SILICON UPTAKE BY RICE PLANT UNDER THE SYSTEM OF RICE INTENSIFICATION AND CONTINUOUS FLOODING IN MKINDO IRRIGATION SCHEME, MOROGORO, TANZANIA

GRACE ERASTO GOWELE

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN IRRIGATION ENGINEERING AND MANAGEMENT OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

2021

ABSTRACT

Silicon (Si) is the second most abundant element available in the earth's crust and is considered as a beneficial element for crop growth especially rice. Si deficiency in the soil may lead to decline in rice yields. A study was conducted in Mkindo Irrigation Scheme, Morogoro, Tanzania to assess Si uptake by rice plant grown under the system of rice intensification and continuous flooding. The experiment was laid out in a randomized complete block design (RCBD) with two treatments which were two water application regimes T_1 and T_2. T_1 was alternate wetting and drying using SRI technology and T_2 was continuous flooding. The treatments were replicated three times and the rice variety used was SARO 5 (TXD 306). The experiment was conducted in two seasons from October 2019 to January 2020 and from March 2020 to June 2020. The available Si status in soils of the experimental site, in rice seeds, grains and in rice plant leaves as well as growth and yield parameters were assessed according to elemental analysis based on Energy Dispersive X- Ray Fluorescence and results were analyzed using GENSTAT software. The soils of the study area had sufficient amount of available Si content which ranged from 230.58 to 240.42 mg kg^{-1}. Si content in rice seeds observed prior to the experiment was within acceptable range between 4-20%. Si content in rice grains was gradually increasing during reproductive stage and later dropped during harvest. Si content in rice plant leaves increased from vegetative to ripening stage whereby T_1 gave the highest Si content (12.37%) while the lowest value (10.15%) was observed in T_2. Similarly, T_1 recorded the highest plant height (147 cm), number of tillers per hill (54), number of productive tillers per hill (46), number of panicles per hill (31) and grain yield (8 tons ha^{-1}) meanwhile T_2 gave the lowest plant height (129 cm), number of tillers per hill (27), number of productive tillers per hill (22), number of panicles per hill (27) and grain yield (3 tons ha^{-1}). It was concluded that, SRI enhanced adequate uptake of Si which in turn improved significantly crop growth and rice yield compared to continuous flooding practices.

DECLARATION

I, **GRACE ERASTO GOWELE,** do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted for a degree award in any other academic institution.

Grace Erasto Gowele Date

(MSc. Candidate)

The declaration above is confirmed by;

Prof. Henry F. Mahoo Date

(Supervisor)

Prof. Frederick C. Kahimba Date

(Supervisor)

COPYRIGHT

ACKNOWLEDGEMENTS

I would like to take this opportunity to remember and acknowledge all those who have contributed in one way or another in the successful completion of this thesis. I am thankful to Almighty God the creator for blessing me with good health and protection during the entire period of my study. I would like to express my deep sense of gratitude to my supervisors Prof. Henry F. Mahoo and Prof. Frederick C. Kahimba for their insightful and inspiring guidance, constant encouragement, constructive criticisms, comments and boundless patience throughout the entire period of my research work to the preparation of this thesis. I wish to extend my sincere gratitude to the teaching and non-teaching staff of School of Engineering and Technology including Dean of School (Prof. Boniface P. Mbilinyi) for their support, encouragement and cooperation during the course of my study.

I would like to express my sincere appreciation to the technicians of Soil Science Laboratory at Sokoine University of Agriculture and Tanzania Veterinary Laboratory Agency (TVLA) for their assistance and cooperation in carrying out all of my samples analysis during the research period. I am grateful to the management of Mkindo Irrigation Scheme and all farmers in the scheme for their support and assistance rendered to me during field work and data collection. Special thanks to my dear parents Mr. Erasto Gowelle and Mrs. Pilly Hariri for their financial and moral support, encouragement and boundless love they have given me during the course of my study. May the God’s grace be with them forever.

I also wish to thank and acknowledge the following for their love, patience, encouragement and support they have given me during the course of my study: my grandmother Isabella Sanga and Mwajuma Juma Paul, my mother’s sister Fatuma

Mpelembe, Mr. Hamisi Ali, my brothers: Issa Mpelembe, Erick Jackson, Edison Jackson, Ali Hamisi and Price Elly as well as my young sisters: Domina Mpelembe, Aisha Hassani, Amina Hamisi and Naiya Hamisi without forgetting my beloved daughter Yusta Mfala and her father Mr. Edga Mfala.

Once again I would like to take this chance to thank Mr. and Mrs. Teophile Mfala's family for their support and encouragement they rendered to me during the course of my study. I will always remember the care and support I received from the late Engineer Teophile Mfala. May his soul rest in eternal peace and may the Almighty God bless his family with good health and protection. I am also thankful to my fellow MSc. students in Department of Civil and Water Resources Engineering: Wilfred Nkongela and Charles Malekela and those from the Department of Soil and Geological Sciences (DSGS): Seth Mathias and Nicholaus Pius Mwakinyala for their cooperation during the entire period of my study.

DEDICATION

I dedicate this work to my beloved parents Mr. Erasto Gowelle and Mrs. Pilly Hariri and to my beloved daughter Yusta Mfala.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND ACRONYMS

>	Greater than
%	Percentage
<	Less than
^0C	Degree centigrade
Al	Aluminum
ASA	Agricultural Seed Agency
Ca	Calcium
CEC	Cation Exchange Capacity
CIIFAD	Cornell International Institute for Food, Agriculture and Development
cm	Centimeter
cmol	Cent mole
Cu	Copper
DAP	Di-ammonium phosphate
DAT	Days after Transplanting
dS/m	DeciSiemens per meter
DSGS	Department of Soil and Geological Sciences
DTPA	Diethylene Triamine Pentaacetic Acid
EC	Electrical Conductivity
EDXRF	Energy Dispersive X- Ray Fluorescence
FAO	Food and Agricultural Organization of the United Nations
Fe	Iron
ha	Hectare
IRRI	International Rice Research Institute

K	Potassium
kg	Kilogram
km	Kilometer
LSD	Least Significance Difference
m	Meter
M	Million
m^2	Square meter
MAFSC	Ministry of Agriculture, Food Security and Cooperatives
Mg kg^{-1}	Milligram (s) per kilogram
Mg	Magnesium
mm	Millimeter
Mn	Manganese
N	Nitrogen
Na	Sodium
OC	Organic Carbon
P	Phosphorus
PAS	Plant Available Silicon
pH	Degree of acidity or alkalinity
ppm	Parts per million
PSD	Particle Size Distribution
RCBD	Randomized Complete Block Design
S	Sulfur
S1	Season 1; the dry season (*vuli*)
S2	Season 2; the wet season (*masika*)
Si	Silicon
SRI	System of Rice Intensification

SUA	Sokoine University of Agriculture
TN	Total Nitrogen
TVLA	Tanzania Veterinary Laboratory Agency
URT	United Republic of Tanzania
USAID	United States Agency for International Development
Zn	Zinc

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

About half of the world's population depends on rice (*Oryza sativa* L.) as their staple food (FAO, 2008; Rajamani, 2012; Ricepedia, 2015; Kangile *et al.,* 2018). In Tanzania, rice is the second most popular cultivated, commercial and staple food crop after maize (Katambara *et al*., 2013; Kahimba *et al.,* 2014; CIIFAD, 2015). It is cultivated over an area of about 681 000 ha which represent 18% of the cultivated land. Nearly half of the country's rice is grown by 230 000 smallholder farmers in Tabora, Shinyanga, and Morogoro Regions (CIIFAD, 2015). Other major rice producing regions include Mwanza, Manyara, Mbeya and Kilimanjaro. Most of the rice producers in developing countries such as Tanzania are subsistence farmers who produce rice under traditional methods. Most commonly is the continuous flooding, a technique that uses large amount of water and results in low yields, low water productivity and low water use efficiency (Katambara *et al.,* 2013; CIIFAD, 2015; Kangile *et al.*, 2018).

Smallholder farmers in Tanzania have realized average rice yields of about 1 to 2 tons ha^{-1} under continuous flooding practices in improved irrigation schemes (URT, 2009; MAFSC, 2009). Low yields of rice under this practice are attributed to various factors including among others: low nutrients uptake, low soil fertility status and inadequate nutrients management practices used by many farmers mainly Nitrogen (N), Phosphorus (P) and Potassium (K) (MAFSC, 2009; Amuri *et al*., 2013). These factors in combination to continuous flooding practices for rice production are inefficient thus calling for adoption of modern water saving technologies such as the System of Rice Intensification (SRI).

The SRI technology involves applying small amount of water regularly by alternating wetting and drying field conditions to maintain a mix of aerobic and anaerobic soil conditions (Uphoff, 2007). SRI is a modern technology for rice production that was introduced in Tanzania in 2009 by various researchers in order to increase the yield of rice, improve the country's food and income security and improves water productivity and water use efficiency (Kombe, 2012; Katambara *et al.,* 2013; Kahimba e*t al.,* 2014; Ali, 2015; Reuben *et al.,* 2016; Kangile *et al.,* 2018; Materu *et al*., 2018; Mboyerwa, 2021 and many others). Various researchers have reported increase in rice yield of about 6 to 8 tons ha^{-1} with subsequent water saving of 25% to 50% after using SRI practice (Katambara *et al.,* 2013; CIIFAD, 2015; Masawe *et al.,* 2017). For instance, in Mkindo Irrigation Scheme rice yield of up to 9.91 tons ha^{-1} was realized by Mkindo farmers under SRI practices in a spacing of 25 cm × 25 cm (Katambara *et al*., 2013; CIIFAD, 2015). Improved performance of SRI practices has been attributed to many factors including more uptakes of nutrients and proper management of water and nutrients (Masawe *et al*., 2017).

Out of all wetland plants, rice is a highly Silicon (Si) accumulating plant and it has the ability to uptake an average of 150 to 300 kg of Si per ha (Jinger *et al*., 2017). Si is the second most abundant element available in the earth's crust after Oxygen, and is considered as a beneficial element for crop growth especially rice (Aarekar, 2012; Rajamani, 2012; Jinger *et al*., 2017; Rao *et al.,* 2017). Si enhances plant growth more clearly under a water-stressed condition than in a non-stressed condition (Ma and Takahashi, 2002). Rice plant which is grown under SRI stands a chance of enhanced uptake of Si due to stress induced through alternate wetting and drying.

Si uptake by rice roots is governed by two genes (transporters) known as Lsi1 and Lsi2. Lsi1 is an influx transporter accountable for transporting Si from the soil to the root cells whereas Lsi2 is an efflux transporter accountable for transporting Si from the inside to the outside of the root cells (Ma *et al*., 2006; Ma *et al*., 2007; Ma and Yamaji, 2008; Rao *et al.,* 2017). Depletion of available Si in the soil may lead to soft and droopy leaves which cause lodging and mutual shading, reduced photosynthetic activity, reduced grain yields, increased occurrence of diseases such as blast and brown spot, reduced number of panicles and the number of filled spikelets per panicle (IRRI, 2018).

