1.1 Soil pH

The pH of Bumbwisudi soil is 7.28, and it is within the neutral range of (6.6 - 7.3) which is suitable for most field crops. Samanta *et al*. (2011) conducted Land suitability analysis for rice cultivation based on multi-criteria decision approach in Morobe Province, Papua New Guinea through GIS and adopted the criteria for its suitability rated as 1 – suitable 2- moderately suitable and 3 – unsuitable for rice cultivation (Table 8). Since the Bumwisudi soil pH is within the range of moderately suitable; it can be judged as suitable for irrigated rice production.

4.1.2 Soil texture

The results showed that the soil of the study area had 54% sand, 13% silt and 33% clay. From the soil texture triangle the Bumbwisudi soil is sandy clay loam which is suitable for rice cultivation (De Detta, 1981). Such type of soil is capable of holding water for long period and support good rice crop (Chatterjee and Maiti, 1985).

Table 7: Physico-chemical properties of soil of experimental site

Chemical property	Quantity	Description
Sand	54	
Silt	13	
Clay	33	
Texture: Sand clay loam		Suitable for rice production
pH,	7.28	Neutral
Cation exchange capacity (CEC) (cmol/kg)	26.4	High
Total Nitrogen (%)	0.12	Low
Exchangeable bases		
Calcium (Ca^{2+}) (cmol/kg)	8.65	Medium
Magnesium (Mg^{2+}) (cmol/kg)	2.2	Medium
Potassium K^+ (cmol/kg)	0.01	Very low
Sodium (N^+) (cmol/kg)	0.50	Medium
Extractable Phosphorous (P) (mg/kg)	2.68	Low

Table 8: Soil pH, nitrogen (N), phosphorus (P) and potassium (K) suitability rating for rice

Soil pH	Rating	Nitrogen (%)	Rating	Phosphorus (ppm)	Rating	Potassium (ppm)	Rating
6.0- 7.0	1	High(> 0.5)	1	High >20	1	High >20	1
7.0 - 8.0	2	Moderate 0.2 to 0.5	2	Moderate 10 to 20	2	Moderate 10 - 20	2
5.0 - 6.0	2						
< 5.0	3	Low <0.2	3	Low <10	3	Low <10	3
> 8.0	3						

Source: Samanta *et al*., 2011

4.1.3 Total nitrogen (N)

The nitrogen content of Bumbwisudi irrigation scheme soil was 0.12% (Table 7). According to Landon, (1991) (Table 9); and (Samanta *et al.,* 2011) (Table 8); this amount is low. Low nitrogen levels are common in humid tropical soils and might be attributed to poor soil fertility management practices and this was evident during the experimental period, few farmers were observed to apply organic fertilizers. It was also observed that animals were grazed in rice plots therefore low N contribution from crop residues. Very low nitrogen level in Bumbwisudi (0.14%) was also observed by Hamad (2000). According to Ponnamperuma (1972) is low for normal rice growth.

Table 9: Rating of soil fertility

	Very low	low	Medium	High	Very high
Organic matter (%)	<1.0	1– 2	2 – 4	4 – 6	> 6
Total nitrogen N (%)	< 0.05	0.05 – 0.1	0.1 – 0.2	0.2 – 0.3	>0.3
Exchangiable Ca (cmol$^{(+)}$/kg)	< 2	2 – 5	5 – 10	10 – 20	> 20
Exchangiable Mg (cmol$^{(+)}$/kg)	< 0.5	0.5 – 1.5	1.5 – 3.0	3.0 – 8.0	>8.0
Exchangiable K (cmol$^{(+)}$/kg)	< 0.1	0.1 – 0.3	0.3 – 0.6	0.6 – 1.2	>1.2
Sum of exchangeable bases(cmol$^{(+)}$/kg)	< 3.0	0.3 – 7.5	7.5 – 15	15 - 30	> 30
Available P (mg/kg)	-	< 7	7 – 20	> 20	-

Source: Landon, 1991

4.1.4 Exchangeable calcium (Ca)

The calcium content of the soils at Bumbwisudi irrigation scheme was 8.65 cmol/kg soil (Table 7). According to Landon, (1991) (Table 9); this amount is high and probably is associated with the soil parent material being of limestone and sandstone (Jonson, 1973). Comparing with the results obtained by Hamad (2000) (3.03 cmol/kg) Ca content in soil was low indicating considerable increase in calcium content and might be added from the applied irrigation water.

4.1.5 Exchangeable magnesium (Mg)

Magnesium content in Bumbwisudi soil was 2.2 cmol /kg (Table 7). This amount was rated as medium according to Landon, (1991) (Table 9). Hamad, (2000) observed similar result (2.31 cmol/kg). The results showed that the Mg content is fairly constant. This situation might be attributed to continuous flooding method of irrigation. Flooding of paddy fields may cause leaching of soluble plant nutrients including Mg. Another cause of small increment in Mg content in Bumbwisudi soil is the removal of paddy straw by grazing cattle from the paddy fields and very low rates of organic matter application. This situation was observed during study period.

4.1.6 Exchangeable potassium (K)

The exchangeable potassium in Bumbwisudi soil was 0.01 cmol/kg soil (Table 7). According to Landon, (1991) (Table 9); this amount is very low. However, according to Samanta, *et al*. (2011) the amount is low and therefore the soils are not suitable for rice cultivation. Potassium is important in regulating water use efficiency in plant (Mengel and Arneke, 1982). The opening of stomata is associated with the concentration of Potassium surrounding the stomata.

4.1.7 Cation exchange capacity (CEC)

Cation exchange capacity of the soil of experimental area was 26.4 cmol/kg soil (Table 7). According to (Landon, (1991) (Table 9), this value is considered as high. When considering individual exchangeable base, large proportion of CEC was contributed by large amount of exchangeable Ca^{2+} and large amount of exchangeable Ca^{2+} might be associated with the lime parent materials underlying the soil (Jonson, 1973).

4.1.8 Extractable phosphorous (P)

Results showed that the soil of the experimental site has 2.86 mg P /kg soil (Table 7). According to Landon, (1991) (Table 9), this amount is low. The low P value might be the result of intensive rice cultivation with suboptimal application of P fertilizers and removal of rice straws after harvest, indicating the necessity of high P fertilizer amendments. The practice of removing rice straws was observed once after harvest cattle were grazed in rice plots remove all straws which after decomposition is a good source of P in the plots. Phosphorous in plant influence root development particularly of the lateral and fibrous roots. It strengthens the straw in cereal crops and therefore prevents lodging (Brady and Weil, 2007).

4.2 Determination of Water Quality for Paddy Rice Production

The results for water analysis are shown in Table 10. It was said in advance that the water quality is assessed in terms of its quality parameters; the pH, dissolved solids measured in electrical conductivity (EC), sodium content measured in sodium adsorption ratio (SAR) and bicarbonate being the most important ones.

Table 10: Chemical properties of Bumbwisudi irrigation water source

Chemical property	Quantity	Normal range (FAO,1985)
pH	8.26	6.5 – 8.4
Electrical conductivity (EC) (dS/m)	0.53	< 3.0 dS/m
Sodium (N) (me/l)	6.5	0 - 40
Calcium (Ca) me/l	4.8	0 - 20
Magnesium (Mg) me/l	2.9	0 - 5
Bicarbonate (HCO_3) (me/l)	4.3	< 8.5
Sodium adsorption ratio (SAR) (me/l)	3.3	< 9.0

4.2.1 pH

The pH of the irrigation water at Bumbwisudi irrigation scheme was 8.26 (Table 10). According to the guidelines for evaluation of irrigation water quality, accepted pH range for irrigation water is from 6.5 to 8.4 (Ayers and Westcott, 1985). Since the pH value is within the standard range for irrigation, the Bumbwisudi water source could be judged as good for irrigation purposes. The value is close to the maximum limit of accepted pH, care must be taken in ensuring that the pH does not shift outside the normal range through regular seasonal monitoring to check if there are additional basic cations in the irrigation water that would slightly elevate the pH.

