EFFECTS OF FLOODING AND SYSTEM OF RICE INTENSIFICATION ON NITROGEN USE EFFICIENCY IN RICE PRODUCTION AT MKINDO, MOROGORO, TANZANIA

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ABSTRACT

An experiment was conducted in a glasshouse in 2016 at Sokoine University of Agriculture Morogoro Tanzania to study the effects of system of rice intensification (SRI) and flooding on Nitrogen Use Efficiency (NUE) for the lowland rice ecosystem. The soil used in the experiment was Eutric fluvisol and was analysed in the laboratory to evaluate soil fertility status. The soil was observed to have some plant nutrient below the critical range like N, 0.09%; K, 0.2 cmol kg-1;P, 4.13 mg/kg and OC, 1.23%. The experimental design was split-plot in randomized complete block design with four replicates.The main plot constituted two water management systems viz. SRI and flooding. Subplot treatments were nitrogen levels viz; 0, 125, 250 and 500 mg N kg-1 of soil. Rice variety used was SARO 5 (TXD 306) which is the improved rice variety adapted for lowland irrigated ecosystem. Analysed data for rice grain yield, Nitrogen Use Efficiency (NUE), dry matter yield and plant height did not show a significant difference ($P< 0.05$) due to the influence of SRI and flooding water management systems, whereby SRI yield ranged from 3.6 – 30.9 g grain yieldpot-1 and flooding was 5.9 – 25.0g grain yield pot-1. NUE ranged from 38.1- 66.1 mg grain mg-1 N for flooding and 54.8-85.7 mg grain mg-1 N. For SRI and flooding, the study confirmed that there was no significant difference ($P< 0.05$) on rice yield and NUE. The significant $P< 0.05$) difference on grain yield, NUE, dry matter and N concentration on rice plant was due to the effect of nitrogen application rates. The grain yield under SRI and flooding water management system ranged from 3.6 – 30.9 g pot-1 and 5.9 – 25 g pot-1 respectively.

DECLARATION

I, JUMANNE ELIYA, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and that it has neither been submitted nor currently being submitted in any other institution.

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LIST OF SYMBOLS AND ABBREVIATIONS

AE	Agronomic Efficiency
ARI	Agricultural Research Institute
ASA	Agricultural Seed Agency
CEC	Cation Exchange Capacity
Cu	Copper
DTPA	Diethylene Triamine Pentaacetic Acid
ESA	Eastern and Southern Africa
EUCORD	European Cooperative for Rural Development
Fe	Iron
(g)	Gas
GHG	Greenhouse Gas
GIS	Geographic Information System
GoT	Government of Tanzania
HYVs	High yielding varieties
IE	Internal utilization Efficiency
IRRI	International Rice Research Institute

K	Potassium
MAFC	Ministry of Agriculture Food Security and Cooperatives
Mn	Manganese
Na^+	Sodium ion
NERICA	New Rice for Africa
NRDS	National Rice Development Strategy
NUE	Nitrogen Use Efficiency
NupE	Nitrogen Uptake Efficiency
NutE	Nitrogen Utilization Efficiency
OM	Organic Matter
P	Phosphorus
PE	Physiological Efficiency
PMP	Recommended management Practices
PNB	Partial nutrient balance
RE	Recovery Efficiency
RYMV	Rice Yellow Mottle Virus
S	Sulphur
SRI	System of Rice Intensification
SSA	Sub- Saharan Africa
Zn	Zinc
ZnS	Zinc Sulphide

CHAPTER ONE

1.0 INTRODUCTION

Rice (Oryzasativa L) is the second most important food and commercial cereal crop in Tanzania after maize. It is among the major sources of employment, income and food security for the Tanzania farming households. The major rice producing regions in Tanzania are Mbeya, Morogoro, Shinyanga, Mwanza, Rukwa, Tabora and Ruvuma, (Belden et al.,2004), which accounts for 78% of the rice produced in the country. Virtually all rice (99%) is grown by smallholders in Tanzania, although some of them are part of large-scale rice irrigation schemes that were formerly state-managed farms (Minot, 2010). One of the challenges facing rice production in Tanzania is low yield 500 – 1000 kgha-1 (Raes et al., 2007). Reasons for low rice yield include use of genetically low yielding varieties, drought, floods, poor water management, low soil fertility, weed infestations, prevalence of insect pests, diseases, and birds (GoT-NRDS, 2009).

Lowland rice is cropped on approximately 128 million hectares worldwide under irrigated rain fed conditions (Ethan et al., 2011). Sahrawat (2005) reported that, growing rice in the submerged soils has a great ameliorative effect on chemical fertility largely by bringing pH to the neutral range, resulting in better availability of plant nutrient and accumulation of organic matter. Upland soils in Tanzania have less clay and are classified inceptisols, rich in organic mateials. (Balasubramanian et al., 2007).Soil test of upland rice in four districts in southern Tanzania (Ulanga, Kyela, Morogoro and Korogwe) found that while the soil was capable of supporting the growth of rice low to medium nitrogen and phosphorus levels restricted rice yields (Mghase, 2010).

Rice production needs to be done in several different production systems in order to meet the food demand of ever growing populations in Tanzania. More farm inputs and limited irrigation water available will continue to limit the prospects of subsistence farmers in developing countries, Tanzania being among them (Katambara et al., 2013).

System of Rice Intensification (SRI) developed in Madagascar, is a new method of rice water management system for increasing the productivity of irrigated rice and has emerged as an alternative to traditional flooded rice water management system under the conditions of water scarcity (Mohandas et al., 2015). Hence, if adopted by rice growers in Tanzania, SRI could help to increase water savings (Katambara et al., 2013).

On other hand, nutrient management represents one of the most expensive inputs to a successful rice crop whereas nitrogen (N) is required by rice in the largest quantity compared to any other nutrients, N is typically not only the largest fertilizer input cost, but the largest input cost for rice producers (Franzen et al., 2011). Profitable rice grain yields are dependent on proper and effective N fertilizer use management (Franzen et al., 2011). However N is subjected to many loss processes when it is applied to rice, and these loss processes that operate in soil-water environment can compete quite successfully with the young rice plant for N (Franzen et al., 2011). An understanding of the behaviour of N in wetland rice soil is therefore a necessary prerequisite for improving wetland rice growth and yield and improving the productive efficiency of fertilizer N. Unfortunately nutrient studies on tropical wetland rice soils are very limited (Yeasmin et al., 2012).

This study thus aimed at determining the effects of flooding and SRI on Nitrogen Use Efficiency (NUE) by rice (Oryza sativa L) production for small holder farmers in Mvomero district, Morogoro region using improved rice variety SARO 5 (TXD 306).

1.2 Objectives of the study

1.2.1 Overall objective

To determine water management systems for NUE in rice (Oryza sativa L) production in Tanzania.

1.2.2 Specific objectives

i. To determine nutrient status of some soils of rice growing farms in Mkindo village, Mvomero district.

ii. To assess the effect of water management systems on NUE.

iii. To assess the effect of water management systems on rice productivity.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Rice plant growth requirements

The soil on which rice grows are variable as the climatic regime to which the crop is exposed. Soil texture ranges from sand to clay; pH from 3 to 10; organic matter contents from 1 to 50%; salt content from almost 0 to 1% and nutrient availability from acute deficiencies to surplus (Talpur et al., 2013). However, soils capable of holding water for a longer period such as heavy neutral soils (clay, clay loam and loam) are most suited for its cultivation.

Rice being a tropical and sub-tropical plant requires a fairly high temperature, ranging from 20°C to 40°C. The optimum temperature of 30°C during day time and 20°C during night time seems to be more favourable for the development and growth of rice crop (Hill et al., 1997; Samanta et al., 2011). The annual moisture requirement ranges from 500 mm to over 2000 mm (Grist, 1986).

2.2 Rice Production systems in Tanzania

In Tanzania rice is grown on three major ecosystems namely rain-fed lowland, upland rice and irrigated lowland (MAFC, 2009).

2.2.1 Lowland–rain fed rice

Rain-fed lowland ecosystem has opportunities associated with availability of water during floods and relatively fertile soils compared to upland ecosystem (MAFC, 2009). In lowland rice farming, water control is the most important management practice that determines the efficacy of other production inputs. Varieties commonly grown under the lowland rice farming system include the

Supa series and Landraces. Yield range from 1.5 to 2.0 tons of paddy per hectare and the fragility of the natural resources base is low. Intensification of rice production is possible given the available resources such as fertile soils and flood water. Also, crop diversification can be practiced and expansion of the rice production area is possible (MAFC, 2009).

2.2.2 Upland rice

Upland rice is mainly grown under a shifting cultivation system. This involves slashing and burning of virgin forest to acquire new and more fertile lands. Shifting cultivationis practiced because poor farm management allows detrimental weed infestation and declining soil fertility within 2-3 years after a field is cleared and planted with rice. Farmers move to new land because rice yield decreases to almost nothing (Gupta and O'toole, 1986). Environmental concerns and increasing human density are discouraging this practice coupled with fact that research on permanent cropping of land is being promoted (Ceesay, 2004). One strategy to facilitate cultivation of the same piece of upland rice field without yield loss and without high input of human labour, fossil energy, fertilizer and herbicide is the use of low input rice varieties (Ceesay, 2004). The low input rice varieties are those that provide fairly good grain yield with moderate levels of fertilizer application. Such varieties also would exploit and utilize both soil and fertilizer nutrients with better efficiency (Usha et al., 2001). Landraces and Supa strains, are the most common varieties and they are aromatic or non-aromatic. NERICA series appear to be more adaptable to this ecosystem, where yield ranges from 0.5 to 0.8 ton of paddy per hectare (MAFC, 2009).

2.2.3 Irrigated lowland

Lowland irrigated rice production has been done under continuously flooded conditions for millennia (Barison and Uphof, 2011). It is the most productive ecosystem and most of the improved varieties like IR64 and SARO 5(TXD 306) are adapted to this production system. Yields range from 2.5 to 4.0 tons of paddy per hectare (National Rice Development Strategy Final Draft, 2009). Intensification of rice production under this ecosystem is possible and the area can be expanded as more irrigation schemes are rehabilitated and constructed. In Tanzania, the total potential area for irrigation development is 29.4 million hectares, out of which 2.3 million hectares are characterized as high potential, 4.8 million hectares as medium potential and 22.3 million hectares low potential (MAFC, 2009). From 2007 to 2009, the area under irrigated lowland rice production increased from 289,245 to 306,745 hectares (EUCORD, 2012).