Silicon is the only element which does not damage plants when accumulated in excess amounts and reduces the concentration of toxic elements like Fe, Mn and other heavy metals (Ma *et al*., 2001; Ma and Takahashi, 2002; Rajamani, 2012). The availability of Si in rice plants facilitates efficiency of sunlight use and increase in photosynthetic activity (Shivay and Dinesh, 2009). Furthermore, Si increases the mechanical strength of cells, decreases lodging due to wind and water and increases resistance to certain insects and diseases (Ma and Yamaji, 2008; Jinger *et al*., 2017). Consequently, it is imperative to consider Si as an essential element for increasing and sustaining rice productivity (Sudhakar *et al.,* 2006; Rao *et al.,* 2017).

1.2 Justification

In Tanzania, rice (*Oryza sativa* L.) is one of the priority crops for agricultural development. Annual per capita rice consumption in Tanzania increased by 6.15%, rising from 20.5 kg in 2001 to 25.4 kg per annum in 2011 (Wilson and Lewis, 2015). Kangile *et al.* (2018) predicted that there would be a need of additional milled rice of about fifty-nine million tons by 2020 above the 2007 consumption of 422 million tons. The potential in meeting such demand depends among other factors a right balance of mineral nutrient in soils to increase demand.

Studies done by Mbaga (2015) and Masawe *et al.* (2017) in Tanzania investigated the effects of some nutrients such as Nitrogen (N), Phosphorus (P), Potassium (K) and Sulfur (S) on yield of rice cultivated under SRI and continuous flooding. Results indicated increased rice yields due to the interaction between nutrients and water applied in the field under study. However, little has been done to assess Si uptake by rice plant grown under SRI and continuous flooding. Therefore, this research was designed to assess Si uptake by rice plant grown under SRI and continuous flooding at various growth stages in Mkindo Irrigation Scheme, Mvomero District, Morogoro Region, Tanzania.

1.3 Objectives

1.3.1 Overall objective

The overall objective of this research was to assess the status of Si uptake by rice plant grown under the System of Rice Intensification and continuous flooding at various growth stages in Mkindo Irrigation Scheme, Mvomero District, in Morogoro Region, Tanzania.

1.3.2 Specific objectives

The specific objectives were:

i. To assess Silicon status in soils of the experimental site at different rice growth stages.
ii. To assess Silicon status in rice seeds at the beginning of the experiment and rice grains at reproductive stage and at harvest.
iii. To assess Silicon status in rice plant leaves at different growth stages.
iv. To examine the magnitude of growth and yield parameters of rice under SRI and continuous flooding in relation to Silicon.

1.3.3 Research questions

The study was guided by the following research questions:

i. What is the Silicon status in soils of the experimental site at different rice growth stages?
ii. What is the Silicon status in rice seeds at the beginning of the experiment and rice grains at reproductive stage and at harvest?
iii. What is the Silicon status in rice plant leaves at different growth stages?
iv. What is the magnitude of growth and yield parameters of rice under SRI and continuous flooding in relation to Silicon?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Rice Plant

Rice (*Oryza sativa* L.) belongs to the family of cereal crops together with wheat, corn, millet, oats, barley, rye and numerous others (Ricepedia, 2015). Two rice species have been identified as *Oryza sativa*, grown worldwide, and *Oryza glaberrima*, grown in some parts of West Africa. These two species belong to a genus which includes about 25 other species (Ricepedia, 2015). Among all cultivated cereal crops, rice is the only plant adapted to grow in both flooded and non-flooded soil conditions and has ability to grow under a wide range of climatic and geographical conditions all over the world (Ricepedia, 2015). Rice is one of the most important food crop in most of the developing countries like Tanzania which serves as the staple food for more than half of the world's population with the production of more than 700 million tons annually; equivalent to 470 million tons of milled rice (Ricepedia, 2015).

2.2 Growth and Development Phases of Rice

The knowledge and understanding of growth and development of the rice plant is important as it enables rice growers to properly implement agronomic practices such as transplanting, irrigation water application, fertilizer application, weeding, harvesting, pest control and plant growth regulation (Dunand and Saichuk, 2014). Growth and development of rice plant can be categorized into three phases namely: vegetative, reproductive, and ripening (IRRI, 2007; Ricepedia, 2015). Furthermore, rice varieties can be classified into two groups: the short-duration varieties which mature in 105–120 days and the long-duration varieties which mature in 150 days. The short-duration varieties when planted in a tropical environment like Tanzania takes about 60 days in the vegetative phase, 30 days in the reproductive phase and 30 days in the ripening phase (IRRI, 2007; Ricepedia, 2015). The above mentioned growth phases are further explained in the following sections.

2.2.1 Vegetative phase

The vegetative phase is the growth period of rice plant from germination to the beginning of panicle development (IRRI, 2007; Dunand and Saichuk, 2014). This phase is characterized by the development of tillers, leaves and a gradual increase in plant height (Ricepedia, 2015). In this phase, there are four stages taking place: (a) seed emergence, (b) seedling development, (c) tillering and (d) internodes elongation (Dunand and Saichuk, 2014).

a) Seed emergence stage

Germination begins after the introduction of heat and moisture inside the seed, whereby the seed swells, gains weight and start to convert carbohydrates into sugars and hence the embryo is formed. The growing embryo obtains nutrients from the endosperm for about 3 weeks and later on starts drawing nutrients from the air and soil (Dunand and Saichuk, 2014). In embryo, two primary structures grow and elongate, which are radicle (first root) and coleoptile (protective covering enveloping the shoot). The radicle and coleoptile applies pressure to the inside of the hull until it becomes weakened then the pointed, slender radicle and coleoptile emerge. Appearance of the radicle and coleoptile loosely signals the completion of germination (Dunand and Saichuk, 2014).

b) Seedling development stage

The seedling stage begins after the first root (radicle) and shoot (coleoptile) emerge and lasts until the first tiller appears (Ricepedia, 2015). After germination, the radicle and coleoptile continues to grow and lengthening until the coleoptile is exposed to light at the soil surface and hence it stops elongation. In this stage, the primary leaf appears shortly after the coleoptile is exposed to light and splits open at the end (Dunand and Saichuk, 2014). The primary leaf acts as a protective covering for the next developing leaf. As the seedling grows, the next leaf elongates through and past the tip of the primary leaf (Dunand and Saichuk, 2014). It takes about 15 to 30 days under the seedling stage, depending upon the seed preparation practices, nursing techniques, nutrient inputs, and climatic conditions. During this stage, the plant root system undergoes rapid and extensive growth until it has ability to draw nutrients from the soil hence a substantial growth of the leaf surface begins. Leaves continue to develop after every 3 to 4 days (Ricepedia, 2015).

c) Tillering stage

Tillering stage begins after the appearance of the first tiller and last until the maximum number of tillers is reached (Ricepedia, 2015). An effective tiller is one which bears a panicle on which the grains will ripen fully. The number of tillers produced by a plant varies and is affected by genetic determinants, the availability of nutrients (including water and sunlight), and the general health of the plant (Dunand and Saichuk, 2014).

d) Internodes elongation

Each stem is composed of nodes and internodes. The swollen area of the stem where the base of the leaf sheath is attached and most of the growth activity occurs is referred to as node. The area between each node is known as internode. The combination of node and internode is known as a joint. The formation and expansion of hollow internodes produces a stem and this determines stem length and contributes to increase in plant height (Dunand and Saichuk, 2014). The stem begins to lengthen and stops growing in height before panicle initiation about 52 days after sowing and this signals the end of the vegetative phase (Ricepedia, 2015).

2.2.2 Reproductive phase

The reproductive phase is the period when the panicle forms and emerges from the base of the tiller (IRRI, 2007; Dunand and Saichuk, 2014). This phase can be subdivided into three stages: (a) Pre-booting, (b) booting, (c) heading (d) flowering (Dunand and Saichuk, 2014).

a) Pre-booting stage

Pre-booting is the interval after the onset of internode elongation and before flag leaf formation is complete. During this stage, the remaining leaves of the plant develop, internode elongation and stem formation continue, and panicle formation begins (Dunand and Saichuk, 2014).

b) Booting stage

Boot is referred to as the sheath of the flag leaf. Booting is the period when growth and development of a panicle and its constituent parts are completed inside the sheath of the flag leaf (Dunand and Saichuk, 2014). During this stage, the remaining leaves of the plant develop, internode elongation and stem formation continues and panicle formation begins to emerge from the stem and continues to grow. This process is called panicle initiation (Ricepedia, 2015).

c) Heading stage

Heading is referred to as the elongation of the panicle through the sheath of the flag leaf on the main stem. The main stem of each plant heads before its tillers (Dunand and

Saichuk, 2014). In heading stage, the panicle is fully visible and about 90% of the panicles have emerged from their sheaths and it lasts for about 10 days (Ricepedia, 2015).

c) Flowering stage

Flowering stage starts a day after the end of the heading stage and continue for about 7 to 10 days until flowers open and shed their pollen on each other so that pollination can occur (Ricepedia, 2015).During the middle hours of the day, mature florets open, exposing both the stigmas and anthers to air. The pollen is carried by wind to the stigmas of the same or nearby plants, then special cells of the pollen grain join special cells within the pistil, completing fertilization and initiating grain formation (Dunand and Saichuk, 2014).

2.2.3 Ripening phase

During this phase, grain filling occurs due to the transportation of nutrients and water from one part of the plant to another and continuous until grains mature and ready to be harvested and this takes about 30 days (Ricepedia, 215). This process is mostly affected by the availability of water and nutrients and by temperature. This stage can be lengthened during rainy or low temperatures days while sunny and warm days may shorten it (Ricepedia, 2015). Ripening phase can be subdivided into milky, dough, (maturity) ripe and over-ripe stages (Ricepedia, 2015).

a) Milk stage

At this stage, the endosperm begins to form a milky liquid and rice becomes very susceptible to attack by sucking insect pests. During milk stage, the accumulation of carbohydrate increases and the panicle begins to lean and turn down. The milky consistency of the starch in the endosperm changes as it loses moisture (Dunand and Saichuk, 2014).

b) Dough stage

At this stage, the milky liquid on the main stem begins to solidify into a sticky white like bread dough or firmer as a result bird pests begin to be a serious problem (Dunand and Saichuk, 2014). As the milky liquid continues to solidify the endosperm becomes firm and has a chalky texture. Dough stage is further subdivided into two stages namely soft and hard dough. In the soft dough stage, grains are capable of being dented without breaking. While in the hard dough stage, grains losses more moisture and become chalky and brittle (Dunand and Saichuk, 2014).

c) Maturity stage

The grain is said to be mature or ripe when the endosperm becomes hard, opaque and the leaves of the plant begin to turn yellow as nitrogen is transferred from the leaves to the seed. The full maturity stage is reached when more than 90% of the grains in the panicles have ripened. Mature grains turn a golden brown, but under wet climatic conditions it may remain somewhat greenish (IRRI, 2007; Dunand and Saichuk, 2014).

d) Over-ripe stage

Grains become over-ripe if the grains are not harvested on time. The vegetative parts of the plant like stems, leaves, and roots begin to die off, then the over-ripe grains fall off the panicles onto the ground in a process known as shattering. Serious crop losses may occur if harvesting is not done on time and in rare instances over-ripe grains left too long on the panicle may undergo germination. Varieties exhibiting this characteristic are said to lack dormancy (IRRI, 2007; Dunand and Saichuk, 2014).