4.2.2 Electrical conductivity (EC)

Electrical conductivity (EC) of Bumbwisudi irrigation water source was 0.53 dS/m. According to water quality standards it is within the range of none restrictions, i.e. less than 0.7 dS/m. According to guideline for evaluation of water quality for irrigation (Ayers and Westcott, 1994), water with EC values less than 0.7 dS/m and TDS values less than 450 mg/l has low salinity level and non restrictions on use

(Table 11). The irrigation water used in the study area can therefore be classified as having low salinity hazards and can be used as source of irrigation water without restrictions and may not pose any injury to the crops.

Table 11: Guidelines for evaluation of water quality for irrigation

Potential irrigation problem	Units	Degree of restriction on use		
		None	Slight to moderate	Severe
Ec_w	dS/m	< 0.7	0.7 - 3.0	> 3.0
Sodium (N)				
Surface irrigation	SAR	< 3	3 - 9	> 9
Bicarbonate (HCO_3)	me/I	< 1.5	1.5 - 8.5	> 8.5
pH		Normal range 6.5-8.4		

Source: FAO, 1985

4.2.3 Sodium (N) measured in sodium adsorption ratio (SAR)

The sodium content of Bumbwisudi water source was 6.5 me/l while SAR was 3.3 me/l (Table 10). According to the guideline for evaluation of water quality for irrigation (Table 11) amount of sodium present is within the accepted range and can be judged as free from sodium hazards. Low value of SAR it implying that there is no influence of sea water intrusion in the water source of the study area. SAR is determined using equation (6) or Nomograph in Appendix 1.

4.2.4 Bicarbonate (HCO_3)

Bicarbonate (HCO_3) content in the Bumbwisudi irrigation water was 4.3 me/l. The bicarbonate content fall in the range of slightly to moderate in the guideline for evaluation of water quality for irrigation. Since the (HCO_3) value is within the standard range for irrigation, the Bumbwisudi water source could be judged as good for irrigation purposes (Bauder *et al.,* 2007; FAO, 1985). Referring to Table 11, water can be used for irrigation but with slight to moderate restrictions on use.

4.3 Effect of Seedling Age and Spacing on Tillering Pattern

Tillering pattern is shown in Table 12. There was no additional tiller during the first week and tillering started effectively on the second week after transplanting and this might be attributed to the plant recovery time. There was significant difference in tillering ability among treatments, treatment T_1 (8 days, 20 x 20 cm) spacing and T_9 (14 days, 20 x 20 cm) were statistically significant at ($P \leq 0.05$), T_{10} (14 days, 25 x 25 cm) was statistically different to T_1 (8 days seedling age, 20 x 20 cm). Except for T_1, the rest of the treatments were not statistically significant at ($P \leq 0.05$). Large number of tillers was observed at 8 days seedling age and spacing 20 cm x 20 cm. while T_{10} recorded the lowest number of tillers at this stage. This could be attributed by the delayed transplanting of T_{10}.When T_{10} was transplanted a week later, T_1 was already established. Transplanted rice takes little longer time period to start tillering as it first needs more time to recover from transplanting shock (Veeramani *et al*., 2012). During the second week after transplanting, T_5, (10 days, 20 x 20 cm), T_9 and T_{10} were statistically different to T_1 at ($P \leq 0.05$).

Table 12: Effect of seedling age and spacing on tillering pattern at different growth stages of rice under (SRI)

Treatment combination	Number of tillers					
	2nd week	3rd week	4th week	5th week	6th week	7th week	8th week
8dys 20x20	7.333 b	15.000 b	20.00 d	33.67 ef	35.67 de	38.33 abc	39.00 abc
8dys 25x25	4.667 ab	11.333 ab	18.00 bcd	35.67 fg	38.33 e	45.67 cde	46.00 cde
8dys 30x30	6.333 ab	9.667 ab	19.00 cd	37.33 g	42.67 f	48.00 de	49.00 de
8dys 35x35	5.333 ab	10.000 ab	20.00 d	41.00 h	47.00 g	49.67 e	49.67 e
10dys 20x20	4.667 ab	8.000 a	15.67 abc	29.33 bcd	32.33 bcd	41.67 abcd	42.33 abcde
10dys 25x25	4.667 ab	8.667 ab	13.67 a	29.33 bcd	32.33 bcd	35.67 a	35.67 a
10dys 30x30	4.333 ab	8.667 ab	15.00 ab	30.67 cde	33.67 cd	43.67 bcde	45.33 cde
10dys 35x35	5.333 ab	11.667 ab	20.67 d	32.67 def	35.67 de	41.33 abcd	42.00 abcd
14dys 20x20	4.000 a	8.000 a	14.67 ab	24.67 a	27.33 a	36.67 ab	37.33 ab
14dys 25x25	3.333 a	7.000 a	13.00 a	24.00 a	26.67 a	35.33 a	36.00 a
14dys 30x30	4.333 ab	10.000 ab	17.33 bcd	26.00 ab	29.00 ab	42.67 abcde	43.67 bcde
14dys 35x35	5.000 ab	9.333 ab	17.33 bcd	28.67 bc	31.67 bcd	40.33 abcd	40.67 abc
21dys (Control)	5.000 ab	9.333 ab	14.67 ab	27.00 ab	30.00 abc	38.33 abc	38.67 abc
Mean	5.03	9.74	16.85	30.77	34.03	41.33	41.95
F. probability	0.017	0.019	< 0.001	< 0.001	<0.001	<0.001	<0.001
S.E	1.05	2.165	1.212	1.166	1.352	2.609	2.455
C.V	20.9	22.2	7.2	3.8	4.0	6.3	5.9

All the rest of the treatments were not statistically significant at ($P \leq 0.05$) but T_1 was statistically different to the rest of the treatments in terms of tiller production.

In the third week after transplanting the results showed that T_6 (10 days, 25 x 25 cm).and T_{10} were statistically different to T_1, T_2, (8 days, 25 cm x 25 cm), T_3 (8 days, 30 x 30 cm), T_4, (8 days, 35 x 35 cm), T_8, (10 days, 35 cm x 35 cm), T_{11} (14 days, 30 x 30 cm) and T_{12}, (14 days, 35 x 35 cm). T_3 was statistically different to T_6, T_7, T_9, T_{10} and T_{13} (control). The treatment T_8 recorded the highest number of tillers while T_{10} recorded the lowest number of tillers.

During the fifth week after transplanting T_9 and T_{10} were statistically different to T_1, T_2, T_3 T_4, T_5, T_6 T_7, T_8 and T_{11}. T_4 recorded the highest number of tillers while T_{10} recorded the lowest number.

During the sixth week after transplanting the number of tillers in treatments T_1, T_2, T_3 T_4, and T_8 were statistically different with T_9, T_{10}, T_{11} and T_{13}.

During the seventh week after transplanting there was significance difference in tiller production between T_4 and T_1, T_5, T_6, T_8, T_9, T_{10}, T_{12}, and T_{13}.

During the eighth week after transplanting T_4 (8 days, 35 x 35 cm) recorded the higher number of tillers and T_6 (10 days, 25 x 25 cm) recorded the lowest number. T_4 was statistically different to T_1, T_6 T_8 T_9, T_{10}, T_{12} and T_{13}. In each growth stage from second week to week eight after transplanting there is a common trend of tiller production. Maxima numbers of tillers under SRI were observed in young seedlings

(8 days old) and minima numbers of tillers were observed in 14 days old seedlings at transplanting. Young seedlings had ample time to recover and started production of tillers earlier where older seedlings stayed longer in nursery and therefore loose potential of producing more tillers (Mobasser *et al*., 2007).