Under irrigated lowland ecosystem, rice fields are kept continuously flooded and are flood free only at the time of harvest. This practice is not only wasteful in terms of water use efficiency, but also leads to leaching of soluble nutrients, blocks aerobic soil microbial activities and biological N fixation as well as slow mineralization of organic matter and nutrient release from the soil organic matter complexes (Ceesay, 2004).

2.3 Climatic and Soil constraints to increased and sustainable rice production in Tanzania

2.3.1 Climate-related constraints

The primary abiotic constraints relevant for rice production in Tanzania under climate are drought and floods.

Drought: both crops and livestock are adversely affected by periodical drought. Increase in the temperature due to extreme climatic conditions may undermine any positive effects by reducing the net revenue for upland rice farms whereas irrigation increase revenue for the irrigated rice farms due to the fact that, irrigation buffers the crop from rainfall shortages (Mugula, 2013).

Floods: cause indirect damage to rice crop and infrastructures supporting rice production such as dams, dykes and roads (Olembo et al., 2010; Saito et al., 2015).

2.3.2 Soil –related constraints

Another primary abiotic constraint relevant for rice production in Tanzania is soil.

Soil fertility depletion and the continued lack of required nutrient replenishment of nutrient depleted soils as well as nutrient losses through wind and water erosion in smallholder farms is the fundamental biophysical root cause for declining per capita food production in Sub-Saharan Africa (Tan et al., 2005; Haefele et al., 2013).This is evident in the long-term decline in crop yields under conditions of low-input and unbalanced fertilization in many parts of Africa, Asia and Latin America (Tan et al., 2005).On other hand intensive agriculture, involving exhaustive high yielding varieties of rice and other crops, has led to heavy withdrawal of nutrients from the soil; imbalanced and discriminate use of chemical fertilizers has resulted in deterioration of soil health, chemically, physically and biologically (Talpur et al., 2013). Nutrient balance is achieved when the nutrient inputs compensates the output, however, input supplies such as insecticides, fertilizers and herbicides are very expensive on the local market (Tan et al., 2005; Olembo et al., 2010; Mghase et al., 2010; Amedi, 2014; Saito et al., 2015).

Iron (Fe) toxicity is a problem associated primarily with rice crop grown on iron rich low land red and laterite soils. Under these conditions Fe3+is reduced to Fe2+ which is absorbed by rice plant in larger quantities and causes Fe- toxicity (Olembo et al.,2010). Fe toxic soils, which show visual symptoms of toxicity, contain 195.1- 569.5 ppm (Landon, 1991). Salinity generally, affects the growth of rice plant at all stages of its life cycle. Excessive soluble salts in soils or in irrigated water may reduce the efficiency of water uptake by the crop plants (Islam et al., 2007). Alkalinity and acidity are among the barrier for rice smallholder rice producers to increase rice production (Olembo et al., 2010; Saito et al., 2015).

2.4 Rice response to soil amendments

The general increase in yield response to soil amendment (fertilizers and manures) is characteristic of all improved rice varieties like SARO 5 (TXD 306) and NERICA lines (Umar et al., 2013). Low crop response to the fertilizer applied can be attributed to two reasons: the limited yield potential of a crop, and the effect of the most limited nutrient element (Tan et al., 2005). It is important to know whether application of soil amendments will have a ‘lasting’ effect, i.e. will contribute to soil organic- matter build up, and eventually to increased soil nutrient-supplying capacity or improved recovery of fertilizer nutrients, or whether it mainly acts as a mineral fertilizer giving a one-time boost to crop growth. A sufficient fertilizer supply along with an appropriate ratio of principal nutrients applied is necessary to optimize rice yield (Tan et al., 2005).

2.5 Nitrogen

The doubling of agricultural food production worldwide over the past four decades has been associated with a 7-fold increase in the use of N fertilizer. Despite the detrimental impact on the biosphere, the use of fertilizers (N in particular) in agriculture, together with an improvement in cropping systems, mainly in developed countries, have provided a food supply sufficient for both animal and human consumption(Hirel et al., 2007).

Furthermore, farmers are facing increasing economic pressure with the rising fossil fuel cost required for production of N fertilizers. Since large quantities of fossil fuels are required to produce N fertilizer, selecting new energy crop species or genotypes of already cultivated crops that have a large capacity to produce biomass with the minimal amount of N fertilizer, could be another interesting economic and environmental challenge. Although it is well known that there is some genetic variability in maximum N uptake in rice and wheat, the physiological and genetic variability could confer on some species or genotypes the ability to store greater quantities of N during periods of abundant N supply, thus avoiding losses into the soil (Hirel et al., 2007).

Nitrogen is the most important nutrient in irrigated rice production, and current high yields of irrigated rice are usually associated with large applications of fertilizer N (Zhao et al., 2010; Yang and Zhang, 2010). Rice plants need sufficient N for both vegetative and reproductive growth as well as optimum yield. Accordingly, rice grain yield is highly sensitive to an excess or a deficiency of N at these critical growth phases. Paddy rice removes 16 to 17 kg N for the production of one ton rough rice, including straw (Akter, 2013). The majority of rice production occurs in an anaerobic environment, thus N fertilizer should be ammonium or ammonium forming. The two N fertilizers used in dry-seeded, delayed-flood rice culture common in United States and most rice growing countries are urea and ammonium sulphate (Zhao et al., 2010).

2.5.1 Nitrogen in soils

Nitrogen is a major component of many important structural, genetics and metabolic compounds in plant cells, such as chlorophyll, proteins, amino acids, enzymes, DNA, and ATP (Akter, 2013;Chaudhuri, 2015). The soil N cycle is the most important nutrient cycle from the point of view of nutrient management, since N is the most important nutrient for obtaining high crop production and quality of the environment through the various pathways of N losses. Moreover, the N cycle is very intimately linked with the C cycle and the cycles of other nutrients in soil (Yeasmin et al., 2012).

Nitrogen in flooded soils and sediments occurs in inorganic forms but predominantly in organic forms. Inorganic forms are NH_4^+, NH_3, NO_3^-, and NO_2^- and are taken up by plants and microbes. The forms of organic N in paddy soils are amide-N, α-amino-N, hexosamine-N, unknown-N and non-hydrolysable-N (Akter, 2013). Organic N comprises over 90% of the N found in soil.

Mineralization of soil organic N is a key process for the supply of N to tropical wetland rice. Inorganic N is the main type of soil N that can be directly absorbed and utilized by plants, but only accounting for 1% of the total soil N (Sabina et al., 2012).The N mineralization rate determines the availability of N for the plant growth. The mineralization process is influenced by a number of factors, such as: soil type, organic matter content, total N contents, C:N ratio, pH, temperature, soil moisture, level of soil acidity, supply of inorganic nutrients and soil-plant interactions. The behaviour of N mineralization in wetland soils is markedly differently from its behaviour in dry land soil (Sabina et al., 2012).In warm, well-drained soil, ammonium transforms rapidly to nitrate (NO_3^-) by the process of nitrification (Sabina et al., 2012). Nitrate is the principal form of nitrogen used by plants. It reaches easily since it is a negatively charged ion (anion) and is not attracted to soil clay (Sabina et al., 2012).

In nitrification ammonia is first converted to nitrite (NO_2^-) and then to nitrate. The principal organisms involved in nitrification processes are the genera Nitrosomonas and Nitrobacter (Reddy et al., 1984). Nitrosomonas can only oxidize ammonia to nitrite, while Nitrobacter is limited to the oxidation of nitrite to nitrate. The entire nitrification process equation described by Reddy et al. (1984) is as follows.

$2NH_3 + 3O_3 \quad 2NO_2 + H^+ + 2H_2O$……………………………..……………….... (i)

2.6 Fates of N in lowland Rice Production system

In rain fed lowland rice production system, it is common for soils to cycle between flooded (anaerobic) and aerobic state, resulting in N losses via denitrification, ammonia (NH_3) volatilization, leaching and runoff (Zia et al., 2001).

2.6.1 Denitrification

Denitrification is an anaerobic process, and there are two types of denitrification namely biological denitrification and chemo-denitrification (Akter, 2013). Biological denitrification refers to biochemical reduction of NO_3—N to gaseous compounds. During denitrification, NO_3^- and NO_2^- are reduced to oxides of N (NO, N_2O) and molecular N (N_2) by micro-organisms. These gaseous products are not available for rice plant uptake (Hofman and Cleemput, 2004). During biological denitrification process methanol provides carbon as source of energy to heterotrophic bacteria. Biological denitrification process may be represented by the following equation developed by Wang et al. (1978) as follows:

$5CH3OH + 6NO3- + 6O2 \rightarrow 5CO2 + 3N2 + 7H2O + 6OH-$ ……………………..………..……….. (ii)

Furthermore, nitrate can be chemically reduced through the process of denitrification to nitrous oxide (N2O) or dinitrogen gas. Oxidation of organic matter provides energy and carbon for denitrifying bacteria and nitrate acts as the terminal electron acceptor. This is described by Sabina et al. (2012) in the chemical equation as follows:

$$2HNO_3 \xrightarrow[-2H_2O]{+4H} 2HNO_2 \xrightarrow[-2H_2O]{+2H} 2NO \xrightarrow[-H_2O]{+2H} N_2O_{(g)} \xrightarrow[-H_2O]{+2H} N_{2(g)}$$ …………………(iii)

On other hand, anaerobic conditions in wet soils result in the accumulation of ammonium which is used by plant at the early growing stages (Yeasmin et al., 2012).

2.6.2 Ammonia volatilization

Ammonia volatilization is the loss of N to the atmosphere as ammonia gas.

It is a physicochemical process where ammonium N is known to be in equilibrium between gaseous and hydroxyl forms as indicated below:

$NH3(aq) + H2O = NH4+ + OH-$ …………………………...………………………….(iv)

At pH of 9.3, the ratio between ammonia (NH3) and ammonium ion (NH4+) has been reported to be 1:1 and the losses via volatilization are significant (Vymazal et al., 1998). In the case of urea application, the initial increase in soil pH through the ammonification process result into NH3 volatilization as shown in the following equation:

NH4+ + OH-□ NH3□+ H2O. …………. ..……………………………………...…………. (v)

Large losses of NH3 from applied fertilizer have been detected from soil, floodwater and irrigation water in many agro ecosystems. In flooded rice, NH3 volatilization can account for 20 to > 80% of the total N lost from fertilizer sources (Junejo et al., 2011).