2.3 Rice Production Practices

Rice production practices can be classified as conventional and non-conventional (Katambara *et al*., 2013). The classification is further explained as follows:

2.3.1 Conventional method for rice production

The conventional rice production practices include upland (20%), lowland (74%) and paddy rice (6%) (Mghase *et al*., 2010; CIIFAD, 2015). In lowland, rice is grown in fields that experienced flood with rainwater for sometimes whereas in upland, rice is grown under dry land fields and in both practices rainfall is the only source of water (Bouman *et al*., 2007). Lowland rice growing practices is similar to upland rice and the major differences include: the risk of inadequate moisture as a result of rainfall variability, low soil fertility of the upland farms as well as biotic and abiotic constraints such as weeds, insects, diseases, nematodes and vertebrates pest, soil acidity, erosion and the effects on the rice yields (Oikeh *et al*., 2008). Paddy rice production practice is referred to as traditional rice growing practice which is mostly practiced on irrigated land (Katambala *et al*., 2013).

Conventional rice farming practices involve continuous flooding the field as well as application of agrochemicals such as chemical fertilizers, pesticides and herbicides (Rubinos *et al*., 2007). On the other hand, Katambara *et al.* (2013) reported that the application of agrochemicals in rice fields is one of the factors limiting the aeration of the roots and the development of a healthy roots system. Under this practice, two or more seedlings are transplanted in a single hole at the age of 21 days or more in a square pattern of 20 cm × 20 cm followed by continuously flooding the field from transplanting to harvest (Katambala *et al*., 2013; Kombe, 2012). Continuously flooding the field helps to reduce weeds growth that cannot tolerate aquatic nature (Ismail *et al*., 2012). However, about 80% of the water resources are used for irrigation purposes (Katambala *et al*., 2013). Nearly half of the water applied ends up irrigating crops while more than 50% of the irrigation water is lost through seepage, deep percolation, excessive unproductive evaporation, runoff, infiltration of uncultivated areas and transpiration through the leaves of weeds (Katambala *et al*., 2013; Masawe *et al*., 2017).

2.3.2 System of Rice Intensification (SRI)

SRI is a modern technology for rice production, which ensures increased rice yields while using less agricultural inputs such as land, seed, water, labor and organic fertilizers (Kahimba *et al*., 2014; Uphoff, 2015). SRI involves applying small amounts of water regularly by alternating wetting and drying field conditions to maintain a mix of aerobic and anaerobic soil conditions (Uphoff, 2007). SRI practice has been reported by various researchers in Tanzania to increase rice yields to about 6 to 8 tons ha^{-1} with subsequent water saving from 25% to 50% (Katambara *et al.*, 2013; CIIFAD, 2015; Masawe *et al.*, 2017). Furthermore, Stoop *et al*. (2002) reported that intermittent water application facilitates improved oxygen supply to rice roots thereby causing stronger and healthier root system which ensures nutrient uptake.

2.4 Principles of SRI

The major principles of SRI include: carefully raising seedlings in prepared nurseries, careful transplanting single seedling per hill at younger age of 7 to 15 days old in a wider spacing recommended 25cm x 25cm, alternating wetting and drying water application, early and frequently weeding with a simple mechanical hand weeder as well as use of organic fertilizers where available to enhance soil fertility (Katambara *et al.*, 2013; CIIFAD, 2015; Uphoff, 2015; Masawe *et al.*, 2017; Kangile *et al.*, 2018).

2.5 Historical Background of the System of Rice Intensification

SRI was developed in Madagascar by French priest Father Henri de Laulanié, S.J. who spent 34 years (1961-1995) working with Malagasy farmers to improve their rice productivity as well as improving their livelihoods without depending on purchased inputs because Malagasy farmers had so little purchasing power (Uphoff, 2015; CIIFAD, 2015). In 1994, TefySaina and the Cornell International Institute for Food, Agriculture and Development (CIIFAD) began working together in a USAID funded project to conserve the rainforest ecosystems in Ranomafana Park. Local farmers around the Park whose yields were less than 2 tons ha^{-1} adopted the principles of SRI in their farms and they experienced increased rice yields averaging 8 tons ha^{-1} and some had even higher yields. They used the same rice varieties on the same poor soils with less water applications and without chemical fertilizers instead relying on compost manure to improve soil fertility (Uphoff, 2015; CIIFAD, 2015). During 2002, SRI was further validated in 15 countries and currently it has been adopted by more than 60 countries worldwide including major rice producers such as India, China, Vietnam, Philippine as well as in Tanzania (Uphoff, 2015; CIIFAD, 2015).

2.6 Overview of the Performance of SRI Practice in Tanzania

During 2013, SRI was introduced in Mkindo and Dakawa in Morogoro Region as well as in Mwanza and Kilimanjaro Regions (CIIFAD, 2015). Numerous studies have been conducted by various researchers in Tanzania to investigate the performance of SRI in different parts of the country. Some of the studies are as follows:

Kombe (2012) conducted a study to evaluate the performance of SRI practices in increasing rice yields and water productivity in Mkindo area, in Morogoro Region, Tanzania. Results indicated that SRI techniques had higher grain yields (4.7 - 6.3 tons ha^{-1}), water saving (64.67%), and higher water productivity (0.47 kg/m^3) compared to conventional practice of continuous flooding which had lower rice yields (3.8 tons ha^{-1}) and lower water productivity (0.14 kg/m^3) (Kombe, 2012; Kahimba *et al.,* 2014).

A review done by Katambara *et al.* (2013) reported the introduction, performance and acceptability of SRI practices under local Tanzanian conditions. This review showed the history and performance of SRI globally and at a regional level and lessons made were drawn from other parts of the world where SRI practice has been successfully adopted then recommendations were made on how the practice can be adopted and up-scaled in Tanzania.

Mbaga (2015) and Masawe *et al. (*2017) investigated the combined effects of some nutrients such as N, P, K and S on yield of rice cultivated under SRI and continuous flooding. Results obtained revealed increased rice yields due to the interaction between nutrients and water applied in the field under study.

Ali (2015) conducted a field experiment at Bumbwisudi rice irrigation scheme in Zanzibar to evaluate the efficacy of SRI practice and determine the optimum spacing and transplanting age of seedlings for better grain yields, productive tillers and water productivity. Results have indicated that eight days old seedlings, transplanted at spacing of 20 x 20 cm recorded significantly higher grain yield (7.38 tons ha^{-1}) as compared to 21 days old seedlings under continuous flooding transplanted at spacing of 20 cm x 20 cm (5.283 tons ha^{-1}).

A study done by Reuben *et al.* (2016) in Mkindo area investigated the optimum transplanting age for maximum rice productivity under the SRI technology. The study treatments were 8, 12 and 15 days old seedlings transplanted in a spacing of 25 cm × 25 cm. Results showed increased rice yields (8.5 tons ha^{-1}) and it was recommended that for Mkindo area and other areas with similar soil conditions and agro ecological characteristics should adopt transplanting rice seedlings at younger age between 8 to 12 days.

Furthermore, a study done by Katambara *et al.* (2016) evaluated the characteristics of rice produced under SRI and conventional practices in Chimala area in Mbarali District of Mbeya Region in Tanzania. The evaluation considered the farm management practices, rice yields and the characteristics of the rice grains. Rice yields obtained under SRI practices were higher (16 tons ha^{-1}) compared to 8 tons ha^{-1} for conventional rice growing practices. The conventional practices resulted into more good rice (69%) than SRI (51%). However, the large percentage of husks (24%) suggests that rice grains produced under SRI are more protected and suitable for seeds. Also, the quality of cooked rice indicated that rice produced under SRI practices had good aroma and fragrance when compared to that produced under conventional practices.

Kangile *et al*. (2018) conducted a study to evaluate the performance of selected rice improved varieties under SRI in different fields and locations in Morogoro Region through an action research. Four rice short varieties namely TXD 88, TXD 306, TXD 307 and SUPA were transplanted at 10 days old using spacing of 25cm x 25cm. All varieties evaluated in this study doubled in yields under SRI in all three locations. However, TXD 88 yielded more than the other varieties (9.13 tons ha^{-1}) while SUPA variety yielded the lowest (6.2 tons ha^{-1}). Also the results showed that TXD 306 was the most superior preferred variety followed by TXD 307, SUPA then TXD 88 in terms of preference.

2.7 Silicon Uptake in Rice Plant

Si uptake by rice roots is governed by two genes (transporters) known as Lsi1 and Lsi2 (Ma *et al*., 2006; Ma *et al*., 2007; Ma and Yamaji, 2008; Rao *et al.*, 2017). Lsi1 is an influx transporter accountable for transporting Si from the soil to the root cells, whereas Lsi2 is an efflux transporter accountable for transporting Si from the inside to the outside of the root cells (Ma *et al*., 2006; Ma *et al*., 2007; Ma and Yamaji, 2008). Suppression of Lsi1 expression resulted in reduced Si uptake meanwhile expression of Lsi1 enhances uptake of Si in rice roots (Ma and Yamaji, 2008).

It is necessary for Lsi1 and Lsi2 to work together to facilitate efficiency uptake of Si in rice (Ma and Yamaji, 2008). Other three Si transporters known as Lsi2, Lsi3 and Lsi6 were identified in the rice node and they are accountable for intervascular transfer of Si for the preferential distribution of Si to the leaves and grains (Yamaji *et al*., 2015). Ma *et al*. (2001) conducted experiment to investigate the role of root hairs and lateral roots in the Si uptake using two rice mutants of rice whereby one was defective in the formation of root hairs (RH-2) while another in the formation of lateral roots (RM-109). Results indicated that the lateral roots contribute to the Si uptake in rice plant whereas root hairs do not.

2.8 Silicon Sources

2.8.1 Characteristics of Si sources

Si sources should have the following characteristics: should have high soluble Si content, provide sufficient water soluble Si to meet the plant needs, be of low cost, readily available for plant uptake, have a physical nature that facilitates storage and application and does not contain substances that will contaminate the soil (Gascho, 2001; Pereira *et al.*, 2004).