In each of the treatments there was an increase in number of tillers as the age of the plants increase. This trend is shown in Figure 3, 4 and 5. The same trend of tiller production was observed by Partha and Samsul (2011). They observed an increase in tiller number from 30 days after transplanting to 60 days after transplanting (8 week). There was a gradual increase in tiller production between week 4 and week 6 after transplanting (Figures 3, 4, and 5). Similar trend was also observed by Fonteh *et al*., (2013).

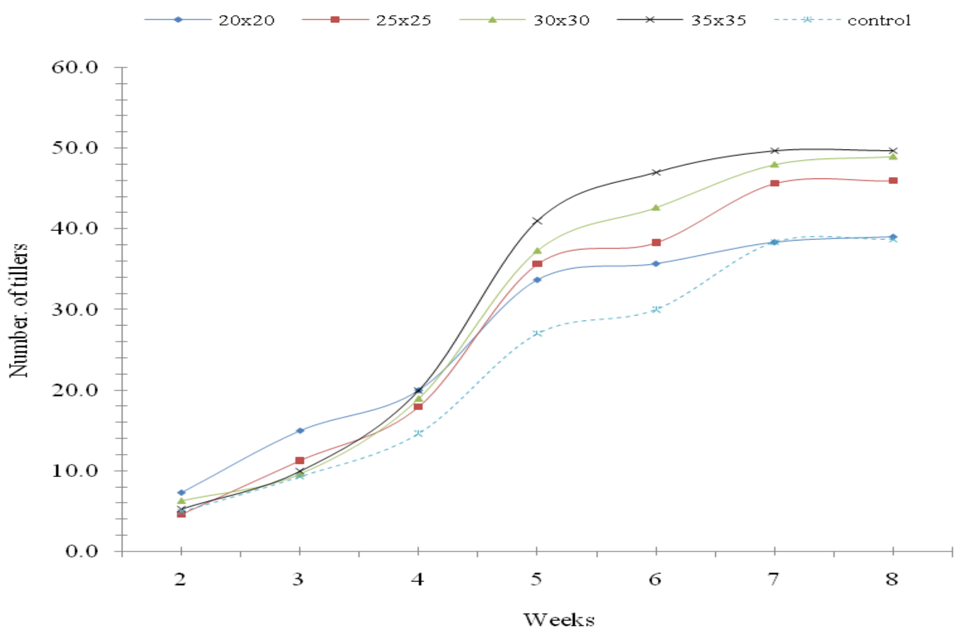

Figure 3: Weekly tiller production for 8 days old seedling

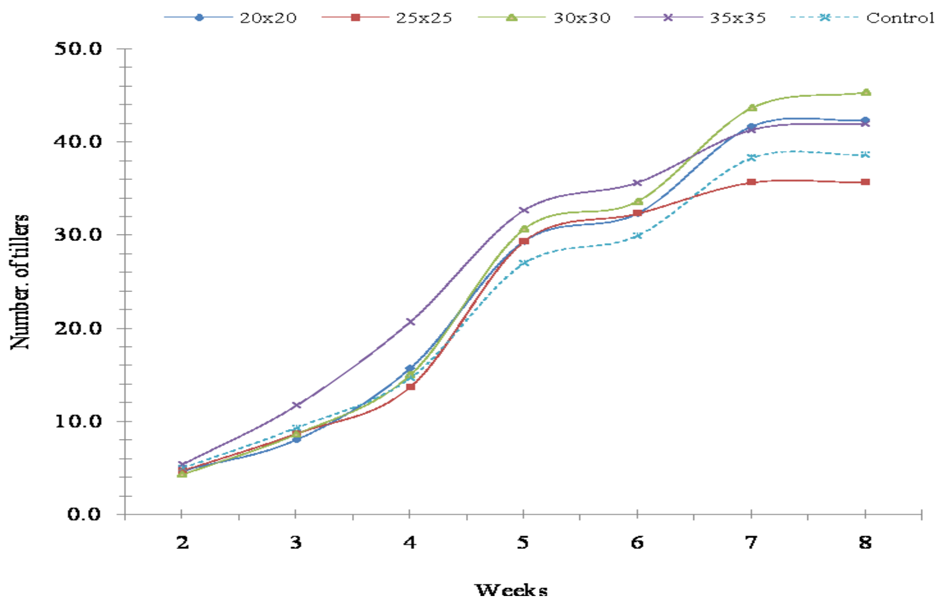

Figure 4: Weekly tiller production for 10 days seedling

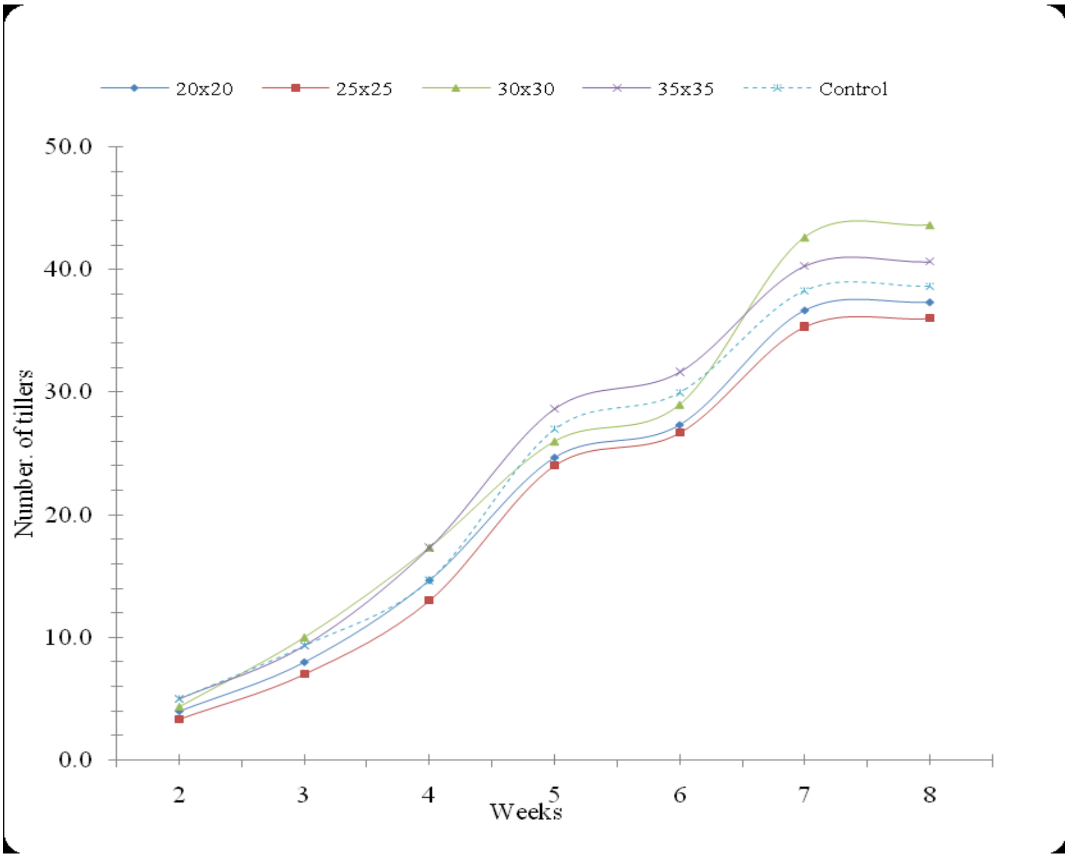

Figure 5: Weekly tiller production for 14 days old seedling

4.4 Effect of Seedling Age and Spacing on Total Number of Tillers and Productive Tillers Per Hill

Treatment T_3 (8 days 30 cm x 30 cm) was observed to have higher number of tillers per hill (51/hill) compared to other treatments (Figure 6) and it was significantly different at ($P \leq 0.05$) to T_1, T_5, T_6 T_8 T_9, T_{10}, $T_{11}T_{12}$ and T_{13} (Table 13). However, T_1, T_6, T_8, T_9, T_{10}, T_{11}, T_{12} and T_{13} were not significantly different at ($P \leq 0.05$). Treatment T_3 was not significantly different at ($P \leq 0.05$) to Treatments; T_2, T_4, T_5 and T_7 in terms of total tiller production (Table 13).