2.6.3 Leaching losses of NO3

Leaching of NO3 is very common in soils due to the high annual rate of rainfall. Major losses of N occur when soil NO-3 content is high and water movement is large. Leaching losses are also strongly influenced by seasonal variations in soil properties, such as water content and temperature. Leaching not only depletes NO3- N but also takes away clay, soil and organic matter, which leads to low chemical fertility and low plant available water reserves (Junejo et al., 2011).

2.6.4 Runoff

Runoff is a problem on poorly drained soils with low sorption capacity because a sizable fraction of the fertilizer N remains in the floodwater following application (Linquist and Sngxua, 2001). It is therefore an important mechanism of nutrient loss (N inclusive) in areas with high probability for inundation following intense rainfall (Linquist and Sngxua, 2001).

2.7 Nitrogen Use Efficiency (NUE)

Nitrogen Use Efficiency (NUE) is defined as the yield of grain per unit of available N in the soil (including the residual N present in the soil and the fertilizers). The NUE can be divided into two areas: Nitrogen uptake Efficiency (NupE) which refers to the ability of the plant to remove N from the soil as nitrate and ammonium ions) and Nitrogen utilization efficiency (NutE) which represents the ability of the plant to use N to produce grain yield) (Hirel et al., 2007). Nitrogen Use Efficiency for rice is in the range of 30-35% with N losses up to > 50% (Zhao et al., 2010).

The nutrient uptake by rice plants vary with growth stage. Absorption is low at the seedling stage and peaks before heading stage, then decreases as root activity declines (Ju et al., 2009). Increasing the N application level could significantly increase rice production within limits depending on plants interaction with environmental factors such as solar radiation, rainfall, temperature and their response to diseases (Baligar et al., 2001). The highest N uptake is observed at the tillering stage, followed by young panicle development stage (Yu et al., 2013).

2.7.1 Common NUE terms and their application

2.7.1.1 Agronomic Efficiency (AEN)

Agronomic efficiency (AEN) is defined as the ratio of the difference between the yield harvested nutrient applied and the yield harvested with no nutrient applied divided by the amount of nutrient applied. It is calculated in units of yield increase per unit of nutrient applied. It closely reflects the direct production impact of an applied fertilizer and relates directly to economic return. According to Drechsel et al. (2015); the calculation of AE requires knowledge of yield without nutrient input, so is only known when research plots with zero nutrient input have been implemented on the farm.

2.7.1.2 Partial Nutrient Balance (PNB)

Partial nutrient balance is defined as the ratio of the nutrient content of harvested portion of the crop divided by the amount of nutrient applied. It is a simplest form of nutrient recovery efficiency, usually expressed as nutrient output per unit of nutrient input i.e. a ratio of “removal to use” (Drechsel et al. (2015). Often, the assumption is made that a PNB close to 1 suggests that soil fertility will be sustained at a steady state. The value of PNB below 1, where nutrient inputs far exceed nutrient removal, might suggest avoidable nutrient losses and thus the need for improved NUE (Snyder et al., 2007); attainable values, however, are cropping system and soil specific. However, in cases where soil nutrient concentration is at or below recommended levels, a PNB > 1 must be regarded as unsustainable (Brentrup et al., 2010).

2.7.1.3 Apparent Recovery Efficiency (REN)

According to Drechsel et al. (2015); REN is most commonly defined as the difference in nutrient uptake in the aboveground parts of the plant between the fertilized and unfertilized crop relative to the quantity of the nutrient applied. It is one of the more complex forms of NUE expressions. Like AE, it can only be measured when a plot without nutrient has been used on the site, but on addition requires measurement of nutrient concentrations in the crop.

2.7.1.4 Internal Utilization Efficiency (IE)

Internal utilization efficiency is defined as the yield in relation to total nutrient uptake. It varies with genotype, environment and management. A very high IE suggests deficiency of that nutrient, while low IE indicates poor internal nutrient conversion due to other stresses (deficiencies of other nutrients, drought stress, heat stress, mineral toxicities and pests) (Drechsel et al., 2015).

2.7.1.5 Physiological Efficiency (PE)

Physiological efficiency is defined as the yield increase in relation to the increase in crop uptake of the nutrient in the aboveground parts of the plant. Like AE and RE, it needs a plot without application of the nutrient of interest to be used on the site. It also requires measurement of nutrient concentrations in the crop and mainly measured and used in research with values of 40-60 being common (Drechsel et al., 2015).

Nutrient use efficiency is a critically important concept in the evaluation of crop production systems. It can be greatly impacted by fertilizer management as well as by soil- and plant-water management (Drechsel et al., 2015). Cereal N- use efficiency is 42 and 29% in developed and developing countries, respectively, (Sarker et al., 2015).

An increase in N-use efficiency of 20% as reported by Sarker et al. (2015) would result in saving in excess of $ 4.7 billion per year in Bangladesh.

2.8 Flooding and System of Rice Intensification

2.8.1 Flooding (Conventional practice)

Fertilizer N is applied to rice fields in the form of ammonium (NH4) or urea (which is rapidly converted to ammonium) (Linquist et al., 2011). Nitrogen is required by plants in larger amounts than any other nutrient. It can be taken up in either of two forms: nitrate and ammonium. When a rice field is flooded, the fertilizer largely remains as ammonium and is taken up as ammonium by the rice plant. Nitrate is susceptible to losses in rice systems, and it disappears from the rooting zone within a week or two of a soil being flooded. The fate of nitrate in flooded soil is difficult to determine. Plants, including rice, can take up nitrate at young stage before being lost by other means (Linquist et al., 2011).

In Tanzania, paddy rice is grown by subsistence farmers who practice conventional approach of continuous flooding, a technique that requires large amounts of water. These agronomic practices have been noted to lead to lower water productivity of less than 0.3 kg/ m3 (Katambara et al., 2013). In addition, 70% of subsistence farmers in Usangu Plain in Tanzania for example, have limited access to the highly needed water resource for irrigation as it is also required for maintaining the ecosystem in the Ruaha National Park and beyond (Kadigi et al., 2007).

Flooded rice soil is a complex of aqueous phase, a solid phase, an interchangeable gaseous phase, and various flora and fauna. The chemical changes of soil brought about by flooding viz. chemical oxidation of water soluble iron (Fe2+) and chemical oxidation of exchangeable and soluble iron (Fe2+) and manganese (Mn2+) have an impact on the supply of micronutrients. Soil submergence for 10 to 12 weeks increase Fe2+ and Mn2+ concentrations in the soil solution, regardless of the type (Ceesay, 2004). The concentration of Zn and Cu decrease in lowland soils and Zn deficiency is reported to be a widespread nutritional disorder of wetland rice (Ceesay, 2004). The imbalance of micronutrient in the soil may impair the nitrogen uptake by the rice crop as a result poor NUE. Awan (2002 reported that there was higher N uptake in rice when it was applied with Zn, rather than applying N alone.

Rice field under a conventional irrigated environment have sufficient water available throughout the growing season with controlled shallow water depth ranging between 5 and 10 cm. Although agronomists recommend that water depth be limited to 2-5 cm, usually farmers do not maintain strict water control and tend to keep their fields flooded as much as possible, thinking that this will ensure water availability (Thiyagarajan and Guja, 2013). Two of the largest factors contributing to the large yield gap between large scale farmers and small scale farmers are management of water and plant nutrients (Mueller et al., 2012).

In flooded soils, N transport occurs through ion diffusion (NH4+ from anaerobic soil layers and NO3- diffusion from aerobic soil layers), leaching, interflow and surface runoff. Positively charged NH4+ are adsorbed by negatively charged clay particles whereas negatively charged nitrite and nitrate ions are not usually adsorbed by clay particles, which results in leaching of nitrate or nitrite from the field. By diffusion to the aerobic zone, NH4+ may either be nitrified to NO3- or may be lost through volatilization as NH3. The NO3- formed in the aerobic zone can move back to the anaerobic layer via diffusion and can then be subsequently removed through denitrification. Atmospheric N2 can be fixed into the soil and rhizosphere in rice paddy fields through biological N fixation (Akter, 2013).

Seedlings of rice are raised in a nursery and seedlings with 20-30 days old, or even 40-60 days old are transplanted into puddled soil with standing water (Thiyagarajan and Guja, 2013). Under flooding, rice seedlings are transplanted in clumps of plant and fairly densely, 50-150 plants m-2. Water is used to control weeds supplemented by hand weeding or use of herbicides (Uphoff, 2007).

The combination of high demand for food, inadequate irrigation and domestic water requirements, as well as the effects that climate change and variability have on the food production processes calls for appropriate water saving technologies as adaptation measures. The technologies to be considered should result in low water consumption, high NUE while producing higher yields that increase food security, and technologies that can easily be implemented by subsistence farmers. These approaches include the system of rice intensification (SRI) (Katambara et al., 2013).

2.8.2 The System of Rice Intensification (SRI)

The System of Rice Intensification (SRI), is a set of ideas and insights that emphasize the use of younger seedlings (< 15-day-old) individually planted at wider spacing, together with the adoption of intermittent irrigation, organic fertilization and active soil aeration (Stoop et al., 2002; Uphoff, 2007). It has emerged as a set of guiding principles that can maintain high yields through stronger and healthier plants and soils while reducing reliance on external inputs. Research and demonstration plots in several tropical countries have shown SRI techniques are productive, by providing very high yields and resource-saving and are environmentally friendly by preventing water pollution mainly due to lower use of agrochemical inputs when compared to conventional rice production (Kabir and Uphoff, 2007; Sinha and Talati, 2007; (Uphoff et al., 2011; Geethalakshmi et al., 2011; Palanisami et al., 2011; Chowdhury et al., 2012; Singh et al., 2014). Developed in Madagascar about 25 years ago, SRI is gaining increasing credence and momentum as probably 500,000 farmers in more than 20 countries are now using the method to increase their rice production while also reducing the use of external inputs and production costs.

2.8.2.1 Principles of SRI

SRI has its elements which include: transplanting young seedling, before the start of their 4thphyllochron of growth; reducing plant population by as much as 80-90% per m2; converting paddy soils from anaerobic, flooded status to mostly anaerobic conditions by alternate wetting and drying (Thiyagarajan et al., 2013).