2.8.2 Organic sources of Si

Crop residues of Si accumulating plants such as rice and sugarcane bagasse are organic sources of Si used by many farmers (Aarekar, 2012). They have high Si content, cheap and easily available but they are slow release Si sources (Pereira *et al.*, 2004; Aarekar, 2012). The important byproducts of rice obtained after harvest are rice husk, rice husk ash and rice straw (Liang *et al.*, 2007; Aarekar, 2012; Sahebi *et al*., 2015). Si content in rice straw and rice husk ranges between 4 to 20% and 9 to 26% respectively (Ma and Takahash, 2002; Rao *et al.*, 2017). Rice straw is used for various purposes such as animal feeding and bedding, biogas production or mushroom cultivation. It was reported that the end products of these uses should be recycled in the field to add Si in the soil (Aarekar, 2012; Rao *et al.*, 2017).

Rice husk ashes have Si as a major constituent and are used in rice nurseries and main fields in different parts of southern India (Aarekar, 2012). Due to lack of understanding, many farmers including Mkindo farmers export Si from rice field by either throw away rice residues (rice straw and rice husk) after harvest or sometimes they use rice husks as a source of fire in burning bricks (Ricepedia, 2015; IRRI, 2018). It is therefore very important to recycle rice residues; rice straw and rice husks in the field after harvest in order to replenish Si in the soil and to improve soil structure.

2.8.3 Industrial sources of Si

Fly ash and basic slag are industrial wastes containing Si. Also calcium silicate, fine silica and sodium silicate are mostly used Si fertilizers (Aarekar, 2012; Rao *et al.*, 2017). Potassium silicate is a highly soluble but an expensive Si source can be used in hydroponic culture and applied through foliage (Aarekar, 2012; Rao *et al.*, 2017). Other industrial Si sources that have been used are calcium silicate hydrate, silica gel and thermo-phosphate (Gascho, 2001).

2.9 Silicon Deficiency

The sufficiency or deficiency of Si in the soil is associated with the rate of replenishment of Si and the rate of Si uptake during plant growth (Marschner, 1995).The critical level of Si in soil is 40 mg kg^{-1} (40 ppm) whereas in rice is <5 Si% (500 mg kg^{-1}) (Shivay and Denish, 2009; Rao *et al.*, 2017). Si deficiency is common in areas poor soils which are characterized with poor fertility, in old and degraded soils, in organic soils with small mineral Si reserves, in highly weathered soils and leached tropical soils, in rain-fed lowland and upland areas (IRRI, 2018).

Si depletion may also occur in soils with continuous mono-cropping and intensive cultivation of cereal crops such as rice and this could be one of the factors leading to reduced grain yields (Miyake, 1993; Mali *et al.*, 2008). Savant *et al*. (1997) reported that the decline in rice yields may be attributed to depletion of plant available Si in the soil. Low base saturation soils and low pH soils such as Oxisols and Ultisols are one of the soils with low plant available Si (Datnoff *et al*., 2005).

Moreover, Si can be depleted from the soil by drainage, by leaching process or by plant uptake if it is not replenished (Rajamani, 2012; Jinger *et al*., 2017). Si deficiency may affect the development of strong leaves, stems, roots and the formation of thick silica layer in the epidermal cells hence make the rice plants susceptible to fungal and bacterial diseases and insect pests infestation (IRRI, 2018).

2.10 The Role of Silicon in the Soil

The solubility of silicate minerals varies under different soils and environmental conditions (Ma and Takahashi 2002; Joseph, 2009). Moreover, the solubility of Si in the soil is affected by different processes occurring in the soil such as the particle size of the Si fertilizer, the soil acidity (pH), organic complexes, the presence of Al, Fe and phosphate ions, dissolution reactions and soil moisture content (Rao *et al.,* 2017). Rajamani (2012) reported that soluble Si may be introduced in the soil by either runoff, weathering of silicate-containing minerals, capillary ascension from the water table or by deposition of silicate materials at the soil surface or run on.

Furthermore, Tubana *et al*. (2016) reported that soils that are less weathered or geologically young have higher ability to supply higher amounts of plant available Si than highly weathered soils. Si is present in the soil as monosilicic acid and polysilicic acid as well as complexes with organic and inorganic compounds such as Al oxides and hydroxides. Plant available Si (PAS) is taken up by rice plants and has a direct influence on crop growth (Berthlesen *et al*., 2003; Rao *et al.,* 2017). The presence of PAS in the soil facilitates the improvement of physical, chemical and biological properties of soil as well as increased rice yields (Rao *et al.,* 2017).

2.11 The Role of Silicon in Rice and Other Plants

All plants contain Si in their tissues at concentrations similar to those of the macro nutrients such as N, P and K. However, Si concentration in plant tissues varies with the plant species ranging from 0.1 to more than 10.0 Si% of whole plant dry matter (Aarekar, 2012; Rajamani, 2012; Jinger *et al*., 2017; Rao *et al.,* 2017). The availability of Si to plant mainly depends on weathering rate of silicate minerals and release of Si to soil (Aarekar, 2012). Rice is a highly Si accumulating plant and is susceptible to various stresses if the available Si in the soil is low for absorption (Rajamani, 2012). The Si content in rice plant increases with the age of the plant from transplanting to harvest (Nayar *et al*., 1982).

Plant absorbs Si from the soil in form of monosilicic acid and deposits it in the cell walls near the cuticle forming silica-cuticle double layer and silica-cellulose double layer on the surfaces of leaves and stem in the form of silicic acid (Raven, 2001; Rao *et al.,* 2017). When plant absorbs more silica than requirements, tend to deposit it on tissues as it cannot be excreted (Jinger *et al*., 2017). Moreover, when silica is deposited in leaf epidermal cells becomes immobile and cannot be translocated to new growing leaves (Tubana *et al*., 2016). It was estimated that the production of 5 tons ha^{-1} of rice removes about 230 to 470 kg of Si per ha from soil depending upon soil and plant factors (Rajamani, 2012; Rao *et al.,* 2017).

Si enhances the growth of plant more clearly under a water-stressed condition than in a non-stressed condition. Furthermore, Si can alleviate water stress by decreasing transpiration of leaves through the stomata and cuticle (Ma and Takahashi, 2002). Availability of Si in rice plants facilitates: increased photosynthesis, increased nutrients availability (N, P, K, Ca, Mg, S, Zn), decrease nutrient toxicity (Fe, Mn, P, Al), increased resistance to biotic and abiotic stresses, increased resistance to wind and water lodging and improved growth and yield of rice (Ma, 2004; Ma and Yamaji, 2008; Jinger *et al*., 2017).

Si has been reported to be effective in controlling diseases in rice, such as leaf scald (*Monographella albescens*), blast (*Magnaporthe grisea*), brown spot (*Cochliobolus miyabeanus*) and grain discoloration (Jinger *et al*., 2017; Rao *et al*., 2017). Moreover, Si has also been reported to increase resistance of rice plant against insect pests such as stem borer, brown plant hopper, rice green-leaf hopper and white backed plant hopper (Jinger *et al*., 2017; Rao *et al*., 2017). The deposition of Silica on epidermal layers acts as a physical barrier preventing the physical penetration by pathogen and insects (Jinger *et al*., 2017; Rao *et al*., 2017).

Zhu *et al*. (2004) conducted experiment to investigate the effect of Si in cucumber plants. Results revealed that Si facilitates plants to withstand oxidative damage under salt stress conditions and helps to improve the growth of cucumber plants. Furthermore, Rajamani (2012) reported that the deposition of Si in plant roots reduces the binding sites for metals thereby leading to decreased uptake and translocation of salts and toxic metals from roots to shoot. On top of that, Ma *et al*. (2002) reported that Si has ability to increase the oxidizing power of roots by converting ferrous iron into ferric iron hence preventing a large uptake of iron and limiting its toxicity.

2.12 Summary of Literature Review

Majority of the rice producers in Tanzania, are subsistence farmers who produce rice under continuous flooding, a technique that uses large amount of water and results in low yields, low water productivity and low water use efficiency (Katambara *et al.,* 2013; SRI-Rice, 2015; Kangile *et al.,* 2018). The decline in rice yields may be attributed to depletion of plant available Si in rice fields (Savant *et al*., 1997). Rice yields can however be increased by adopting modern water saving technologies such as the System of Rice Intensification (SRI).

SRI is one of the modern techniques which help to increase rice yields and improve water productivity through its principles (CIIFAD, 2015). Furthermore, rice under SRI are less affected by wind and water stress due to more uptake of plant nutrients especially Si. Si enhances plant growth in water stress conditions by decreasing transpiration of leaves through the stomata (Ma and Takahashi, 2002). SRI is a technique which involves water-stress conditions by alternating wetting and drying field conditions, hence SRI plants may be advantaged by Si uptake.

Little has been done to assess Si status in rice fields as well as in rice plants at different growth stages. Therefore, this study was designed to provide an understanding of Si uptake by rice plant grown under SRI and continuous flooding in Mkindo Irrigation Scheme, Morogoro, Tanzania.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Study location

The study was conducted at Mkindo Farmer Managed Irrigation Scheme located at Mkindo Village, Mvomero District in Morogoro Region, Tanzania. Farmers in this scheme have adopted SRI and their producing rice for two seasons in a year. The first season starts from September to December and the second season starts from March to May. The scheme is situated between latitudes $6^0$16’ and $6^0$18’ South and longitudes $37^0$32’ and $37^0$36’ East and an altitude between 345 and 365 meters above mean sea level. The site is located about 85 km from Morogoro Municipality (Figure 1). The Mkindo Irrigation Scheme was constructed between 1980 and 1983 and started producing rice in 1985 with only 17 ha under cultivation. The water used in this scheme is drawn from Mkindo Perennial River through a well-organized irrigation infrastructure with lined main canal and unlined secondary, tertiary and drainage canals (Reuben *et al*., 2016). Rice is the only crop produced in the scheme which serves as food and income generation. Currently the scheme has an arable area of about 740 ha with only 300 ha under rice cultivation.