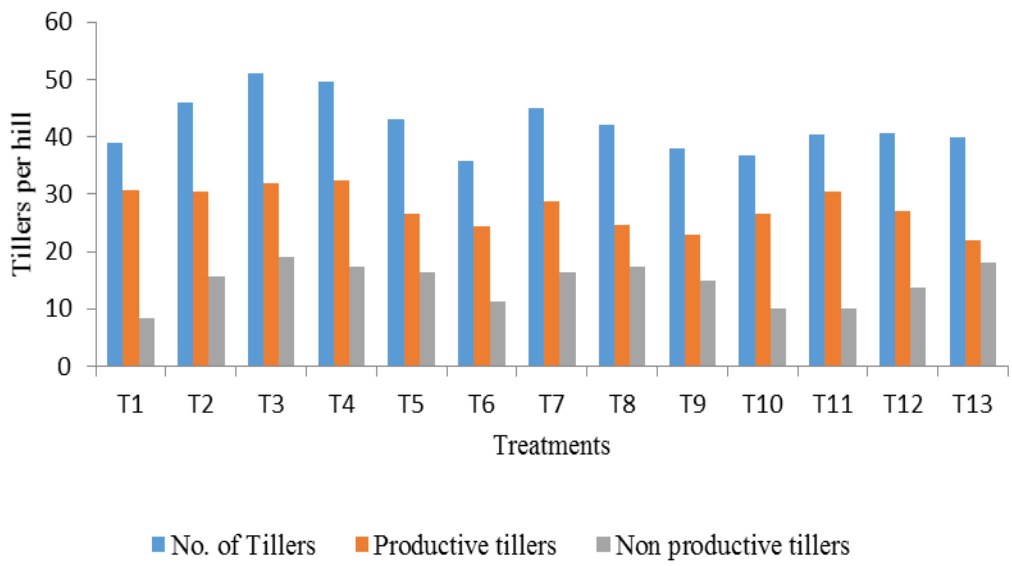

Figure 6: Total tillers, productive tillers and non-productive tillers

There was no significant difference at ($P \leq 0.05$) in terms of number of productive tillers per hill between treatments T_3 and T_4 but they are statistically significant to T_9 and T_{13} (Table 13). The difference in the growth of tillers and productive tillers among treatments is shown in Figure 6. This situation was also observed by (Sinha and Talati, 2007, Shymashree and Bisht, 2012). There was an increase of 44.8% in the number of productive tillers in SRI treatment as compared to continuous flooding treatment. The same trend was observed on the total number of tillers; there was an increment of 27.5% in total number of tillers in SRI treatment as compared to continuous flooding (Table 13).

Table 13: Mean effects of seedling age and spacing combinations on growth and yield parameters of rice under SRI condition

Treatment combinations	No. of tillers	Prod. tillers	Plant height (cm)	Grain yield (tons/ha)	Straw yield (t/ha)	Total biomass (t/ha)	Harvest index	Water productivity (kg/m^3)	Water use eff. (kg/ha.mm)
8dys 20x20	39.00 abcd	30.67 ab	76.33 a	7.38 f	7.780 b	15.16 d	0.49 a	0.44 bc	11.882 c
8dys 25x25	46.00 def	30.33 ab	83.53 a	5.68 abcd	5.850 a	11.53 abc	0.49 a	0.38 bc	9.147 ab
8dys 30x30	51.00 f	32.00 b	79.77 a	6.413 de	7.320 ab	13.73 cd	0.47 a	0.42bc	10.327abc
8dys 35x35	49.67ef	32.33 b	75.57 a	6.187 bcde	6.600 ab	12.03 abc	0.45 a	0.41 bc	8.749 ab
10dys 20x20	43.00 bcde	26.67 ab	73.67 a	6.347 cde	7.267 ab	13.61 bcd	0.47 a	0.45 b	10.22abc
10dys 25x25	35.67 a	24.33 ab	79.20 a	6.690 ef	6.493 ab	13.18 bcd	0.51 a	0.41 bc	10.773bc
10dys 30x30	45.00 cdef	28.67 ab	79.00 a	5.380 ab	6.480 ab	11.86 abc	0.45 a	0.37 bc	8.663 a
10dys 35x35	42.00 abcd	24.67 ab	79.47 a	6.187 bcde	6.820 ab	13.01 abcd	0.47 a	0.40 bc	9.962abc
14dys 20x20	38.00 abc	23.00 a	84.33 a	5.990 abcde	6.783 ab	12.77 abc	0.47 a	0.37 bc	8.572 a
14dys 25x25	36.67 ab	26.67 ab	74.33 a	5.140 a	5.783 a	10.92 a	0.47 a	0.36 b	8.277 a
14dys 30x30	40.33 abcd	30.33 ab	79.00 a	5.603 abcd	6.620 ab	12.22 abc	0.46 a	0.40 bc	9.018 ab
14dys 35x35	40.67abcd	27.00 ab	74.87 a	5.187 a	5.687 a	10.87 a	0.48 a	0.39 bc	8.352 a
21dys20x20 (Control)	40.00 abcd	22.33 a	73.00 a	5.283 ab	6.230 ab	11.51 ab	0.46 a	0.24 a	8.508 a
Mean	42.08	27.62	77.85	5.9	6.59	12.49	0.47	0.39	9.42
F.prob.	<0.001	0.002	0.305	<0.001	0.005	<0.001	0.154	<0.001	<0.001
S.E	2.452	2.886	5.553	0.315	0.584	0.741	0.023	0.029	0.7
C.V	5.8	10.5	7.1	5.3	8.9	5.9	5	7.4	7.4

Means in the same column followed by the same letter(s) are not significantly different at Turkey's 95% confidence limit.

Table 14: Mean effects of seedling age and spacing combinations on water productivity of rice under SRI

Treatment combinations	Grain yield (tons/ha)	Irrig.water (m^3)	Irr.+ Rain (m^3)	Irrig.water productivity WP_I (kg/m^3)	Irr.+ Rain .water proctivity WP_{I+R}(kg/m^3)	ET. water productivity WP_{ET} (kg/m^3)	Water use efficiency (kg/ha.mm)
8dys 20x20	7.38 f	13.45 d	16.12 d	0.44 bc	0.36 c	1.21 c	12.059 c
8dys 25x25	5.68 abcd	12.05 abcd	14.72 abcd	0.38 bc	0.31 bc	0.93 ab	9.281 ab
8dys 30x30	6.413 de	12.32 abcd	14.99 abcd	0.42bc	0.34 bc	1.05abc	10.479abc
8dys 35x35	6.187 bcde	10.68 a	13.35 a	0.41 bc	0.33 bc	0.89 ab	8.878ab
10dys 20x20	6.347 cde	11.18 ab	13.85 ab	0.45 c	0.37 c	1.04abc	10.370abc
10dys 25x25	6.690 ef	13.04 cd	15.71 cd	0.41 bc	0.34 bc	1.09bc	10.931bc
10dys 30x30	5.380 ab	11.65 abc	14.32 abc	0.37 bc	0.30bc	0.88 a	8.791 a
10dys 35x35	6.187 bcde	12.47 bcd	15.14 bcd	0.40 bc	0.33 bc	1.01abc	10.109abc
14dys 20x20	5.990 abcde	11.37 abc	14.04 abc	0.37 bc	0.30 bcd	0.87 a	8.698 a
14dys 25x25	5.140 a	11.19 ab	13.86 ab	0.37 b	0.30 b	0.84 a	8.399 a
14dys 30x30	5.603 abcd	11.13 ab	13.80 ab	0.40 bc	0.32 bc	0.92 ab	9.150 ab
14dys 35x35	5.187 a	10.75 a	13.50 ab	0.39 bc	0.31 bc	0.85 a	8.475 a
21dys20x20 control	5.283 ab	17.38 e	20.05 e	0.24 a	0.21 a	0.86 a	8.633 a
Mean	5.9	12.20	14.88	0.39	0.32	0.96	9.56
F.probability.	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
S.E	0.315	0.567	0.565	0.029	0.023	0.071	0.71
C.V	5.3	4.6	3.8	7.5	7.2	7.4	7.4

Means in the same column followed by the same letter(s) are not significantly different at Turkey's 95% confidence limit.