Early transplanting, the key to success with SRI is the transplanting of very young seedlings, before they are 15 days old, and 8 to 12 days after emergence. Seedlings then have only their small roots, with seed still attached, and a first (main) tiller and two tiny leaves. However, direct seeding can avoid spending so much time and resources establishing a nursery and transplanting the seedlings, both labour-intensive activities. With SRI, the soil only needs to be kept moist during the period of growth when the plant is putting out tillers, leaves and roots, before it begins to flower and to produce grains (Ceesay, 2004). The irrigation regime in SRI is to provide the growing plants with sufficient but never excess water, so that the roots do not suffocate and degenerate (Thiyagarajan and Guja, 2013). In Tamil Nandu, India the water management for SRI is prescribed based on field experimentation. Up to panicle initiation stage, it is recommended to irrigate the field to 2.5 cm height after the previously irrigated water disappears and hairline cracks develop. After panicle initiation, a thin layer of water is applied and remains continuously on the field (Ceesay, 2004). At the hairline cracking stage, soil is not kept dry but it is still moist (Thiyagarajan and Guja, 2013).

With SRI, seedlings are transplanted spaced at 25 cm × 25 cm spacing and early and regular weeding is practiced. Application of compost is encouraged; but no use of herbicides and chemical fertilizers (Stoop et al., 2002). The seeding rate is 5-10 kg ha-1, compared to 50-100 kg ha-1or more conventionally (Ceesay, 2004).

The SRI practice has been reported to result in higher yields ranging from 6 to 8 ton/ha with subsequent water saving of up to 25%. The practice also produces quality grains with stronger aroma (Ndiiri et al., 2012). Proportional increase in yield and decrease in water use have also been reported in Madagascar and China. In Madagascar, an equal range of between 25% and 50% increase in yields and decrease in water use were reported (Stoop et al., 2002).

On the other hand, N2O emission could increase under water saving techniques like SRI because of increased nitrification and denitrification processes, with soil conditions constantly changing between anaerobic and aerobic and related changes in redox potentials (Zheng-Qin et al., 2007; Sharma et al., 2008). Jain et al., (2014) have reported a higher (23%) N2O emission from SRI than from flooded rice. However, SRI has often been a subject of discussion among the scientific community with regard to its potential to increase yield and reduce Greenhouse gas (GHG) emissions and climate change mitigation. For example, McDonald et al. (2008) reviewed different publications where SRI was compared to recommended management practice (RMP) and found that SRI yields were not higher than under recommended management practice. They insisted that aside from one set of experiments in Madagascar where SRI more than doubled rice grain productivity with respect to best management practices (BMPs) (140-245% increase), they found no evidence of a yield advantage of that magnitude elsewhere. They concluded that there is no empirical evidence beyond Madagascar that SRI yields are superior to those achievable with BMPs (McDonald et al., 2008). On other hand Uphoff (2008) reported that SRI water management system produced rice plants with strong tillering, and resistant to lodging and tolerance to environmental stress. McDonald et al.(2008); Uphoff et al. (2008) argued that, hybrid rice varieties used with SRI should have these characteristics, not that SRI method produce them. However, it was found that this discussion was rather theoretical and not very relevant to the conditions in Africa, as most lowland rice is cultivated under poor management conditions. Any approach that will improve growth conditions will therefore increase yields (Noragric Report, 2014).

2.8.2.2 The reason for promoting SRI can be presented as follows:

(a) Is considered to be a suitable rice cultivation; this is due that the SRI cultivation, practice to adapt to the changing climate as it requires less water compared to the conventional paddy rice system. According to Jain et al. (2014) water saving of 36% was observed with SRI, and SRI increased water productivity by 45% compared to conventional flooded transplanted rice. One of the benefits of SRI is mitigating methane emission. This is because continuous flooding is prohibited in SRI and fields are instead irrigated through alternate wetting and drying (Uprety et al., 2012)

(b) Minimal capital cost; the system does not require purchase of new varieties of seed, chemical fertilizers or agronomic inputs although chemical inputs can be used (Thiyagarajan et al., 2013)

(c) Increased farmer’s net income; with increased output and reduced costs farmer’s net income by more than more than their augmentation of yields (Thiyagarajan et al., 2013).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Soils

Eight soil samples were collected from Mkindo village, rice irrigation scheme in Mvomero district for soil analysis and one among them was selected as source of soil for pot experiment. Msanya et al. (2002) classified the soil as Eutric fluvisol.

3.2 Soil sampling and sample preparation

From selected eight farms, soils were sampled using a hoe and shovel. The names of the farmers from whose farms, soil samples were taken are as follows with their corresponding soil sample number in brackets: Abdalah Mbete (1), Mr.Mganga (2), Kalori Clement (3), Mr.Alphonce (4), Athuman Kazumba (5), Mwanaidi Hamza (6), Eliza Simon (7) and Salum Abdalah (8). The bulk soil for pot experiment was collected from Mr Kazumba's farm. The coordinates of the farms are shown in Apendix 9. The sampling depth of 0-20 cm was chosen based on plant root growth of rice which is slightly more than 20 cm deep. Ten sub samples were sampled from each farm which were in turn mixed thoroughly to form one composite soil sample for each farm, givinga total of eight composite soil samples). The composite soil samples were air dried ground and sieved to pass through 2 mm.

3.3 Soil analysis

The 2 mm sieved soil samples were subjected to physico-chemical analysis to determine soil fertility status. Particle size distribution for each composite soil sample of each farm was carried by the hydrometer method (Gee and Bauder, 1986). The textural classes were established using the textural triangle (USDA, 1975).

Soil pH was measured in water at 1:2.5 soil: water ratio following the procedure outlined by McLean (1982).

Organic carbon was determined by the wet digestion method of Walkley and Black (Nelson and Sommer, 1982). To 1 g soil sample, 10 ml of 1 M K2Cr2O7 and 20 ml of concentrated H2SO4 were added to oxidize organic carbon. The amount of dichromate reduced was used to estimate the organic carbon content of the soil. Total N was determined by macro-Kjedahl digestion followed by distillation (Bremmer and Mulvaney, 1982).

Available P was extracted according to the Bray-1 method (Bray and Kurtz, 1945) and P in the extract was determined colorimetrically after developing blue colour with ascorbic acid as described by Murphy and Riley (1962). Sulphur was determined following the procedure described by Searle (1988). It was extracted by Ca (H2PO4) 2.H2O and the absorbance was measured in a spectrophotometer at 535 nm.

The cation exchange capacity (CEC) was determined by the ammonium acetate saturation method as described by Chapman (1965). The amount of K, Ca, Mg, and Na (exchangeable bases) in the 1M NH4OAc (pH 7) filtrate were determined using Atomic Absorption Spectrophotometer.

The available micronutrients (Zn, Cu, Mn and Fe) were extracted by 0.005M diethylene Triamine Penta Acetic acid (DTPA) following the procedure described by Lindsay and Norvell (1978).

3.4 Pot experiment

Pot experiment was conducted in the glasshouse at SUA, Morogoro to evaluate effects of flooding and System of rice intensification on Nitrogen use efficiency in rice (Oryza sativa L) production. The bulk soil collected from Mr Athuman Kazumba's farm in Mkindo irrigation scheme was air dried ground and passed through a 4 mm sieve to obtain a soil for pot experiment. After that 128 kg of the sieved soil was weighed for 32 plastic pots each with 4 kg of soil.

3.4.1 Mixing soil with fertilizers

Prior to transplanting, 96 kg of soil were mixed thoroughly with 2.112 g of ZnSO4, 40 g of TSP and 13.932 g of KCl to supply 5 mg Zn/kg soil, 80 mg P/kg soil and 100 mg K/kg soil respectively. The mixing exercise was done on polythene sheet by first taking a ½ kg of soil and mixed with each fertilizer thoroughly; the mixture soil and fertilizer was then mixed with 2 kg of soil which in turn was mixed thoroughly with other 10 kg of soil making a total of 12½. The 12½ kg of soil were mixed thoroughly with other 30 kg of soil to get 42½ kg of soil which in turn finally were mixed thoroughly with 53½ kg of soil to obtain 96 kg of soil thoroughly mixed with fertilizers indicated above. Thirty two kg of soil did not receive any fertilizer for control treatment.

The 96 kg of soil thoroughly mixed with fertilizers were put into 24 plastic pots with capacity of 4 litres; each pot contained 4 kg of soil. The rest 32 kg were put in other 8 pots for experimental control purposes making a total of 32 experimental pots which were then transferred in the glass house. In the glass house 16 pots were used for SRI and 16 pots for flooding. 16 pots for SRI were moistened each with 800 ml of water in 24 hours before transplanting. While the other 16 for flooding were left for 10 days. The treatment tested for both SRI and flooding experiments were

i. Absolute control: No nutrient was added (N0P0K0S0Zn0)

ii. N125 + Zn5 + S80 +P80 + K100

iii. N250 + Zn5 + S80 +P80 + K100

iv. N500 + Zn5 + S80 +P80 + K100

The subscripts indicate the rate of the different nutrients applied in mgkg-1 of soil.

The sources of N ware urea and sulphate of ammonia, while the source of P was triple superphosphate; Zn came from zinc sulphate (ZnSO4.7H2O). Potassium was applied as potassium chloride and sulphur was applied as ammonium sulphate. An absolute control treatment was included in this study to evaluate rice yields under natural fertility status. For other treatments, all nutrients except N and S were thoroughly mixed with soil samples before transplanting. Sulphur and N fertilizers were applied twice as topdressing. First topdressing for SRI with N and S was done at 15 days after transplanting (DAT) and for flooding at 7 DAT with application rates of 50 mg N kg-1of soil, 100 mg N kg-1of soil and 200 mg N kg-1of soil for treatments 2, 3 and 4, respectively and40 mg S kg-1of soil was added in all other pots except for the absolute control. The second top dressing was done at 56 DAT for SRI and 51 DAT for flooding with the rates of 75 mg N kg-1of soil, 150 mg N kg-1of soil and 300 mg N kg-1of soil for treatments 2, 3 and 4, respectively. Sulphur was added in all other pots except for the absolute control at the rate of 40 mg Skg-1of soil at the same day which N was applied for the second time. Treatments were replicated four times and arranged in the Completely Randomized Block Design.