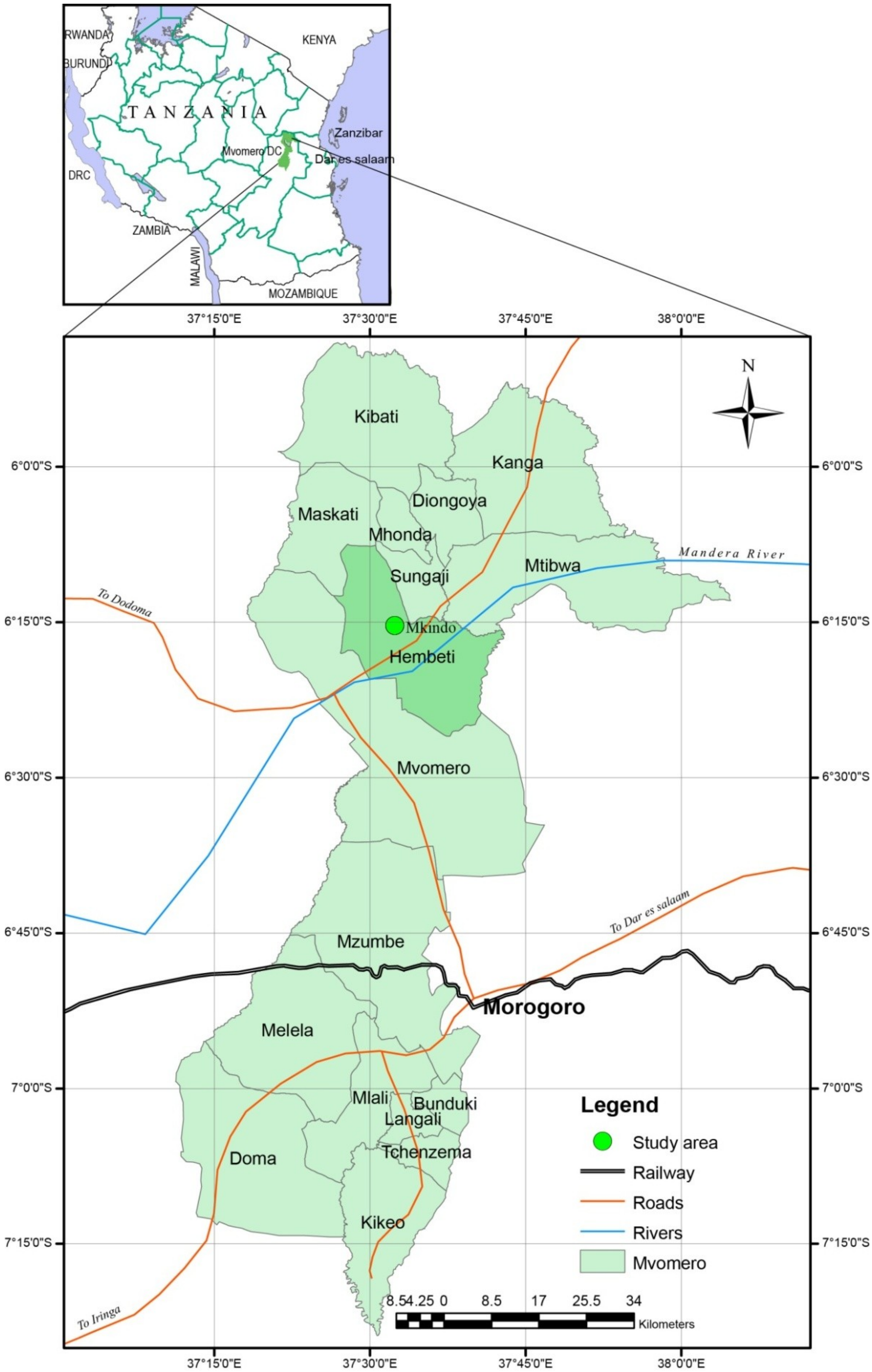

Figure 1: Location map of MkindoVillage in Mvomero District, Morogoro Region, Tanzania

3.1.2 Climate of the study area

The rainfall distribution of the study area is bimodal with short rains from October to December (OND) and long rains from March to May (MAM). The binomial rainfall regime determines two growing seasons namely the dry season (*vuli*) and the wet season (*masika*). In Mkindo area, the long rains receive more rains ranging from 112.6 to 250.3 mm with a total rainfall of 571.1 mm, respectively. On the other hand, the short rains receive less rains ranging from 52.6 to 116 mm with a total rainfall of 254.5 mm, respectively. The average annual rainfall ranges between 716.5 and 1503.5 mm (Figure 2). The average monthly maximum temperature at the experimental site varies from 35.1^{o}C to 28.5^{o}C for February and June while the average monthly minimum temperature varies from 20.4^{o}C to 15.8^{o}C for January, March and July, respectively (Figure 3).

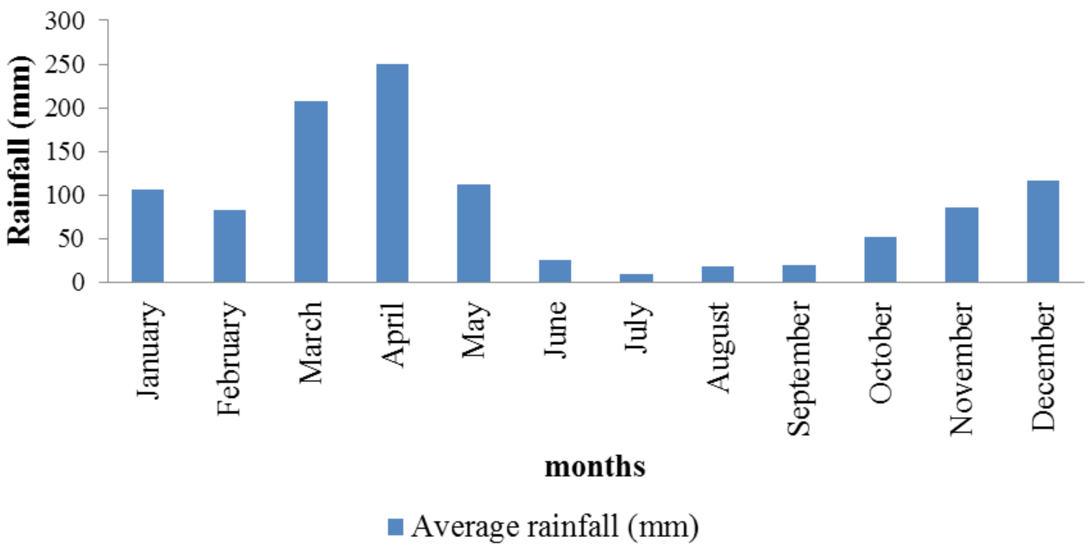

Figure 2: Average rainfall (mm) at MkindoVillage (1999 to 2019)

Source: Mtibwa Sugar Meteorological Station, 2020

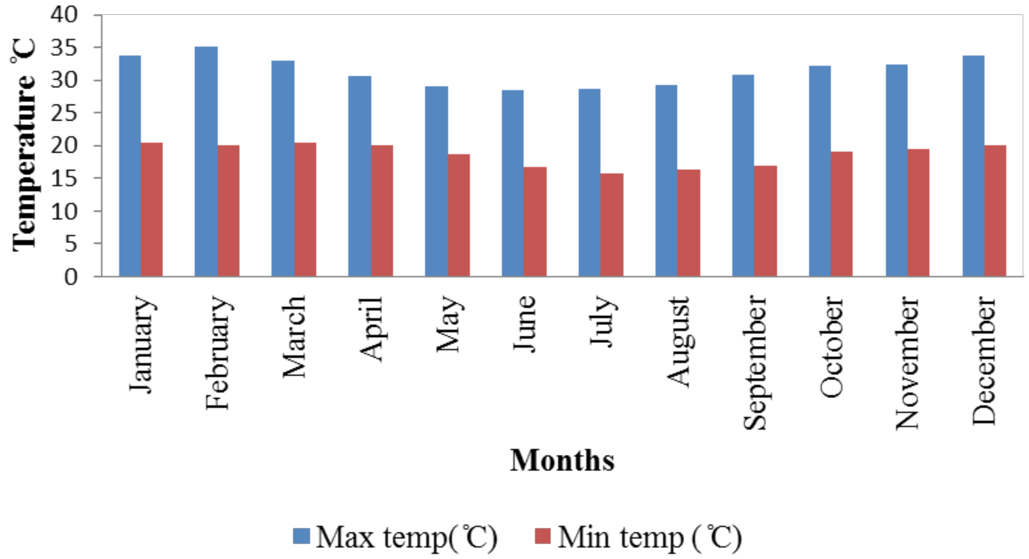

Figure 3: Average maximum and minimum monthly temperature at Mkindo village (1999 to 2019)

Source: Mtibwa Sugar Meteorological Station, 2020

3.2 Experimental Design

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The treatments were two water application regimes: T_1 was alternate wetting and drying using SRI technology and T_2 was continuous flooding. The experiment was conducted in two seasons from October 2019 to January 2020 and from March 2020 to June 2020. In T_1 (SRI plots), one seedling per hill was transplanted in a square pattern of 25 cm × 25 cm using 10 days old seedlings. In T_2 (continuous flooding plots), two seedlings per hill were transplanted in a square pattern of 20 cm × 20 cm using 21 days old seedlings. Again in SRI plots, irrigation water was applied by alternating wetting and drying field conditions whereas in continuous flooding plots, 5 cm depth of water was maintained from transplanting to harvest. The individual plot size was5 m × 10 m (50 m^2) each separated from the other by 1 m buffer zone. Table 1 and Figure 4 show the treatments details and layout.

Table 1: Treatment details on the experimental plots

Treatments	Water application regimes	Transplanting age (days)	Seedling per hill	Spacing (cm)
T_1	Alternate Wetting and Drying	10	1	25 × 25
T_2	Continuous Flooding	21	2	20 × 20