The higher number of total tillers as well as productive tillers might be attributed to quick recovery of the younger seedlings transplanted at earlier stage with short roots. Younger seedlings have short roots and shot root seedlings are less prone to disturbance, have ample time to recover from transplanting shocks before the starts of the first phyllochron and wider spacing provided sufficient solar radiation, minimum competition of nutrients and enhance photosynthesis. Mobasser *et al.* (2007) observed that when seedlings stay for a longer period of time in the nursery beds, primary tiller buds on the lower nodes of the main culm become degenerated leading to reduced tiller production.

4.5 Effect of Seedling Age and Spacing on Plant Height

There were no significant variations at ($P \leq 0.05$) among plant heights in all treatments (Table 13). However, treatment T_9 recorded the high value of 84.33 cm and T_{13} control recorded the lowest plant height of 73 cm. Plant height is mainly variety specific determined by genetic makeup of the cultivar. Fonteh *et al.* (2013) observed no significant variation in plant height between continuous flooding and intermittent wetting and drying regime (SRI).

4.6 Effect of Seedling Age and Spacing on Yield and Yield Components

The highest grain yield (7.38 t/ha) was observed in T_1 (20 x 20) cm transplanted when the seedling age was 8 days, (Table 13) This yield is significantly different at ($P \leq 0.05$) compared to yields observed in T_2, T_4, T_7, T_9, T_{10}, T_{11}, T_{12} and T_{13} (control). However, the yield observed in T_1 showed no statistical variation at ($P \leq 0.05$) with yields recorded in treatments T_3, T_5, T_6 and T_8. The lowest grain yield was recorded in T_{10} (14 days 25 cm x 25 cm) spacing (5.14 t/ha) however, showed no statistical variation at ($P \leq 0.05$) with the continuous flooding (control) practice T_{13} (5.28 t/ha). There was an increase in yield between 26.6% - 39.7% in SRI practice compared to continuous flooding (Table 13). The highest yield in treatment T_1 might be attributed to early transplanting which gave rice seedlings sufficient time to recover and attain high production potential. Another factor attributed to higher yield was the large number of hills per square metre and therefore large plant population. Generally yields obtained from SRI treatments were higher compared to continuous flooding condition, these results were in conformity with the ones obtained by Sinha and Talati (2007). They obtained 40% increase in grain yield with SRI treatment compered to continuous flooding in Balrampur India. Gopalakrishnan *et al*. (2013) obtained 35% grain yield increase with SRI compared with continuous flooding. Figure 7 shows variations in grain yield and above ground biomass among treatments.

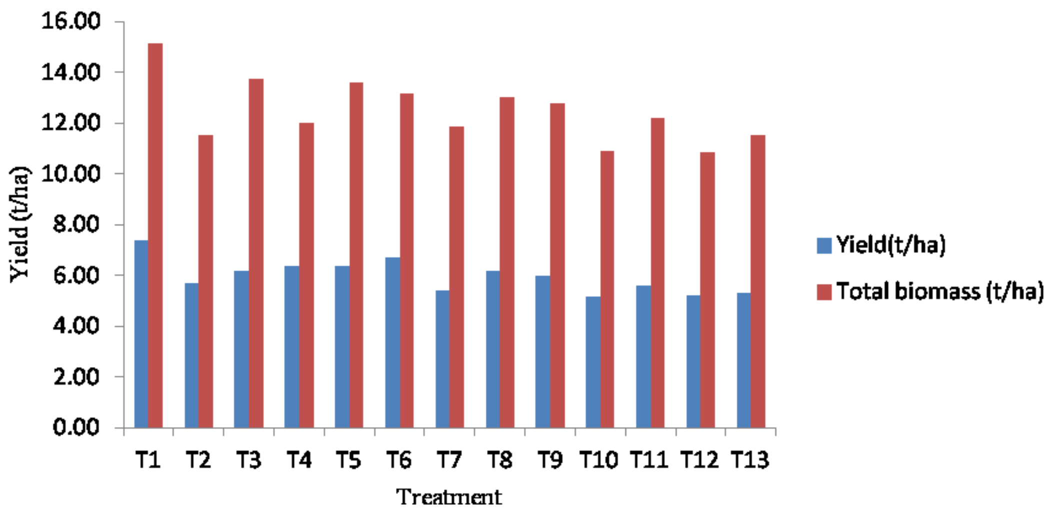

Figure 7: Grain yield and above ground biomass for different treatments

4.7 Effect of Seedling Age and Spacing on Total above Ground Biomass.

Results from Table 13 shows that the maximum biomass (15.16 t/ha) was recorded in treatment T_1 (8 days, 20 cm x 20 cm) and the minimum (10.87 t/ha) was recorded in T_{12} (14 days, 35 cm x 35 cm). These results were significantly different at ($P \leq 0.05$). There was significant variation in biomass production between control treatment and a set of SRI treatments (T_1 and T_3). Other SRI treatments T_{11} and T_{12} out weight the continuous flooding regime treatment however, they were not significantly ($P \leq 0.05$) different. There was an increment of 24.9% in straw yield, and 31.7% in total above ground biomass in SRI practice as compared to continuous flooding (Table 13). Sinha and Talati (2007) observed 54% increment in straw yield in SRI compared to continuous flooding.

4.8 Effect of Seedling Age and Spacing on Total Irrigation Water Input

Results from Table 13 shows that the total volume of irrigation water input to meet the crop water demand was higher (17.38 m^3) in T_{13} (the control treatment) and it was significantly different at ($P \leq 0.05$) to all SRI treatments. Treatments T_1, T_2, T_3, T_6 and T_8 were not significantly different at ($P \leq 0.05$). The reason for large volume of irrigation water input in control plots is additional water for maintaining continuous flooding. There was about 22.6% reduction of irrigation water in SRI treatment plots compared to continuous flooding. Keisuke *et al*. (2007) observed 40 70% reduction in irrigation water input. In another study in Kenya Ndiiri *et al*. (2013) observed 31% water saving in SRI compared to continuous flooding. Differences in irrigation water input among treatments are better visualized in Figure 8.