3.5 Harvesting

3.5.1 Harvesting of rice shoots

At 74 DAT, one plant from each pot was randomly selected, measured the plant height and cut at the base above soil surface. The shoots were dried at 70oC to constant weight. The samples were weighed to obtain dry matter yield (DMY), ground with a cyclone sample mill and sieved through 1 mm sieve ready for analysis of N content.

Plate 1: Rice under flooding water management 74 DAT

Plate 2: Rice under SRI water management 74 DAT

3.5.2 Harvesting of rice grains

At 147 DAT the plant height from the base above soil surface to the tip of panicles, number of panicles per pot and panicle length were recorded. Then rice plants from each pot were harvested

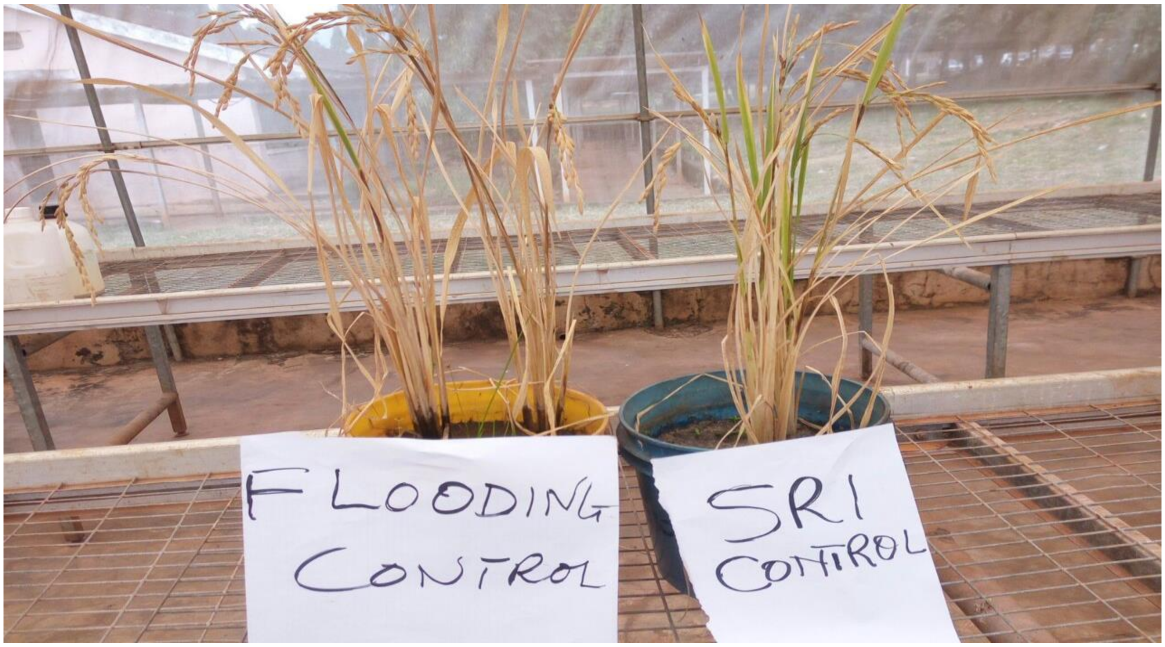

Plate 3: Rice plants at maturity for control pots for SRI and flooding water management.

Plate 4: Rice plants at maturity with N level of 125 mg N kg-1 of soil for SRI and flooding water management.

Plate 5: Rice plants at maturity with N level of 250 mg N kg-1 of soil for SRI and flooding water management.

Plate 6: Rice plants at maturity with N level of 500 mg N kg-1 of soil for SRI and flooding water management

3.6 Plant analysis

Plant samples were digested using the Micro-Kjeldahl wet oxidation procedure of Kalra (1998). A 0.2 g of ground plant sample was weighed and transferred to 350 ml Kjedahl tubes. The sample was added with 2 g of salt mixture were added into each tube, followed by concentrated H2SO4 and shaken gently until all the plant sample and acid were thoroughly mixed. The digestion tubes were then placed on the digestion block with temperature set at 125oC for 2 hours, then taken off and cooled.

After cooling 50 ml of boric acid was mixed with methyl orange indicator ready for distillation after thoroughly mixing the contents in the tube.200 ml of the distillate was collected and titrated with 0.05N H2SO4 to a pink endpoint. The amount of H2SO4 was corrected for the sample after subtracting the amount needed for the blank.

3.7 Data Analysis

The dry matter yields, N concentration in plants, plant height, number of tillers, panicle length and 1000 grain weight in response to water management, N application and interaction of N with water management were subjected to analysis of variance using GenStart software. The statistical model used was:

Yij = □ +Ni + Mj + NMij+ Eij ………………………………………..…..…………… (vi)

Where

Yij = Response

□ = General effect

Ni = Subplot factor effect (N-levels)

Mj = Main factor effect (water)

NMij= Interaction effect between N and water

Eij = Random error effect

The treatment means were compared using Duncan’s New Multiple Range Test at P□0.05.

Nitrogen use efficiency was calculated by the equation of Craswell and Godwin, (1984)

AEN = (YN – Y0)/FN………………………………………………............………… (vii)

Where:

AEN = Agronomic efficiency of applied N (mg grain mg-1N applied

YN = crop yield with applied N (mg pot-1)

Y0 = crop yield (mg pot-1)) in a control treatment with no N

FN = amount of (fertilizer) N applied (mg N kg-1 soil)

Agronomic N use Efficiency (AEN) was used for the assessment of NUE for the systems (SRI and flooding cultivation methods) that are at a relatively steady-state with regard to soil organic N content.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Soil fertility status of rice growing soils of Mkindo village

The physical and chemical properties of soil of the study are shown in Table 1.

4.1.1 Physical Properties of soils

4.1.1.1 Soil Textural Classes

The soil textural class of soils was sandy loam (Table 1). The soil on which rice grows, texture ranges from sand to clay (Talpur et al., 2013). It has also been reported that rice plants perform well in fine to medium textured soils (Landon, 1991). Based on the textural classes of soil at Mkindo village the soils are suitable for rice production, if the other rice plant growth factors are optimal.

4.2 Chemical properties

4.2.1 Soil pH

The soil pH ranged from 4.7 to 6.1 (Table 1). Msanya et al. (2001) categorised the soil pH as follows: 6.1-6.5 slightly acid, 5.6 -6.0 medium acid, 5.1-5.5 strongly acid, 4.5-5.0 very strongly acid and <4.5 extremely acid. 55% of the soils were strongly acidic, 22.2% very strongly acidic while 22.2% were slightly acidic. The optimum pH for rice crop 5.5 to 6.5 non- irrigated rice production system and 5.5 to 7.2 under flooded conditions (Masawe, 2012). Talpur et al. (2013) reported that the pH requirement for rice ranges from 3 to 10. The pH of the soils in the study area was within the range recommended for rice production.

Table 1: Some of the physical and chemical properties of some rice growing soils of Mvomero District

	soil sample								
Soil parameters	1	2	3	4	5	6	7	8	9
pH	5.1	4.8	4.9	6.1	5.4	5.3	5.3	5.3	6.3
Organic carbon (%)	1.3	1.5	1.0	0.9	1.4	0.9	1.3	1.4	1.2
Total nitrogen (%)	0.12	0.11	0.07	0.07	0.09	0.10	0.07	0.09	0.09
Extractable Bray1(mg kg^{-1})	11.0	4.8	2.0	2.3	1.9	8.4	12.8	12.0	4.1
Extractable S(mg kg^{-1})	21.5	22.2	24.3	27.0	29.3	21.3	20.8	20.6	10.8
Exchangeable Ca (cmol kg^{-1})	6.1	2.8	1.6	2.4	1.6	2.0	1.6	2.0	5.9
Exchangeable Mg (cmol kg^{-1})	0.9	0.6	0.5	0.6	0.6	0.6	0.5	0.4	4.4
Exchangeable Na (cmol kg^{-1})	0.1	0.2	0.5	0.7	0.3	0.1	0.1	0.04	0.7
Exchangeable K (cmol kg^{-1})	0.5	0.6	0.5	0.3	0.2	0.2	0.2	0.3	0.2
CEC (cmol kg^{-1})	15.6	10.8	8.0	7.8	9.4	13.0	9.6	8.8	14.7
Zinc (mg kg^{-1})	3.0	9.0	1.2	1.2	1.8	3.0	2.1	3.0	3.0
copper (mg kg^{-1})	4.7	4.4	3.2	3.8	5.3	4.4	3.8	3.5	5.3
Iron (mg kg^{-1})	481.0	449.0	535.0	103.0	266.0	884.0	505.0	611.0	367.0
Manganese(mg kg^{-1})	57.2	68.3	65.9	48.2	59.6	24.5	65.3	84.2	80.9

Particle size distribution									
Sand (%)	77.0	79.0	75.0	79.0	71.0	73	81	83.0	60.0
Silt (%)	8.9	4.9	6.9	6.9	16.9	8.9	6.9	4.9	10.0
Clay (%)	14.1	16.1	18.1	14.1	12.1	18.1	12.1	12.1	22.0
Textural class	SL	SL	SL	SL	SL	SL	SL	LS	SL

Letters associated with rating (**) according to Msanyaet al. (2001) and (*) according to Landon (1991) were; SA = Slightly acidic, VH= Very High, H=High, M=Medium, L= Low, VL= Very low

Numbers of Soil sample with the corresponding names of farm's owner; 1= AbdalahMbele, 2= Mr Mganga, 3= Kalori Clement, 4= Mr Alphonce, 5= AthumanKazumba, 6= MwanaidiHamza, 7= Eliza Simon, 8= SalumAbdala; +: Representation soil sample from a bulk Soil used for pot experiment

4.3.2 Total Nitrogen

Total N values ranged from 0.07 to 0.12% (Table 1). Msanya et al. (2001) rated N as follows: >0.5%N high, 0.21-0.5%N medium, 0.10-0.20 low and <0.10%N very low. This shows that 100% of soils from Mkindo village had very low N content thus the use of N fertilizers is necessary for increased rice yields. It is reported that some selected paddy growing soils of Tanzania including these of Morogoro have low total N (Amur, 2003). These findings continue to provide evidence that N is limiting in many soils of Tanzania. The low total N might have been caused by limited use of organic soil amendments resulting into low organic carbon, N uptake by plants, leaching and denitrification of applied N as fertilizers.