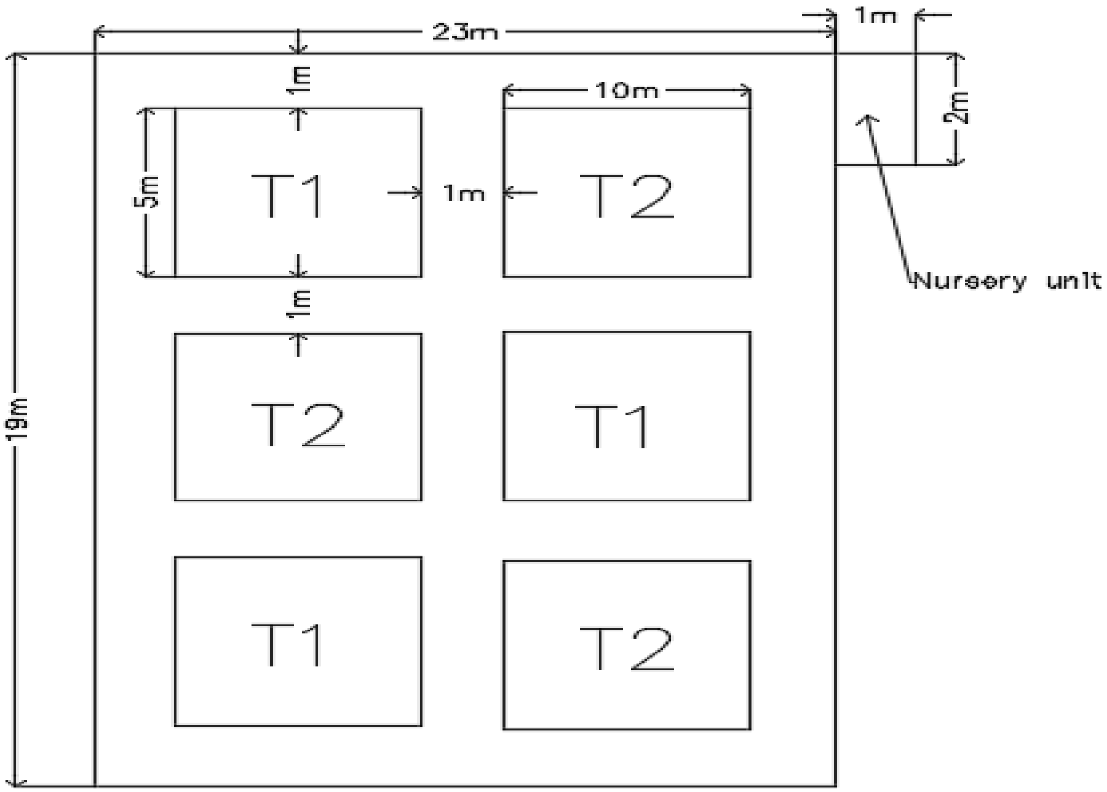

Figure 4: Layout of experimental plots showing treatments

3.3 Physical and Chemical Properties of the Soil at the Experimental Site

Prior to the experiment, representative soil samples were collected from the experimental site using an auger at the depth of 0 to 30 cm below the soil surface. The samples were then mixed thoroughly to form a composite sample. The composite sample was then air dried, hand pounded, passed through a 2 mm sieve and placed in a labeled bag then taken to Soil Science Laboratory at SUA and Tanzania Veterinary Laboratory Agency (TVLA) for analysis to characterize the physical and chemical properties of the soil.

The physical parameter assessed included particle size distribution (PSD), meanwhile the chemical parameters analyzed included: soil pH, available Si content, organic carbon (OC), cation exchange capacity (CEC), electrical conductivity (EC), total nitrogen (TN), extractable phosphorus (P), exchangeable bases; calcium (Ca), magnesium (Mg), potassium (K), sodium (Na) as well as extractable micronutrients; zinc (Zn), manganese (Mn), iron (Fe) and copper (Cu).

The particle size distribution was determined using hydrometer method as described by Gee and Bauder (1986) and the textural class by USDA (1975). The soil pH was determined potentiometrically using glass electrode pH meter in 1: 2.5 soil suspension as described by Maclean (1982). Organic carbon (OC) was determined using wet oxidation method as described by Nelson and Sommers (1982). Cation exchange capacity (CEC) was determined using neutral buffered 1M ammonium acetate saturation method as described by Somners and Miller (1996). Electrical conductivity (EC) was determined electrometrically using electric conductivity meter in 1:2:5 soil: water suspensions as described by Rhoades (1996).

Total nitrogen (TN) was determined using micro-Kjeldahl digestion distillation method as described by Bremmer and Malvaney (1982). Extractable phosphorus (P) was determined using Olsen method as described by Shio (1996). Exchangeable bases of calcium (Ca) and magnesium (Mg) were determined using ammonium acetate extract while potassium (K) was determined using flame photometer and sodium (Na) was determined using atomic absorption spectrophotometer as described by Hesse (1971). Extractable micronutrients: Cu, Zn, Fe and Mn were determined using the DTPA method as described by Lindsay and Norvell (1978). Results for physical and chemical parameters were judged according to Msanya *et al.* (2001) and Landon (2014).

3.4 Agronomic Practices

The agronomic practices carried out during the study period are described in the following sub-sections:

3.4.1 Seed selection using the egg-salt test

In this study, rice variety SARO 5 (TXD 306) was used as a test crop for the experiment in all experimental plots. This rice variety was chosen because it was recommended by the ministry of agriculture of Tanzania and also it showed better performance in Mkindo Irrigation Scheme and other areas with similar climatic conditions like Mkindo (Kombe, 2012; Kahimba *et al*., 2014; Mbaga, 2015; Reuben *et al*., 2016; Masawe *et al*., 2017, Kangile *et al*., 2018). It was obtained from Agricultural Seed Agency (ASA) in Morogoro Region, Tanzania. It is a 120 day rice variety which spends about 60 days in the vegetative phase, 30 days in the reproductive phase, and 30 days in the ripening phase (CIIFAD, 2015).

First, an egg was introduced in a container of fresh water (10 liters). The egg submerged to the bottom and then it was removed. Second, salt was added into the container of fresh water and then the egg was re-introduced. The egg was submerged again. The egg was removed and more salt was added until the egg floated in the salt water solution. Rice seeds were then introduced into the container of salt water solution. All seeds that floated in the salt water solution were removed and the remaining seeds that settled down at the bottom of the container were removed, washed with fresh water and then soaked in clean water for 24 hours then incubated for 48 hours in a plastic bag for seed emergence.

3.4.2 Nursery preparation

A small portion of the main field was demarcated then ploughed and levelled by hand hoe to form two raised seed beds of size 2 m × 1 m from which emerged seeds were uniformly distributed for seedling development. Then farm yard manure was applied in all the nursery plots prior to distribution of the emerged seeds in order to ensure proper growth of seedlings.

3.4.3 Main field preparation

The main field was manually ploughed using hand hoe followed by puddling with the help of power tiller and later levelled by hand leveller to ensure uniform distribution of water. Six individual plots of size 5 m × 10 m (50 m^2) were formed each separated from the other by 1 m buffer zone.

3.4.4 Transplanting

The emerged seedlings were transferred from the nursery plots to the main field with proper care to avoid roots damage. Transplanting was done in two scenarios as follows. In SRI plots one seedling per hill was transplanted in a square pattern of 25 cm × 25 cm using 10 days old seedlings. Kahimba *et al*. (2014) and Reuben *et al*. (2016) suggested that spacing of 25 cm × 25 cm and 8-12 days old seedlings are recommended for Mkindo area. On the other hand, in continuous flooding plots two seedlings per hill were transplanted in a square pattern of 20 cm × 20 cm using 21 days old seedlings. The spacing and age of seedlings adopted under continuous flooding practice were mostly used by many farmers around the scheme.

3.4.5 Irrigation water management

Irrigation water was maintained by two scenarios as follows**.** In SRI plots, irrigation water was applied by alternating wetting and drying field conditions whereas in continuous flooding plots, 5 cm depth of water was maintained from transplanting to harvest. The water depth used in continuous flooding plots was adopted from the research done by

Kahimba *et al*. (2014) in Mkindo Irrigation Scheme. The drainage channels were formed between plots for removal of excess water from the experimental plots.

3.4.6 Fertilizer application

For proper crop growth, the recommended doses of fertilizers namely DAP and UREA was applied uniformly in all the experimental plots at the rate of 100 kg ha^{-1}(Mbaga, 2015). DAP was applied during transplanting, whereas UREA 46% N was applied in two splits: one split during fourteen days after transplanting (DAT) and the second split during fifty DAT.

3.4.7 Weeding

In order to minimize yield losses, four weeding were done by the help of push weeder in all experimental plots during the growth stages. First weeding was done fourteen DAT followed by three weeding consecutively after every three weeks. Frequent weeding was done due to weeds infestation which was favored by alternating wetting and dry field conditions. Stoop *et al*. (2002) and Reuben *et al.* (2016) reported that the intermittent wetting and drying field conditions favors weeds infestation and the weeding process improves the soil aeration of root zone by providing oxygen that facilitates the development of strong and healthy roots that leads to optimal tillering and development of healthy rice grains. Katambara *et al*. (2013) also reported that the weeding process helps to aerate the soil and makes oxygen available to the roots and other biological organism involved in facilitating some biochemical processes.

3.5 Assessing the Available Silicon Status in Soils of the Experimental Site

Representative soil samples were randomly collected from each field plot at the beginning of the experiment and during vegetative (55 DAT), reproductive (85 DAT) and ripening phase (115 DAT). Six soil samples were randomly collected from each field plot using an auger at the depth of 0 to 30 cm below the soil surface. Then the soil samples from each field plot were mixed thoroughly to form a total of six composite samples which were then air dried, hand pounded, passed through 2 mm sieve and placed in a labelled bag then taken to TVLA for analysis. In the laboratory the soil samples were placed in a labelled plastic bottle then introduced in the Energy Dispersive X- Ray Fluorescence (EDXRF) machine for analysis to determine the Si status according to elemental analysis based on EDXRF as described by Yao *et al.* (2015).

3.6 Assessing Silicon Status in Rice Seeds and Grains

First, seed samples (SARO 5; TXD 306) were taken from Agricultural Seed Agency (ASA) at the beginning of experiment then a portion of it weighing 500 gm was stored in a labeled bag and taken to TVLA for Si analysis. Second, grain samples were randomly collected during reproductive (85 DAT) and ripening phase (115 DAT). From each field plot a randomly selected area of 1 m^2 was demarcated then grain samples were collected, air dried, stored in a labelled bag and taken to TVLA for analysis. In the laboratory seeds and grains samples were placed in a labelled plastic bottle then introduced in the Energy Dispersive X- Ray Fluorescence (EDXRF) machine for analysis to determine the Si status according to elemental analysis based on EDXRF as described by Yao *et al.* (2015).

3.7 Assessing Silicon Status in Rice Plant Leaves

Samples for rice plant leaves were collected randomly at vegetative (55 DAT), reproductive (85 DAT) and ripening phase (115 DAT). From each field plot, a randomly selected area of 1 m^2 was demarcated then leaf samples i.e. 3^{rd} or 4^{th} leaves from the top of the plant were collected randomly. The collected plant samples were air dried, chopped into small pieces and placed in a labelled bag then taken to TVLA for analysis. In the laboratory plant samples were placed in a labelled plastic bottle then introduced in the Energy Dispersive X- Ray Fluorescence (EDXRF) machine for analysis to determine the Si status according to elemental analysis based on EDXRF as described by Yao *et al.* (2015).

3.8 Examining Growth and Yield Parameters of Rice

Growth and yield parameters assessed included: total number of tillers per hill, number of productive tillers per hill, number of panicles per hill, plant height and grain yields. From each field plot, a randomly selected area of 1 m^2 was demarcated and then data for the stated parameters were collected. Five plants around the demarcation zone were selected and data for plant height, total number of tillers per hill, number of productive tillers per hill and number of panicles per hill were taken during vegetative (55 DAT), reproductive (85 DAT) and ripening phase (115 DAT). At harvest, the border rows on all sides of the demarcation zone on individual plots were first harvested, then the crops under the demarcation zone were cut and seeds were separated from the straw followed by air drying to reach 15% moisture content. Grain yield was measured using digital electronic balance.