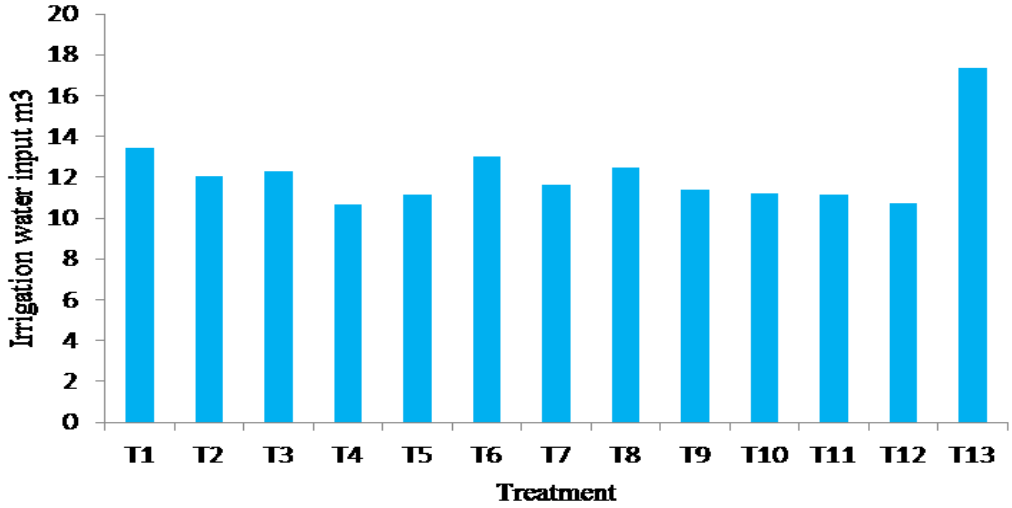

Figure 8: Irrigation water input under various treatments

4.9 Effect of Seedling Age and Spacing on Crop Water Productivity Under SRI

High irrigation water productivity was observed in T_5; 10 days, 20 x 20 cm (0.45 kg /m^3) and the lowest water productivity was observed in continuous flooding regime T_{13} (0.24 kg/m^3). Control treatment; T_{13} was significantly different at ($P \leq 0.05$) to all SRI treatments. Among SRI treatments, T_5 was statistically different to T_{10} however, all the rest of SRI treatments were not significantly different. High irrigation water productivity values in SRI treatments were definitely attributed to low volumes of irrigation water inputs and higher yields attained by SRI practice. On the contrary, the low water productivity in control treatment plot was due to low grain yield and large volume of water input. Abdul-Ganiyu *et al*. (2012) obtained similar results of crop water productivity of 0.43 kg/m^3 in the Bontanga irrigation scheme in Ghana. Kombe, (2012) obtained similar results (0.46 kg/m^3) for a spacing of 25 cm x 25 cm in Mkindo irrigation scheme. The implication of the (WP) values in this study is that, 4167 litres of water were used to produce one kg of rice under continuous flooding while only 2222 litres of water were used to produce one kg of rice using SRI. A total of 1944.4 litres (46.7%) could be saved while still producing reasonable yields if under SRI practice. Ndiiri *et al.* (2013) obtained 31% water savings in SRI compared to continuous flooding practice. Pandian *et al*. (2014) obtained 41% water saving in SRI as compared to continuous flooding in Tamil Nadu.

If Pereira, (2013) and Humphreys, (2006) formulae for computing (WP) are adopted, which include water contributed by rainfall during the growing season, the actual water productivity (WP_{I+R}) would be as follows:

Total rainfall during the growing period (September to second week of January 2014) was 535 mm and effective rainfall was 334 mm results in additional water input of (0.334 m^3/m^2) or 2.672 m^3 in every treatment plot. Following this scenario water productivity would be 0.37 kg/m^3 for the treatments T_1 and T_5 and the lowest 0.21 kg/m^3 for the control treatment.T_{13}.

Evapotranspiration (WP_{ET}) water productivity was the highest in T_1 (1.2 kg/ m^3) and lowest in T_{12}, (0.84 kg/ m^3). T_1 was significantly different at ($P \leq 0.05$) compared to T_2, T_4, T_7, T_9, T_{10}, T_{11}, T_{12} and T_{13}. Although T_{12} was the lowest, it was statistically different to T_{13} (control) at ($P \leq 0.05$) significant level. WP_{ET} water productivity is a function of yield since evapotranspiration was the same for all treatments, and therefore higher WP_{ET} (1.2 kg/m^3) obtained in T_1 is due to higher grain yield.

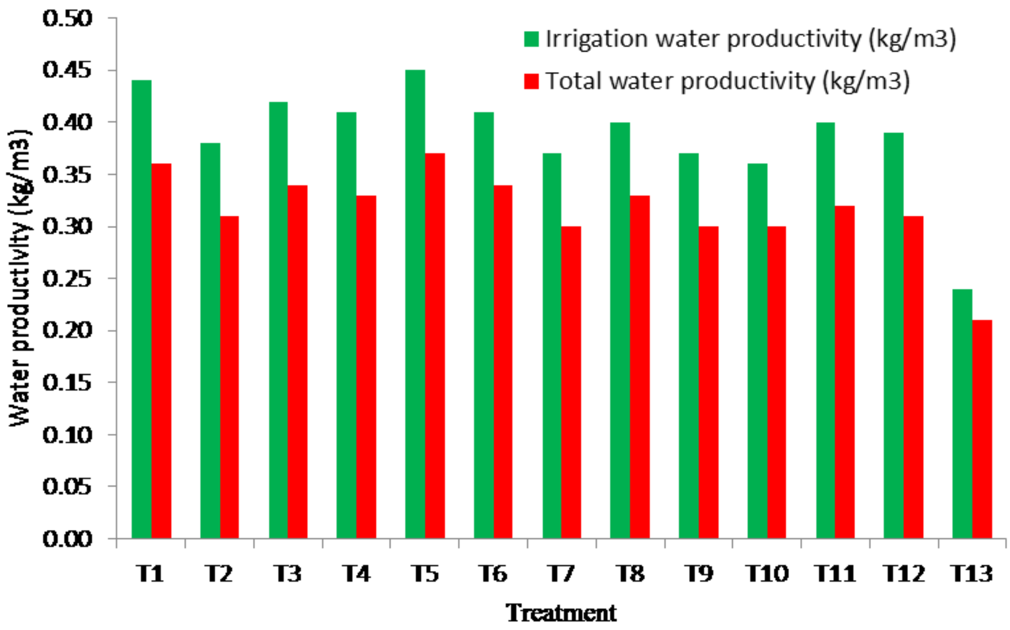

Figure 9: Irrigation water productivity under various treatments

4.10 Effect of Seedling Age and Spacing on Crop Water Use Efficiency Under SRI

Results showed that the highest WUE (Figure 10) was observed in T_1 (12.06 kg/ha/mm) and it was significantly different at ($P \leq 0.05$) significant level with T_2, T_4, T_7, T_9, T_{10}, T_{11}, T_{12} and T_{13} (control). However, it was not statistically different at ($P \leq 0.05$) with T_3, T_5, T_6, and T_8. The lowest WUE was observed in T_{10} (8.57 kg/ha/mm), however it was not significantly different at ($P \leq 0.05$) with T_{13} (control) (Table 14).

The low WUE value in T_{10} was attributed to the low yield level due to delayed transplanting and low plant population.

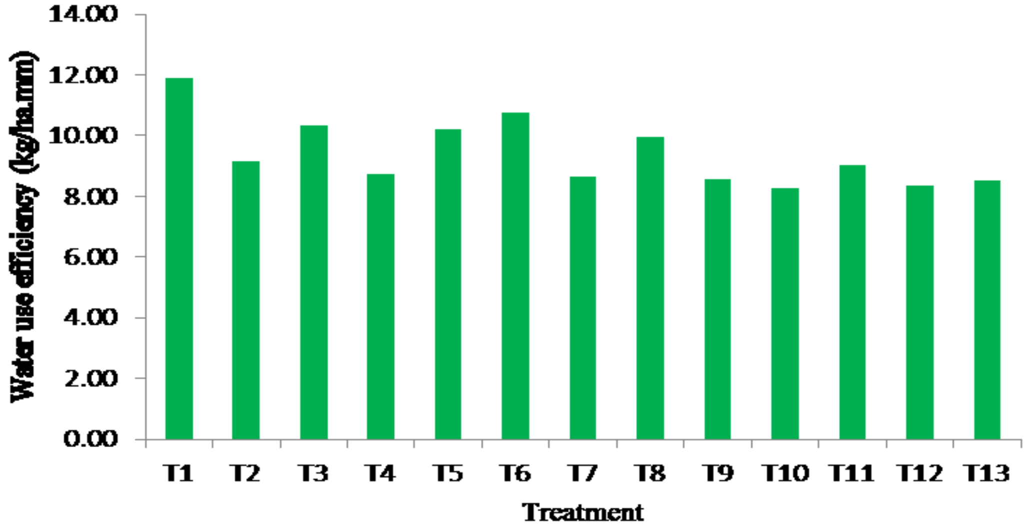

Figure 10: Irrigation water use efficiency under various treatments

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

This research was conducted to evaluate the performance of the system of rice intensification in terms of yield and water productivity in Zanzibar. With The specific objectives included determining the optimum spacing and seedling age to transplant the rice for higher yield and water productivity. Based on findings obtained from this study the following are the conclusions:

1. The quality of the irrigation water used in the study area is good and free from total salinity and sodium hazards.

2. The soil of the experimental site was ideal for rice cultivation in terms of its physical properties. However it has low nitrogen low extractable phosphorus and very low potassium, therefore in order to realise full maximum potential of SRI, the nutrients must be added in terms of fertilizers.

3. Tillering starts in two weeks' time after transplanting (common tendency of many rice varieties) and increases gradually, but tends to slow in week seven and almost cease in week eight.

4. A spacing of 20 cm by 20 cm in combination with the seedling age of 8 days was the best for SUPA BC rice variety in terms of grain yield, total biomass, crop water productivity and water use efficiency in dry *vuli* season.

5. The maximum tillering occurred in treatment spacing 30 cm by 30 cm and productive tillers was the best in 35 cm by 35 cm however, there is no statistically significant variations between two treatments.

6. Water saving of up to 46.7% in SRI practice is possible compared to continuous flooding practice.

5.2 Recommendations

From this study, the following recommendations can be made

1. Irrigation water source in Bumbwisudi irrigation scheme can continue to be used as irrigation water because it is free from salinity and sodium hazards.

2. Application of recommended dosage of fertilizes particularly N, P and K with the integration of other soil fertility management; application of compost, manures and retention of crop residues in rice plots is highly recommended for best performance of SRI.

3. More research is needed in terms of other rice varieties and diversification of locations and seasons in SRI in Zanzibar in order to come up with guidelines for optimum spacings and seedling age to be adopted.

4. Conducting experiments involving a number of varieties used by farmers and the ones that have shown better performance in other places for the purpose of selecting varieties that perform best under SRI practice in Zanzibar.

5. Among the benefits of SRI is water saving and minimizing transplanting shocks, it is advised to undertake research involving direct seeding using pre-germinated seeds at various spacings instead of transplanting to investigate their effects in water savings and because in direct seeded water might be saved because it is not needed for land preparation.

6. Conducting researches involving economics of SRI to find out how much a farmer can save per season to pay irrigation fees under the SRI system.

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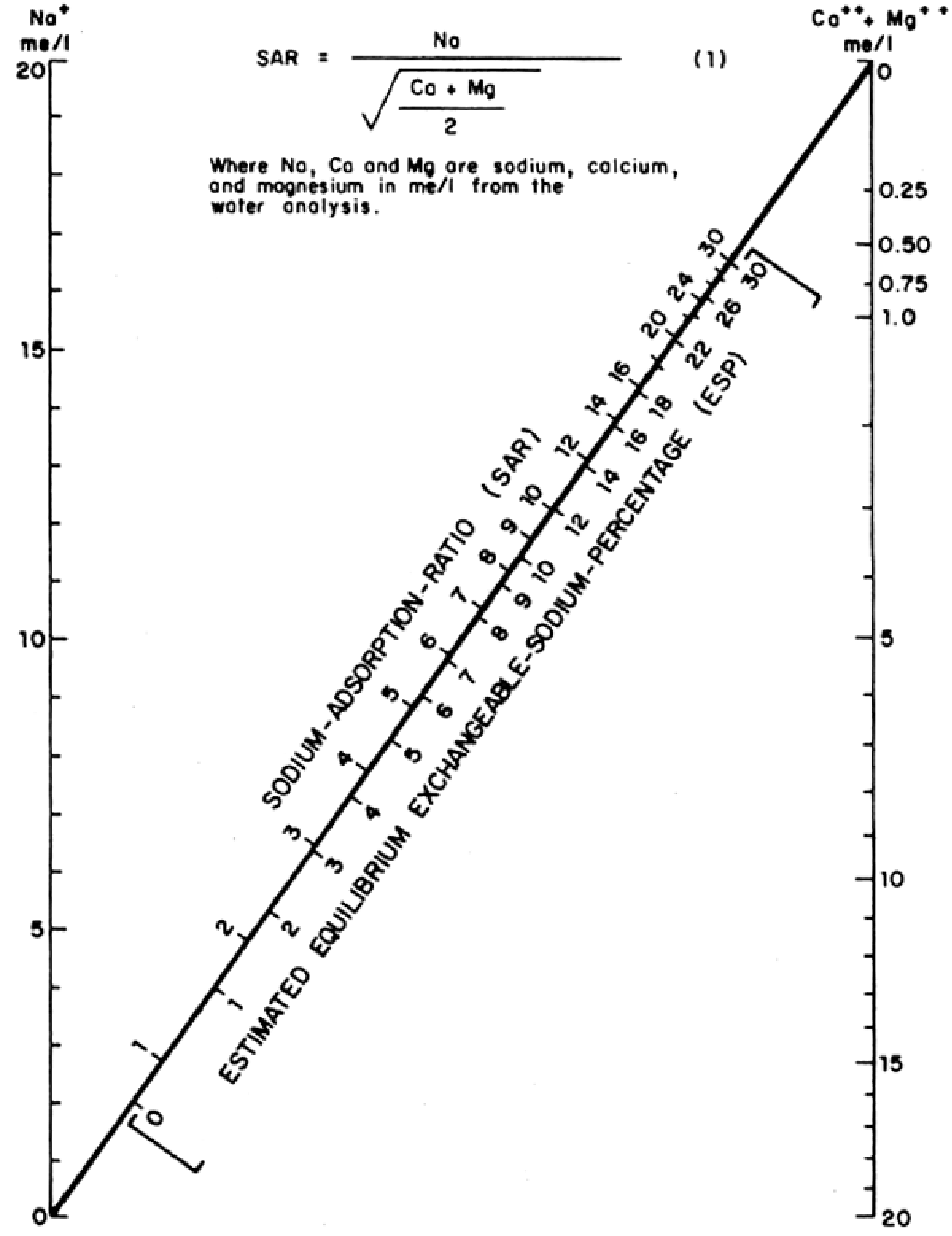
APPENDICES

Appendix 1: Crop coefficients

Crop	Initial stage	Crop development. stage	Mid-season stage	Late season stage
Barley/Oats/Wheat	0.35	0.75	1.15	0.45
Bean, green	0.35	0.70	1.10	0.9
Been, dry	0.35	0.70	1.10	0.3
Cabbage/carrot	0.45	0.75	1.05	0.9
Cotton/Flax	0.45	0.75	1.15	0.75
Cucumber/Squash	0.45	0.75	0.90	0.75
Eggplant/Tomato	0.45	0.75	1.15	0.80
Grain/Small	0.35	0.75	1.10	0.65
Lentil/Pulses	0.45	0.75	1.10	0.50
Lettuce/Spinach	0.45	0.6	1.00	0.90
Maize, Sweet	0.40	0.8	1.15	1.00
Maize ,grain	0.40	0.8	1.15	0.70
Melon	0.45	0.75	1.00	0.75
Millet	0.35	0.70	1.10	0.65
Onion green	0.50	0.70	1.00	1.00
Onion dry	0.50	0.75	1.05	0.85
Peanut/groundnut	0.45	0.75	1.05	0.70
Pea, fresh	0.45	0.80	1.15	1.05
Pepper, fresh	0.35	0.70	1.05	0.90
Potato	0.45	0.75	1.15	0.85
Radish	0.45	0.60	0.90	0.90
Sorghum	0.35	0.75	1.10	0.65
Soybeans	0.35	0.75	1.10	0.60
Sugar	0.45	0.80	1.15	0.80
Sunflower	0.35	0.75	1.15	0.55
Tobacco	0.35	0.75	1.10	0.90