4.3.3 Organic Carbon

The Organic Carbon content for the soils in the study area ranged from 0.91% to 1.50% (Table 1) with the mean content of 1.21%.Msanyaet al. (2001) rated the Organic Carbon as follow: >3.5% very high, 2.51-3.50% high, 1.26-2.50% medium, 0.60-1.250% low and <0.6% very low. Of all soil samples analysed, 55.56% had medium Organic Carbon and 44.44% had low Organic Carbon. The low content of Organic Carbon is translated to low organic matter content in the soils. Organic matter influences physical, chemical and biological properties of soils, such as soil structure, water retention, nutrient content and retention, as well as of micro-biological life and activities in soils. In order to improve organic carbon and sustain rice productivity of the soils of Mkindo village, organic matter amendments like manures or crop residues (rice straws and weeds) have to be applied or incorporated into the soils on regular basis.

4.3.4 Available Phosphorus

The Bray-1 extractable Phosphorus in the soils ranged from 1.9 to 12.8 mg Pkg-1of soil (Table 1). Landon (1991) categorized extractable Bray-1 as: > 50 mg kg-1as high, 15-50 mg kg-1 of soil as medium and < 15 mgkg-1of soil as low. Based on this categorization all the eight soils had low available P contents. The low P in the studied soils could be due to the low pH values, P fixation and crop uptake (Table 1). According to Tisdale et al. (1993), P availability is low in acidic soils as well as in calcareous soils. Rice being a high P demanding crop, the observed soil available P values would not satisfy the phosphate demand or requirement by rice crop, hence rice response to phosphate application in these soils as in organic or organic fertilizers would be expected. The amount of P to be added should aim at raising the P availability status to the critical P concentration range of 15 – 20 mg P kg-1 of soil (Masawe, 2012).

4.3.5 Extractable Sulphur

Exchangeable Sulphur in the soils ranged from 10.8 – 29.3 mg kg-1of soil (Table 1). According to Landon (1991), the levels of Sulphur are rated as follows : > 10 mg kg-1of soil as high, 6.1 -10.0 mg kg-1of soil as medium, 3.1 – 6.0 mg kg-1of soil as low, and < 3.0 as very low. Results for all soils indicated having high S contents. Landon (1991) reported that critical levels for S depend greatly on the crops; for example, cereals and grains will flourish in soils too deficient in S for alfalfa and clover; which are themselves less demanding than cotton, tomatoes and tobacco. Rice being among cereal crops, the contents of S in the soils satisfy the requirement of S for rice. However S requirement of rice varies according to the N supply, this might be the reason why rice yield increased as the amount of N increase with application of 80 mg S kg-1of soil despite of sufficient amount of S in the soil, hence the uptake of S by rice plant might have enhanced by N application regardless the sufficient amount of S applied. Furthermore Lathiff et al. (1982) reported that the availability of S to rice has been found to be lower under flooded conditions than under upland conditions, making rice more subject to S stresses than other field crops. When S becomes limiting, addition of N does not change the yield or protein level of plant (Sigh et al., 2012).

4.3.6 Cation Exchange Capacity (CEC)

Cation exchange capacity (CEC) ranged from 8.0 to 15.6 cmol (+) kg-1of soil (Table 1). According to Landon (1991), all soils from the study area had low CEC values. It appears that the low CEC values in all soils may be due to the influence of soil texture and type of the clay minerals and the soil organic matter contents. Clayey soils are reported to have higher CEC than sandy soils mainly due to charges resulting from isormorphous substitution (Sanga, 2013). Landon (1991) reported that CEC values of 8 to 10 cmol (+) kg-1of soil are indicative minimum values in the top 30 cm of soil for satisfactory production of rice under irrigation, provided that other factors are favourable. For this reason soils from Mkindo village have CEC values which satisfy rice production.

4.3.7 Exchangeable Bases

4.3.7.1 Calcium

The values of Ca for the soils tested from the study area are shown in Table 1. The values ranged from 1.6 to 6.1cmol (+) kg-1of soil. Landon (1991) categorized levels of calcium and indicated that < 4 cmol (+) kg-1of soil is considered as low and > 10 cmol kg-1of soils considered as high. This implies that 88% of all the eight soil samples had low calcium contents and 22% had medium Ca contents. The low Ca observed in 88% soils samples may be due to the low pH values parent materials and plant uptake. Soils with pH 5.0 or lower are likely to be deficient in calcium (Chapman, 1965; Hazelton and Murphy, 2007).

4.3.7.2 Magnesium

The data for exchangeable Mg are presented in Table 1. The exchangeable Mg ranged from 0.4 to 4.4 cmol (+) kg-1of soil. Landon (1991), reported that soils having < 0.2 cmol (+) kg-1 soil are Mg deficient and soils having 0.2 - 0.5 cmol (+) kg-1of soil are medium Mg contents and > 0.5 cmol (+) kg-1of soil are high in magnesium. According to Landon (1991), all soils in the study area are of adequate Mg level, except soil sample number 9 which was used for pot experiment had high Mg levels.

4.3.7.3 Sodium

The values of Na for the soils tested are shown in Table 1. The ranges of these values were 0.04 to 0.68 cmol (+)Na kg-1of soil. Based on Landon (1991), > 1 cmol (+) kg-1of soil Na+ content is in high range. Thus, all soils in the study area are of low to medium range. Although Na may, in particular circumstances, be utilized by some plants as partial substitute for K, it is not an essential plant nutrient. Its absence, or presence in only very small quantities, is therefore not detrimental to plant nutrition (Landon, 1991).

4.3.7.4 Potassium

The range of exchangeable K in the area under the study was 0.17 to 0.57cmol (+) kg-1of soil (Table 1). Landon (1991) rated K contents in soil as follows: > 0.5 1 cmol (+) kg-1 soil high, 0.5-0.25 1 cmol (+) kg-1of soil medium and < 01 cmol (+) kg-1of soil low. Forty four percent of the soil samples analysed had low K value concentration, forty four percent of soils had medium K contents and eleven percent of soils had high concentration of K. In general terms, a response to K fertilizer is likely when a soil has an exchangeable K value of below about 0.2 1 cmol (+) kg-1of soil (Hazelton and Murphy, 2007; Landon, 1991). Therefore, potash fertilization on these soils is required to replace nutrients removed in grain and straw, to avoid further deterioration of soil K status, and to increase productivity of high quality rice.

4.4 Micronutrient contents

4.4.1 Zinc

The amount of the DTPA extractable Zn contents is shown in Table 1, which ranged from 1.2 to 9.1 cmol (+) kg-1of soil. According to Alloway (2008) extractable Zn values 0.1 – 1.0 Cmol (+) kg-1of soil is low and 1 – 10 cmol (+) kg-1of soil is rated as adequate. Soils from study area indicate that the values for DTPA extractable Zn are adequate. Deficiency symptoms rarely occur in acidic soils unless native in reserves are very low, but on calcareous soils Zn disorders are common (Landon, 1991). Soils from Mkindo village are acidic and that is why they have adequate amount of Zn as stated by Landon (1991). Although Zn content in soils from the study area is sufficient, still Zn was added because there is a tendency in acidic soils for the available Zn to form insoluble Zinc Sulphide (ZnS) which cannot be used by rice plant as reported by Rehman et al. (2012). On other hand Sigh et al. (2012) found that S applied along with Zn resulted in good performance of rice in terms of plant height, dry matter and grain as compared to S application alone.

4.4.2 Copper

The DTPA extractable Cu contents are shown in Table 1, which ranged from 3.20 to 5.30 mg kg-1of soil. According to Landon (1991) and Lindsay and Norvel (1978) the DTPA extractable Cu values (> 0.75 mg kg-1of soil) are rated as sufficient. Hence the soils from study area have adequate amounts of available Cu for rice production.

4.4.3 Manganese

The DTPA extractable Mn contents is shown in Table 1, and ranged from 24.45 to 84.15 mg kg-1of soil. According to Landon (1991) and Lindsay and Norvel (1978), the DTPA extractable Mn> 20 mg kg-1of soil is rated as sufficient, hence the soils of Mkindo village have adequate amounts of available Mn for rice production.

4.4.4 Iron

The DTPA extractable Fe is shown in Table 1, which ranged from 102.5 to 884.0 mg kg-1 of soil. According to Landon (1991) and Lindsay and Norvel (1978) the DTPA extractable Fe in the soil are rated as sufficient (> 5 mg kg-1of soil). The concentration of Fe contained in the soils analysed is higher than the critical range of 2.5 to 5.0 mg kg-1 Fe as reported by Randhawa et al. (1978). Therefore, the soils of the study area have adequate amounts of available Fe for rice production. Although most mineral soils are rich in iron, the expression of iron toxicity symptoms in leaf tissues occurs only under flooded conditions, which involves the microbial reduction of insoluble Fe3+ to soluble Fe2+ (Nagajyoti et al., 2010). The appearance of iron toxicity in plants is related to high Fe2+ uptake by root and its transportation to leaves and via transpiration streams (Nagajyoti et al, 2010). Due to high level of Fe from the analysed soils from Mkindo village, the area is likely to experience Fe toxicity as far as rice is managed under flooded conditions. In order to minimize the Fe concentration in soil and to avoid environmental pollution and chemicals containing heavy metals like fungicides should be avoided.

4.5 Effect of N levels, water management systems and interaction of N with water management systems on rice dry matter yields.

Results of the dry matter yields for both SRI and flooding methods of water management are presented in Table 2 and Appendix 1. There was a significant ($P<0.05$) increase in dry matter yields due to application of N over control on both SRI and flooding water management systems. The control gave the lowest dry matter yields on both water management practices. This indicates the need of N application in the soil during rice production in order to increase yields. Both management systems (SRI and flooding)did not significantly ($P <0.05$) affect the increase of dry matter yields. Furthermore the interaction of N levels with SRI and flooding water management systems had no significant effect on the increase of dry matter. The significant ($P < 0.05$) increase in dry matter was due to the effect of N levels, whereas 125 mg N kg-1of soil yielded 8.40 g of dry mater and 250 mg N kg-1of soil yielded 13.45 g of dry matter. There was no significant increase in dry matter yield when N was increased to 500 mg N kg-1of soil as compared to 250 mg N kg-1of soil. This might be due to the effects of the controlled environments in the greenhouse contributed to minimize N loss through NH3volatilization and denitrification process hence no significant ($P< 0.05$) difference in on rice dry matter in both SRI and flooding systems.