3.9 Data Analysis

The data gathered from the experiment at different growth stages were analyzed using GenStat 15th Edition statistical software and the significant differences between means were separated using Least Significance Difference (LSD) based on p-value of 0.05. Results were presented using tables and bar charts.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Physical and Chemical Properties of Soils at the Experimental Site

Results for physical and chemical properties of soils of the study area are presented in Table 2.

Table 2: **Physical and chemical properties of soils of the study area**

Physical and Chemical properties	Value	Description
pH	5.85	Medium acidic soils
Organic carbon (OC) (%)	1.04	Low
Cation exchange capacity (CEC) cmol (+) kg^{-1}	11.20	Low
Electrical conductivity (EC) dS/m	0.14	No effect on rice yield reduction
Total nitrogen (TN) (%)	0.04	Very low
Extractable phosphorus (P) (mg kg^{-1})	14.06	Medium
Available Si content (mg kg^{-1})	235.50	Sufficient
Particle size distribution		
Sand	82.32%	Sandy loam
Clay	13.80%	
Silt	3.92%	
Exchangeable bases (cmol (+) kg^{-1})		
Calcium (Ca)	3.69	Medium
Magnesium (Mg)	0.72	Low
Potassium (K)	0.16	Low
Sodium (Na)	0.29	Low
Extractable micronutrients(mg kg^{-1})		
Zinc (Zn)	1.42	Medium
Manganese (Mn)	79.29	Very high
Iron (Fe)	428.64	Very high
Copper (Cu)	2.92	High

4.1.1 Particle size distribution (PSD)

From Table 2, the soil of the study area is sandy loam with 82.32% sand, 13.8% clay and 3.92% silt. This type of soil is considered as moderately suitable for most crop growth because it has moderate ability to hold water and nutrients.

4.1.2 Soil pH

The soil pH of the study area was 5.85 rated as medium acidic (Table 2). Msanya *et al.* (2001) and Landon (2014) reported that the soil pH ranges 5.5-7.0 as medium acidic soils. These results are in agreement with those found by Kombe (2012) in Mkindo Irrigation Scheme. It was reported that the soil pH of the study area was 6.2 rated as medium acidic soils. Therefore the soils of the study area can be judged as suitable for rice cultivation.

4.1.3 Organic carbon (OC)

The OC content of the soil of the study area was 1.04% which is at low range (Table 2). Msanya *et al.* (2001) and Landon (2014) reported that the OC content ranges between 0.1-0.2% rated as low. The low OC content might be associated with the low organic matter content in the soil of the study area (Mbaga, 2015). It was observed from the study area that most of the farmers were removing away and some were burning crop residues after harvest which is one of the sources of organic matter in the soil.

4.1.4 Cation exchange capacity (CEC)

From Table 2, the CEC of the soil at the study area was 11.2 cmol (+) kg^{-1} which is low and needs to be improved. According to Msanya *et al.* (2001) and Landon (2014) the CEC value ranges 5-12 cmol (+) kg^{-1} is rated as low. The low CEC of the soils could be attributed to low organic carbon (OC) content in the soils. Similar results were reported by Mbaga (2015) in Dakawa Irrigation Scheme. It was observed that the OC content and CEC of the soils at the study area were low to medium range mainly due to low organic matter content in the soils.

4.1.5 Electrical conductivity (EC)

Results in Table 2 show that the EC of the soil at the experimental site was 0.1442 dS/m which is considered has no effect on rice yield reduction. Msanya *et al.* (2001) and Landon (2014) reported that the soil with EC of < 1.7 dS/m has no effect on rice yield reduction, hence the Mkindo soil could be judged as suitable for rice production.

4.1.6 Total nitrogen (TN)

The TN content of the soil at Mkindo Irrigation Scheme was 0.04% which is considered as very low (Table 2). Msanya *et al.* (2001) and Landon (2014) rated that TN of less than 0.1% as very low. This might be attributed to leaching of nutrients such as N due to irrigation or plants uptakes. Therefore the Mkindo farmers should apply the recommended fertilizers rich in N to improve rice productivity.

4.1.7 Extractable phosphorus (P)

The extractable P of Mkindo soil was 14.06 mg kg^{-1} which is at medium range (Table 2). According to Msanya *et al.* (2001) and Landon (2014), P value ranges between 7-20 mg kg^{-1} is rated as medium and is considered as optimal for rice production.

4.1.8 Exchangeable Calcium (Ca)

The exchangeable Ca content of the soil at Mkindo Irrigation Scheme was 3.69 cmol (+) kg^{-1} rated as medium range (Table 2). Msanya *et al.* (2001) considered that the Ca content ranges 2.1-4 cmol (+) kg^{-1}) as medium range hence it is optimal for rice cultivation.

4.1.9Exchangeable Magnesium (Mg)

The exchangeable Mg content of the soil at Mkindo Irrigation Scheme was 0.718 cmol (+) kg^{-1}which is at low range (Table 2). Msanya *et al.* (2001) and Landon (2014) indicated that the Mg content ranges 0.25-1.5 cmol (+) kg^{-1}as low. The low level of Mg content in Mkindo soils might be attributed to low Mg contents in the soils parental materials or loss of nutrients including Mg due to removal of crop residues after harvest or leaching of nutrients due to continuous flooding the fields or through plant uptake (Mbaga, 2015). Hence it needs to be improved for better rice growth.

4.1.10 Exchangeable potassium (K)

The exchangeable K of the soil in the study area was 0.16 cmol (+) kg^{-1} which is considered as low range (Table 2). Msanya *et al.* (2001) and Landon (2014) indicated these values (0.1 – 0.3 cmol (+) kg^{-}1) as low. Therefore the K content in Mkindo soils could be considered as not optimal for rice cultivation hence it needs to be improved by applying fertilizers rich in K.

4.1.11Exchangeable sodium (Na)

The exchangeable Na content of the soils at Mkindo Irrigation Scheme was 0.293 cmol (+) kg^{-1} rated as low (Table 2). Msanya *et al.* (2001) and Landon (2014) indicated that the Na content ranges 0.1-0.3 cmol (+) kg^{-1} is as low. The low level of Na content in soils might be attributed to leaching losses down the soil profile due to irrigation or continuous flooding (Mbaga, 2015).

4.1.12 Extractable micronutrients

The extractable Zinc (Zn) level in the soil from the study area was 1.416 mg kg^{-1} (Table 2) rated as medium since it is >1.0 mg kg^{-1} as indicated by Landon (2014). The extractable

Manganese (Mn) level was 79.29 mg kg^{-1} rated as very high (> 1.5 mg kg^{-1}) as suggested by Landon (2014). The extractable Iron (Fe) level in the soil from the study site was 428.64 mg kg^{-1} rated as very high (>10 mg kg^{-1}) as reported by Landon (2014). The extractable Copper (Cu) level in the study area was 2.923 mg kg^{-1} rated as high (> 0.75 mg kg^{-1}) as indicated by Landon (2014). Therefore, the soil of the study area had higher amount of extractable micronutrients.

4.2 Available Si Status in the Soil at three Rice Growth Stages

Available Si status in soils of Mkindo Irrigation Scheme for the two consecutive seasons is presented in Figure 5 and 6.

There was significant difference (at $P < 0.05$) in Si content in soils at the experimental site in all rice growth stages for the growing seasons. The available Si content in Mkindo soils observed at various rice growth stages is described as follows.

4.2.1 Si status in soils at the beginning of the experiment

The available Si content in Mkindo soils observed at the beginning of the experiment was 235.5 mg kg^{-1}(Table 3), rated as sufficient for rice production as indicated by Shivay and Dinesh (2009) and Rao *et al*. (2017).

4.2.2 Si status in soils during vegetative stage

At this stage, there was decrease in Si content in soils of the experimental site when compared to what was observed at the beginning of the experiment (Figure 5 and 6). The decrease in Si content in soils might be attributed to higher uptake of Si by rice plants for the establishment of different parts of the plant such as roots, leaves and panicles. The highest Si content in soils was observed in treatment T_1 (150.82 mg kg^{-1}) using SRI technology whereas the lowest Si content was observed in treatment T_2 (120.93 mg kg^{-1}) under continuous flooding (Figure 5 and 6).

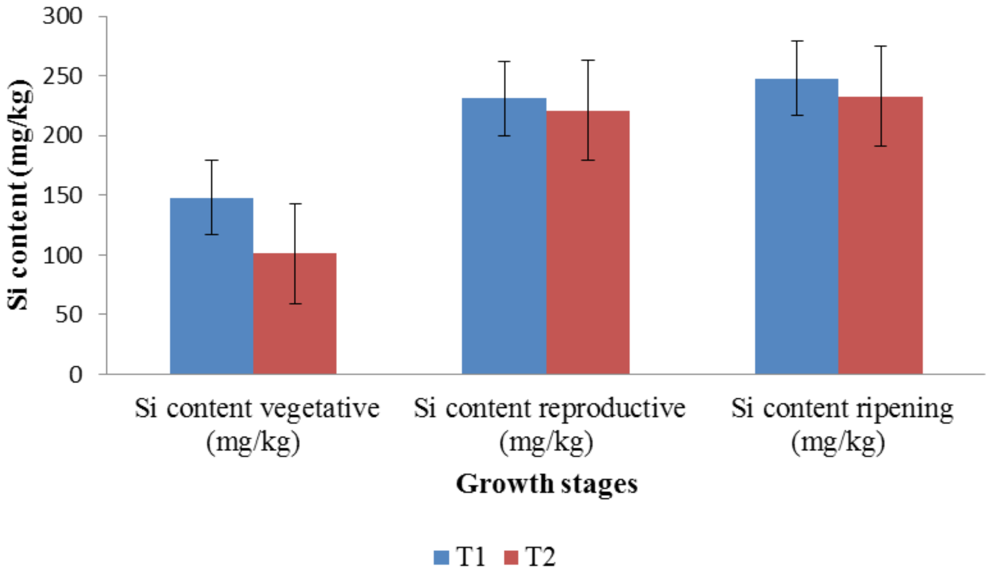

Figure 5: Si content in soils of the experimental site during the dry season (*vuli*)

T_1: Treatment 1 using SRI technology and T_2: Treatment 2 under continuous flooding.