Source: Brouwer and Heibloem, 1986

Appendix 2: Nomograph and formula for determination of SAR value



(Source: FAO, 1985)

Appendix 3: Indicative values of crop water requirements

Crop	Crop water need (mm/total growing period)	Sensitivity to drought
Alfalfa	800-1600	Low -medium
Banana	1200-2200	High
Barley/Oats/Wheat	450-650	Low to medium
Bean	300-500	Medium – high
Cabbage	350-500	Medium – high
Citrus	900-1200	Low – medium
Cotton	700- 1300	Low
Maize	500-800	Medium – high
Melon	400-600	Medium – high
Onion	350-450	Medium – high
Peanut	500-700	Low – medium
Pea	350-500	Medium – high
Pepper	600-900	Medium – high
Potato	500-700	High
Rice (paddy)	450-700	High
Sorghum/Millet	450-650	Low
Soybean	450-700	Low – medium
Sugarbeet	550-750	Low –medium
Sugarcane	1500-2500	High
Sunflower	600-1000	Low – medium
Tomato	400-800	Medium - high

Source: Brouwer and Heibloem, 1986

Appendix 4: Average rainfall vs rainfall 2013

Month	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Rainfall 2013 (mm)	11.8	0	334	300.2	131.7	36.4	9.9	55.1	44.1	124	170.9	196
Ave. Rainfall (mm)	75.7	50.6	180.1	351	209.8	61.3	17.1	31.8	42.6	96.5	221.2	179.2

Appendix 5: Irrigation time for each treatment for the month of September (2013)

		1st irrigation		
		Irrigation duration (min)		
Treatment	Depth above weir (cm)	Rap I	Rap II	Rap III
T_1	6.8	19:38	18:24	19:02
T_2	6.8	16:31	16:48	17:56
T_3	6.8	17:07	18:43	16:38
T_4	6.8	15:21	15:28	14:36
T_5	6.8	15:23	16:46	15:25
T_6	6.8	18:43	17:56	18:51
T_7	6.8	17:20	16:27	15:19
T_8	6.8	17:37	18:16	17:12
T_9	6.8	16:08	16:12	16:00
T_{10}	6.8	15:40	17:26	14:28
T_{11}	6.8	14:30	16:55	15:57
T_{12}	6.8	14:19	14:25	16:00
T_{13}	7.0	23:07	23:17	22:07

Appendix 6: Irrigation time (min) for each treatment for the month of October (2013)

		1st irrigation			2nd irrigation			3rd irrigation		
		Irrigation duration (min)			Irrigation duration (min)			Irrigation duration (min)		
Treatments	Depth above weir (cm)	Rap I	Rap II	Rap III	Rap I	Rap II	Rap III	Rap I	Rap II	Rap III
T_1	6.5	6:00	5:00	5:00	4:17	4:37	4:00	-	-	-
T_2	6.5	4:37	5:00	4:20	4:00	3:47	5:13	-	-	-
T_3	6.5	4:25	4:16	4:20	4:36	5:30	4:19	-	-	-
T_4	6.5	4:00	4:00	3:22	4:00	4:04	4:18	-	-	-
T_5	6.5	4:12	4:20	4:14	3:48	3:24	3:50	-	-	-
T_6	6.5	5:32	5:27	5:08	4:14	4:16	4:03	-	-	-
T_7	6.5	5:04	4:52	4:10	4:00	3:42	4:13	-	-	-
T_8	6.5	4:46	5:06	4:33	4:20	4:26	4:26	-	-	-
T_9	6.5	4:48	4:12	4:19	4:37	4:16	4:03	-	-	-
T_{10}	6.5	4:11	4:44	4:36	4:00	4:22	3:37	-	-	-
T_{11}	6.5	4:47	4:30	4:20	2:46	4:20	4:12	-	-	-
T_{12}	6.5	4:16	4:00	4:21	3:13	4:06	4:00	-	-	-
T_{13}	6.5	8:30	8:00	8:42	10:17	10:00	9:36	9:34	9:56	8:15

Appendix 7: Irrigation time (min) for each treatment for the month of November (2013)

				1st irrigation
		Irrigation duration (min)		
Treatment	Depth above weir (cm)	Rap I	Rap II	Rap III
T_1	6.5	3:28	3:22	3:18
T_2	6.5	2:50	2:55	3:04
T_3	6.5	2:57	3:13	2:52
T_4	6.5	2:38	2:40	2:31
T_5	6.5	2:38	2:52	2:31
T_6	6.5	3:14	3:00	3:16
T_7	6.5	3:00	2:50	2:45
T_8	6.5	3:00	3:09	3:00
T_9	6.5	2:47	2:48	2:45
T_{10}	6.5	2:40	3:00	2:29
T_{11}	6.5	2:30	2:55	2:46
T_{12}	6.5	2:28	2:45	2:46
T_{13}	6.5	4:17	4:20	4:05

Appendix 8: Irrigation time for each treatment for the month of December (2013)

		1st irrigation			2nd irrigation			3rd irrigation		
Treatments	Depth above weir (cm)	Rap I	Rap II	Rap III	Rap I	Rap II	Rap III	Rap I	RapII	RapIII
T_1	6.8	9:08	8:29	7:36	7:04	6:42	8:12	-	-	-
T_2	6.8	7:34	7:25	7:14	6:06	6:27	7:34	-	-	-
T_3	6.8	7:20	8:13	7:00	6:28	7:15	6:43	-	-	-
T_4	6.8	7:10	7:16	7:03	5:29	5:28	6:00	-	-	-
T_5	6.8	7:12	7:36	7:13	5:30	6:12	5:31	-	-	-
T_6	6.8	7:48	8:00	8:42	7:40	6:49	5:51	-	-	-
T_7	6.8	7:13	7:30	7:24	7:00	6:05	5:52	-	-	-
T_8	6.8	8:00	7:34	7:11	6:32	7:30	7:00	-	-	-
T_9	6.8	7:13	7:10	7:00	6:00	6:02	6:11	-	-	-
T_{10}	6.8	7:00	7:10	6:57	6:54	7:14	5:00	-	-	-
T_{11}	6.8	6:42	7:00	7:12	5:12	6:56	6:00	-	-	-
T_{12}	6.8	6:48	7:30	6:41	5:00	5:14	6:30	-	-	-
T_{13}	6.8	7:42	8:13	8:20	6:24	7:31	7:00	6:42	5:00	4:23

Appendix 9: Irrigation time (min) for each treatment for the month of January (2014)

		Irrigation duration (min)		
Treatment	Depth (cm) above weir	Rap I	Rap II	Rap III
T_1	6.0	1:21	1:15	1:18
T_2	6.0	1:06	0:56	1:12
T_3	6.0	1:16	1:15	1:10
T_4	6.0	1:04	1:07	1:00
T_5	6.0	1:02	1:14	1:04
T_6	6.0	1:17	1:12	1:18
T_7	6.0	1:09	1:06	1:06
T_8	6.0	1:12	1:17	1:10
T_9	6.0	1:07	1:08	1:07
T_{10}	6.0	1:08	1:13	1:09
T_{11}	6.0	1:00	1:08	1:06
T_{12}	6.0	1:04	1:10	1:10
T_{13}	6.0	1:21	1:22	1:38