Table 1: Effect of water management, N levels and interaction of N with water management on rice dry matter yields.

Main factor (Water management)	SRI	Flooding
	DM(g)	DM(g)
	10.65 a	9.15 a
Sub factor (N levels)	N-levels	
	N0	2.92 a
	N125	8.40 b
	N250	13.45 c
	N500	14.85 c
N levels *Water management		
N-Levels	SRI	Flooding
N0	1.72 a	4.11 a
N125	8.14 a	8.65 a
N250	15.09 a	11.80 a
N500	17.64 a	12.05 a
CV (%)	7.70	7.70
SLD	2.84	2.84

SRI: System of Rice Intensification; DM: dry matter (N125, N250 and N500): milligrams of Nitrogen applied per kilogram of soil. Means in the same column and row followed by the same letter(s) are not significantly different ($P<0.05$) according to Duncan's New Multiple Range Test. F - Statistics Table is given in Appendix 1.

4.6 Effect of water management, N levels and interaction of N with water management on N concentration in rice plants.

Nitrogen concentration in plant on both SRI and flooding water management are shown in Table 3. Water management systems viz: SRI and flooding had no significant effect on plant N concentration. The significant effect ($P<0.05$) on plant N concentration was due to N levels (Appendix 2). Nitrogen concentration in plants significantly increased as amount of N applied increased from absolute control (N0), N125, N250 to N500 with 0.97%N, 1.70%N, 2.10%N and 2.50% N, respectively.

The interaction of water management systems and N levels, showed a significant ($P< 0.005$) increase of N concentration in rice plant along with N levels increase on flooding system only. But this increase of N concentration in rice plant under flooding was not significant ($P< 0.05$) if compared with that under SRI system. According to Campbell (2000) the critical sufficient range of N in rice plant is 3.0 – 3.4%. The results show that concentration of N in plants in both SRI and flooding was below the critical range. The low concentration of plant N even at high rate in the soil might be due to high concentration of soluble Fe in the soil. Some literature report that, roots of plants growing in soils high in soluble Fe may be coated with oxide Fe which may reduce the uptake of other nutrients (U.S. Environmental Protection Agency, 2003). Luo et al. (1997) cited by Fageria (2001) reported that, excessive Fe^{2+} reduce N, P, K and Mg uptake in rice genotypes.

Table 3: Effect of water management, N levels and interaction of N with water management on nitrogen concentration on rice plants

Main factor (Water management)	SRI	Flooding
	N%	N%
	1.73 a	1.91 a
Sub factor (N levels)		
	N levels	
	N0	0.97 a
	N125	1.70 b
	N250	2.10 c
	N500	2.50 d
N levels * Water management		
N-Levels	SRI	Flooding
N0	0.89 a	1.05 a
N125	1.71 b	1.69 b
N250	1.92 b	2.28 c
N500	2.39 cd	2.62 d
CV (%)	2.6	2.6
L.S.D	0.25	0.25

SRI: System of Rice Intensification; (N125, N250 and N500): milligrams of Nitrogen applied per kilogram of soil. Means in the same column and row followed by the same letter (s) are not significantly different ($P<0.05$) according to Duncan's New Multiple Range Test. F - Statistics Table is given in Appendix 2.

4.7 Effect of water management, N levels and interaction of N with water management on rice grain yield

Grain yield data is presented in Table 4.Results indicate that the grain yield of rice differed significantly ($P< 0.05$) with the different levels of N under both SRI and flooding water management systems.

Table 4: Effect of water management, N levels and interaction of N with water management on rice grain yield

Main factor (Water management)	SRI	Flooding
	Grain yield (g)	Grain yield (g)
	17.52 a	15.47 a
Sub factor (N levels)	N-levels	
	N0	4.79 a
	N125	14.28 b
	N250	18.90 c
	N500	28.00 d
N levels * Water management		
N-Levels	SRI	Flooding
N0	3.59 a	5.99 a
N125	14.31 b	14.26 b
N250	21.19 cd	16.61 bc
N500	30.97 e	25.03 de
CV (%)	6.4	6.4
L.S.D	6.15	6.15

SRI: System of Rice Intensification; (N125, N250 and N500): milligrams of Nitrogen applied per kilogram of soil. Means in the same column and row followed by the same letter(s) are not significantly different ($P<0.05$) according to Duncan's New Multiple Range Test. F - Statistics Table is given in Appendix3.

Analysis of variance is given in Appendix 3. Flooding and SRI water management systems had no significant effect on rice grain yields at ($P<0.05$). The significant increase in rice grain yield was in agreement with increase of N levels from absolute control N0 to N500. Rice grain yield increased from 4.79 g pot-1for the absolute control to 28.00 g pot-1for 500 mg N kg-1ofsoil.Rajbhandari (2007) reported similar trend in rice grain yield following increasing rates of N application and associated it to increase in chlorophyll content of leaves which led to higher photosynthetic rate and ultimately plenty of photosynthates available during grain filling. This indicates the necessity of application of nitrogenous fertilizer in order to supplement the low amount N available in the soil to get increased rice yield. The interaction of N levels with SRI had a significant effect on rice grain yield increase at ($P< 0.05$) as N levels increased over absolute control treatment. The flooding water management systems showed a significant ($P< 0.05$) increase on rice grain yield at the rate of 500 mg N kg-1 of soil over control pots. However the grain yield increase compared among the two water management systems with N interaction was not significant at ($P< 0.05$).

4.8 Effect of water management, N levels and interaction of N with water management on rice thousand (1000) grain weights.

Analysis of variance data on the effect of water management, N levels and interaction of N with water management on rice thousand (1000) grain weights is presented in Table 5. Flooding and SRI water management systems had no significant effect ($P < 0.05$) on a thousand grain weight per pot (Appendix 4). Likewise, N levels and the interaction of N with SRI and flooding had no significant effect on a thousand rice grain weight per pot. The increase of N levels without effects on 1000 g weight increase is probably the result of insufficient translocation of carbohydrates to its spikelets. This effect further results in poor dry matter accumulation in spikelets of rice. Pramanik and Bera (2013) reported that increased number of spikeletes and vigorous growth of rice due to high rates of N fertilizer application induce competition for carbohydrate available for grain filling and spikelet formation.

Table 5: Effect of water management, N levels and interaction of N with water management on rice thousand (1000) grain weights.

Main factor (Water management)	SRI 1000Gwt(g)	Flooding 1000Gwt(g)
	26. 86 a	26.58 a
Sub factor (N levels)	N-levels	
	N0	26.06 a
	N125	27.18 a
	N250	26.80 a
	N500	26.08 a
Water management * N levels		
N-Levels	SRI	Flooding
N0	26.00 ab	27.70 b
N125	27.60 b	26.75 b
N250	26.70 b	26.90 b
N500	27.15 b	24.98 a
CV (%)	1.50	1.50
L.S.D	1.62	1.62

SRI: System of Rice Intensification; Gwt: grain weight; (N125, N250 and N500): milligrams of Nitrogen applied per kilogram of soil. Means in the same column and row followed by the same letter(s) are not significantly different ($P<0.05$) according to Duncan's New Multiple Range Test. F - Statistics Table is given in Appendix4.

4.9 Effect of water management, N levels and interaction of N with water management on Nitrogen Use Efficiency (NUE)

Data for agronomic N use efficiency are presented in Table 6. The two water management systems: SRI and flooding did not differ significantly ($P<0.05$) on nitrogen use efficiency (Appendix 5). This means, the two water management practices had no significant influence on the ability of rice plant to increase grain yield in the response of N application. This could be due to the fact that the experiment for both water management systems was conducted in the glasshouse (under controlled environmental conditions) different to what the rice plant is exposed to when grown in the field like sunlight and wind. The glasshouse condition might have contributed to minimize N loss through NH3volatilization and denitrification process hence no significant ($P< 0.05$) difference in NUE in both SRI and flooding. This was due the experimental pots were not exposed to wind and sunlight. Nitrogen levels significantly ($P<0.05$) affected agronomic N use efficiency of rice yields. The agronomic N use efficiency for 125, 250 and 500 mg N kg-1 of soil was 46.42, 56.44 and 75.93 mg grains mg-1 N, respectively. Thus, the grain yield increase was influenced by increase on N level. For the interaction of N and (SRI and flooding) did not show a significant ($P< 0.05$) effect on NUE among themselves, but the interaction of SRI and N showed a significant($P< 0.05$) decrease on NUE as N level increased, while there was no significant ($P< 0.05$) increase on NUE under flooding with N interaction.

Table 6: Effects of SRI, flooding and N levels on rice N use Efficiency (NUE).

Main factor (Water management)	SRI NUE(mg grains mg^{-1}N)	Flooding NUE(mg grains mg^{-1}N)
	52.70 a	36.70 a
Sub factor (N levels)	N levels	
	N0	0.00 a
	N125	46.42 b
	N250	56.44 bc
	N500	75.93 c
Water management * N levels		
N-Levels	SRI	Flooding
N0	0.00 a	0.00 a
N125	85.74 d	66.12 bcd
N250	70.40 cd	42.48 bc
N500	54.76 bc	38. 08 b
CV (%)	11.70	11.70
L.S.D	28.50	28.50

SRI: System of Rice Intensification; (N125, N250 and N500): milligrams of Nitrogen applied per kilogram of soil. Means in the same column and row followed by the same letter(s) are not significantly different ($P<0.05$) according to Duncan's New Multiple Range Test. F - Statistics Table is given in Appendix5.

4.10 Effect of water management, N levels and interaction of N with water management on rice plant height

The mean of plant height for both SRI and Flooding water management systems are presented in Table 7 and Anova table is presented in Appendix 6.

Table 7: Effects of water management, N levels and interaction of N with water management on plant height.

Main factor (Water management)	SRI	Flooding
	PH(cm)	PH(cm)
	58.60 a	58.90 a
Sub factor (N levels)	N-levels	
	N0	51.71 a
	N125	60.37 b
	N250	60.79 b
	N500	62.12 b
Water management * N levels		
N-Levels	SRI	Flooding
N0	45.58 a	57.83 b
N125	64.83 b	59.41 b
N250	60.75 b	60.00 b
N500	63.33 b	58. 25 b
CV (%)	2.10	2.10
L.S.D	6.42	6.42

SRI: System of Rice Intensification; PH: plant height; (N125, N250 and N500): milligrams of Nitrogen applied per kilogram of soil. Means in the same column and row followed by the same letter(s) are not significantly different ($P<0.05$) according to Duncan's New Multiple Range Test. F - Statistics Table is given in Appendix 6

There was no significant ($P<0.05$) increase in plant height due to the effect of water management practices (SRI and flooding). Application of different levels of N significantly ($P< 0.05$) increased plant height above the control plants, but the increase was not statistically different ($P< 0.05$) between N levels as well as water management systems. Furthermore the interaction of water management practices and N levels had no significant ($P< 0.05$) effect on plant height.

4.11 Effect of water management, N levels and interaction of N with water management on panicle length

Analysis of variance data on the effect of water management, N levels and interaction of N with water management on panicle length is presented in Table 8. Flooding and SRI water management systems had no significant ($P<0.05$) effect on the length of panicles (Appendix 7).

Nitrogen application levels showed a significant effect on length of panicles over the control at the rate of 125 mg N kg-1 soil. Excess N at 500 mg N kg-1of soil had no significant effect on panicle length as compared to 250 mg N kg-1of soil. Panicle length increased due to increase in N levels, this is because N takes part in panicle formation as well as panicle elongation (Pramanik and Bera, 2013). The shortest panicles length 16.17 cm was observed at the lowest N levels (N0).Interaction of water management systems, SRI and flooding, only SRI showed a significant ($P< 0.05$) increase of panicle length over control experiment at the rate of 250 mg N kg-1of soil, but this had no significant ($P< 0.05$) difference on panicle length as compared to flooding.

Table 8: Effect of water management, N levels and interaction of N with water management systems on panicle length

Main factor(Water management)	SRI	Flooding
	PL(cm)	PL(cm)
	25.58 a	25.21 a
Sub factor (N levels)	N-levels	
	N0	16.17 a
	N125	19.71 b
	N250	32.67 c
	N500	33.04 c
Water management * N levels		
N-Levels	SRI	Flooding
N0	14.50 a	17.83 b
N125	20.42 c	19.00 bc
N250	32.75 de	32.59 de
N500	34.67 d	31.42 d
CV(%)	2.30	2.30
L.S.D	1.70	1.70

SRI: System of Rice Intensification; PL: panicle length; (N125, N250 and N500): milligrams of Nitrogen applied per kilogram of soil. Means in the same column and row followed by the same letter (s) are not significantly different (P<0.05) according to Duncan's New Multiple Range Test. F - Statistics Table is given in Appendix7.

4.12 Effect of water management, N levels and interaction of N with water management on number of tillers.

The average number of rice tillers under both SRI and Flooding water management systems are presented in Table 9.The analysis of variance data shows that there was no significant effect(P<0.05) on number of tillers due to the SRI and flooding water management practices (Appendix 8). The application of different levels of N showed a significant effect on the increase on the number of tillers over the control. The control pots produced lowest number of tiller with average of 2 tillers where as the number of tillers increased as N levels increased. The highest number of tillers of 10.75 was observed at the highest N rate of 500 mg N kg-1mg N kg-1of soil as compared to 125 and 250 mg N kg-1of soil which resulted into 5.63 and 7.13 tillers, respectively. There was no significant difference between 5.63 and 7.13 tillers resulted from N rates of 125 and 250 mg N kg-1of soil, respectively. The results showed the importance of plant nutrition especially N on increasing the tillering capacity of rice crop. The interaction of water management systems, the SRI and flooding with N levels did not show significant difference on number of tillers produced.

Table 9: Effect of water management, N levels and interaction of N with water management systems on number of tillers

Main factor (Water management)	SRI	Flooding
	NT	NT
	6.44 a	6.31 a
Sub factor (N levels)	N-levels	
	N0	2.00 a
	N125	5.63 b
	N250	7.13 b
	N500	10.75 c
Water management * N levels		
N-Levels	SRI	Flooding
N0	1.25 a	2.75 ab
N125	5.50 bc	5.75 bc
N250	7.75 cd	6.50 c
N500	11.25 e	10.25 de
CV(%)	15.30	15.30
L.S.D	2.15	2.15

SRI: System of Rice Intensification; NT: number of tillers; (N125, N250 and N500): milligrams of Nitrogen applied per kilogram of soil. Means in the same column and row followed by the same letter(s) are not significantly different (P<0.05) according to Duncan's New Multiple Range Test .F - Statistics Table is given in Appendix 8.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

On the basis of the results obtained from this study, it therefore concluded that:

(i) The soil fertility evaluation results showed that all the soils of the study area had very low concentration of total N and available P. The low concentration of these primary elements in the soil from the study area, may contribute to low rice yield.

(ii) There was no difference of NUE between the two water management systems, the SRI and flooding. This is can be concluded that, N uptake by rice plants was similar in both water management systems (SRI and flooding)

(iii) Water management systems the SRI and flooding had no effect on rice productivity. This can be concluded that both water management systems did not create a different environment on rice plants that resulted into rice yield which did not differ significantly.

5.2 Recommendations

The following recommendations are suggested with respect to improving irrigated rice productivity at Mkindo village and elsewhere with similar conditions in Tanzania

(i) Farmers are advised to apply N and P to supplement their low levels in the soil

(ii) Either of the two water management systems, the SRI and flooding can be used for rice production under lowland ecosystem of the study area and elsewhere with similar soils and environmental conditions, this is subject to findings under field conditions because current findings were from a screen house experiment.

(iii) This study also needs to be conducted at Mkindo as field experiments to assess the effect of water management on rice productivity and NUE

(iv) Further studies need to be conducted to assess N use efficiency using different lowland rice varieties

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APPENDICES

Appendix 1: F- Statistics for dry matter yield (g pot-1) - ANOVA table

Source of variation	Degrees of Freedom	Sum of. Squares	Mean. Square	F Values	Prob
Replication	3	14.727	4.91	1.32	

N levels	3	704.652	234.88	62.96	<.001
Water management	1	17.835	17.84	4.78	0.040
Water management* N levels	3	78.109	26.04	6.98	0.002
Residual	21	78.349	3.73		
Total	31	893.673			

Appendix 2: F- Statistics for N - concentration in plant (N %) - ANOVA table

Source of variation	Degrees of Freedom	Sum of. Squares	Mean. Square	F Values	Prob
Replication	3	0.05436	0.01812	0.61	
N levels	3	10.23656	3.41219	114.89	<.001
Water management	1	0.27011	0.27011	9.10	0.007
Water management* N levels	3	0.15374	0.05125	1.73	0.192
Residual	21	0.62368	0.02970		
Total	31	11.33845			

Appendix 3: F- Statistics for rice grain yields (g pot-1) - ANOVA table

Source of variation	Degrees of Freedom	Sum of. Squares	Mean. Square	F Values	Prob
Replication	3	26.57	8.86	0.51	
Water management	1	33.35	33.35	1.91	0.182
N levels	3	2240.45	746.82	42.71	<.001
Water management* N levels	3	90.73	30.24	1.73	0.192
Residual	21	367.19	17.49		
Total	31	2758.29			

Appendix 4: F- Statistics for thousand (1000) grain weight pot-1 ANOVA table

Source of variation	Degrees of Freedom	Sum of. Squares	Mean. Square	F Values	Prob
Replication	3	3.791	1.264	1.04	
Water management	1	0.633	0.633	0.52	0.478
N levels	3	5.301	1.767	1.45	0.256
Water management* N levels	3	16.133	5.378	4.43	0.015
Residual	21	25.517	1.215		
Total	31	51.375			

Appendix 5: F- Statistics for N use efficiency (NUE) mg grains mg N-1 applied ANOVA table

Source of variation	Degrees of Freedom	Sum of. Squares	Mean. Square	F Values	Prob
Replication	3	654.6	218.2	0.58	
N levels	3	24913.5	8304.5	22.05	<.001
Water management	1	2062.7	2062.7	5.48	0.029
Water management* N levels	3	823.3	274.4	0.73	0.546
Residual	21	7908.4	376.6		
Total	31	36362.6			

Appendix 6: F- Statistics for plant height (cm) - ANOVA table

Source of variation	Degrees of Freedom	Sum of. Squares	Mean. Square	F Values	Prob
Replication	3	37.76	12.59	0.33	
Water management	1	0.49	0.49	0.01	0.911
N levels	3	542.16	180.72	4.74	0.011
Water management* N levels	3	411.34	137.11	3.59	0.031
Residual	21	800.94	38.14		

Total 31 1792.69

Appendix 7: F- Statistics for panicle length (cm) - ANOVA table

Source of variation	Degrees of Freedom	Sum of. Squares	Mean. Square	F Values	Prob
Replication	3	8.232	2.744	1.03	
Water management	1	1.129	1.129	0.42	0.523
N levels	3	1831.128	610.376	228.46	<.001
Water management* N levels	3	46.295	15.432	5.78	0.005
Residual	21	56.105	2.672		
Total	31	1942.888			

Appendix 8: F- Statistics for the number of tillers - ANOVA table

Source of variation	Degrees of Freedom	Sum of. Squares	Mean. Square	F Values	Prob
Replication	3	22.750	7.583	1.77	
N levels	3	315.250	105.083	24.59	<.001
Water management	1	0.125	0.125	0.03	0.866
Water management* N levels	3	9.625	3.208	0.75	0.534
Residual	21	89.750	4.274		
Total	31	437.500			

Appendix 9: Coordinates of the farms from Mkindo irrigation scheme on which soils were sampled

S/No.	Name of the Farmer	Coordinates
1		6o 15'17.09" S

	AbdalahMbete	37o	32'27.68" E
2		6o	15'23.86" S
	Mr.Mganga	37o	32'25.64" E
3		6o	15'26.12" S
	Kalori Clement	37o	32'19.78" E
4		6o	15'26.95" S
	Mr.Alphonce	37o	32'25.50" E
5*		6o	15'24.69" S
	AthumanKazumba	37o	32'23.59" E
6		6o	15'24.41" S
	MwanaidHamza	37o	32'21.48" E
7		6o	15'21.37" S
	Eliza Simon	37o	32'20.99" E
8		5o39'45.38" S	
	SalumAbdalah	64o11'46.09" E	
9**		6o	15' 24.69" S
	AthumanKazumba	37o	32'23.59" E

Key: 9** = Bulk soil used for experiment from farm 5*

The scheme is under rice cultivation since 1985. Fertilizers used are DAP as basal dressing and Urea as top dressing.

The average yield is 3-3.5 t acre-1