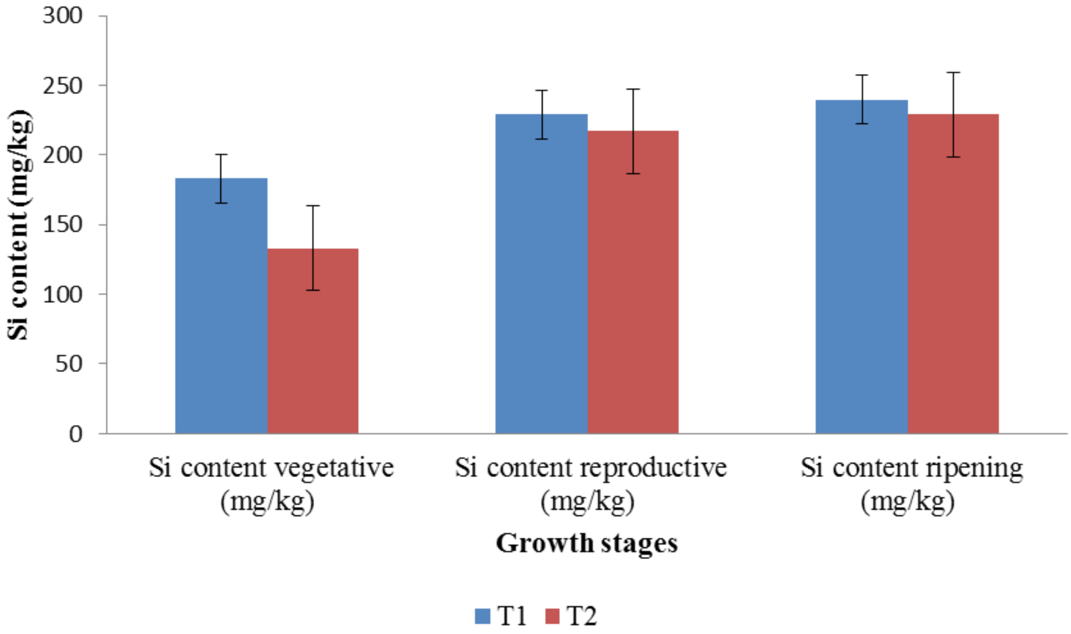

Figure 6: Si content in soils of the experimental site during the wet season (*masika*)

T_1: Treatment 1 using SRI technology and T_2: Treatment 2 under continuous flooding.

This shows that plants grown under SRI had higher ability to take up more Si from the soil and had higher ability to replenish Si in the soil as compared to continuous flooding. This might be attributed to alternating wetting and drying field conditions which enhance oxygen supply in the root zone as well as more uptakes of nutrients as suggested by Reuben *et al.* (2016).

4.2.3 Si status in soils during reproductive and ripening stage

There was increase in Si content in soils among all treatments during reproductive and ripening stage (Figure 5 and 6). During these stages, all parts of the plant such as roots, leaves and panicles were well established as a result little Si content was taken up by rice plant from the soil to support crop growth, hence this attributed to increase in Si content in soils of the experimental site. The increase in available soil Si content might also associated with its release from ferrosilicon complexes under reducing soil conditions as reported by Savant *et al*. (1997).

For the two seasons, the average values observed ranged 219.8-242.5 mg kg^{-1}during reproductive and ripening stage (Figure 5 and 6). However, T_1 recorded highest value (242.5 mg kg^{-1}) compared to T_2 (231.2 mg kg^{-1}) during the ripening stage. The highest value observed in T_1 may be attributed to proper management of irrigation water, younger seedling used of ten days old and wider spacing used of 25 x 25cm in SRI plots. Therefore, Mkindo soils observed to have sufficient amount of Si content (> 40 mg kg-^{1}) in all rice growth stages as suggested by Shivay and Dinesh (2009) and Rao *et al*. (2017), hence it could be judged as suitable for rice cultivation.

These results are in agreement with those reported by Paye (2016) who conducted a study to determine the critical soil Si level for rice production in Louisiana, Liberia using different extraction procedures. The experimental sites observed to have low to high initial soil Si content which ranged between 11-164 mg kg^{-1}at the beginning of the experiment. However, at harvest stage Si contents in soils with low pH and low initial Si were significantly ($p<0.01$) increased as a result of Si fertilization at the beginning of the experiment.

On the other hand, Rajamani (2012) reported different results in India. It was observed that the available Si content in soils under study ranged from 79.06 to 94.19, 80.73 to 96.41 and 73.62 to 87.53 kg SiO_2 ha^{-1} at initial, tillering and harvest stage, respectively. There was increase in Si content at tillering stage after conjunctive application of N and Si to the soils of the study area at the beginning of the experiment.

However, during harvest stage there was gradual decrease in available soil Si content. This might be attributed to depletion of available Si due to continuous rice cultivation, low solubility, slow dissolution of soil Si, and higher uptake of Si by rice crops and/or limited attempts by farmers to recycle Si through crop residues (Savant *et al*., 1997).

4.3 Si Status in Rice Seeds and Grains at Three Stages

4.3.1 Si status in rice seeds at the beginning of the experiment

The available Si content in rice seeds observed at the beginning of the experiment was 6.76%. This value is within the acceptable range (4-20%) of Si content in rice plants as suggested by Shivay and Dinesh (2009) and Rao *et al.* (2017).

Data for Si status in rice grains at reproductive stage and at harvest is presented in Figure 7 and 8.

4.3.2 Si status in rice grains during reproductive stage

For the two growing seasons, Si content in rice grains in treatment T_1 was significantly different at $P < 0.05$ from treatment T_2 (Figure 7 and 8). There was also significant increase in Si content in rice grains in both treatments during the two seasons. The significant increase in Si content in both treatments might be due to higher uptake of Si by rice plant for establishment of rice grains.

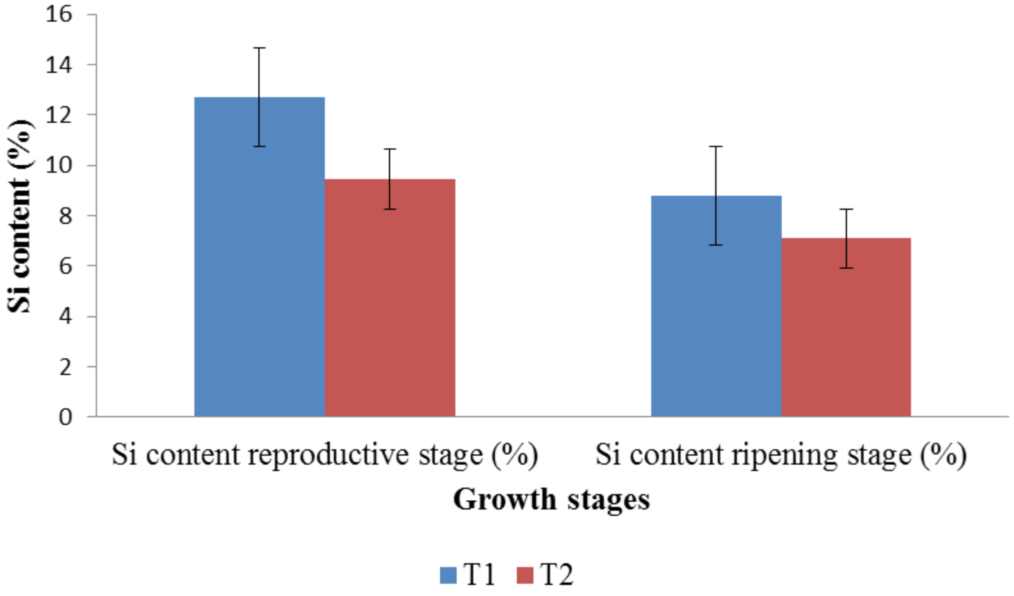

Figure 7: Si content (%) in rice grains during the dry season (*vuli*)

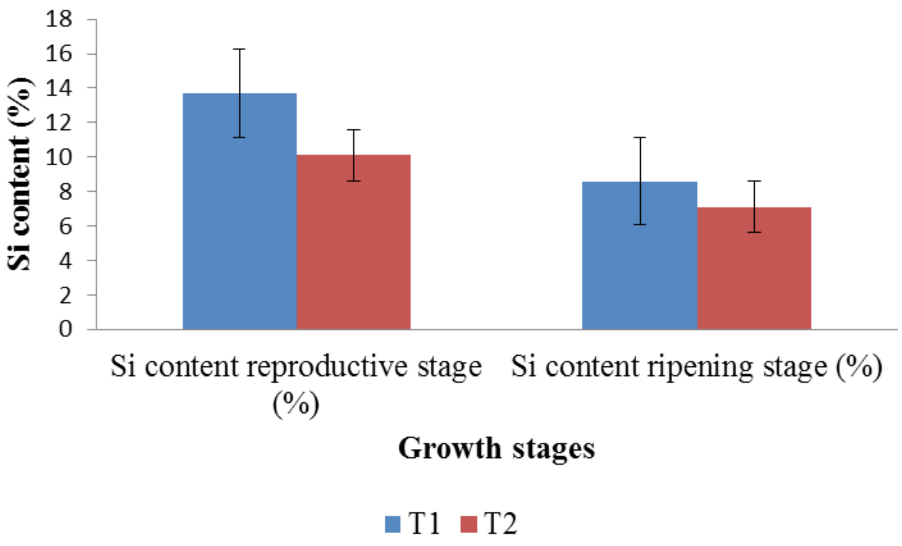

Figure 8: Si content (%) in rice grains during the wet season (*masika*)

The highest Si content in rice grains was recorded in treatment T_1 (13.2%) while the lowest value was observed in treatment T_2 (9.8%) (Figure 7 and 8). The highest value observed in treatment T_1 might be attributed to intermittent water application, younger seedlings used of ten days old, wider spacing of 25 x 25cm and weeding process which facilitates improved oxygen supply in rice roots thereby causing stronger and healthier root system which ensures higher Si uptake from the soil as suggested by Katambara *et al*. (2013) and Reuben *et al.* (2016).

4.3.3 Si status in rice grains at harvest

There was significance different at $P < 0.05$ in Si content in rice grains between the treatments. The highest Si content in rice grains was recorded in treatment T_1 (8.7%) while the lowest value was observed in treatment T_2 (7.1%) (Figure 7 and 8). There was also reduction in Si content in rice grains at this stage when compared to what observed at the reproductive stage. This might be attributed to loss of moisture content as most of the rice grains dry at harvest hence the whole plant dry matter and the percentage in Si content in grains get reduced. However, the values observed at this stage were higher than what was observed in rice seeds at the beginning of the experiment (6.76%). The lower value of Si content observed in rice seeds may be influenced by loss of moisture content due to storage of rice seeds. Similar results were observed by Paye (2016) who reported increase in Si content in rice straw and panicles during harvest stage after Si application in soils under the study at the beginning of the experiment.

4.4 Silicon Status in Rice Plant Leaves at Three Growth Stages

Similarly to Si content in rice seeds and grains, Si content in rice plant leaves were also within acceptable range (4-20%) for proper rice growth as suggested by Shivay and Dinesh (2009) and Rao *et al.* (2017). They reported that Si content of < 5% as critical level in rice plants. In all rice growth stages, there were significant differences at P ≤ 0.05 in Si content in rice plant leaves among the treatments during the dry (*vuli*) and wet (*masika*) seasons. Moreover, there was significant increase in Si content in rice plant leaves from vegetative to ripening stage due to higher uptake of Si from the soil.

Results for Si content in rice plant leaves at three growth stages are presented in Figure 9 and 10.

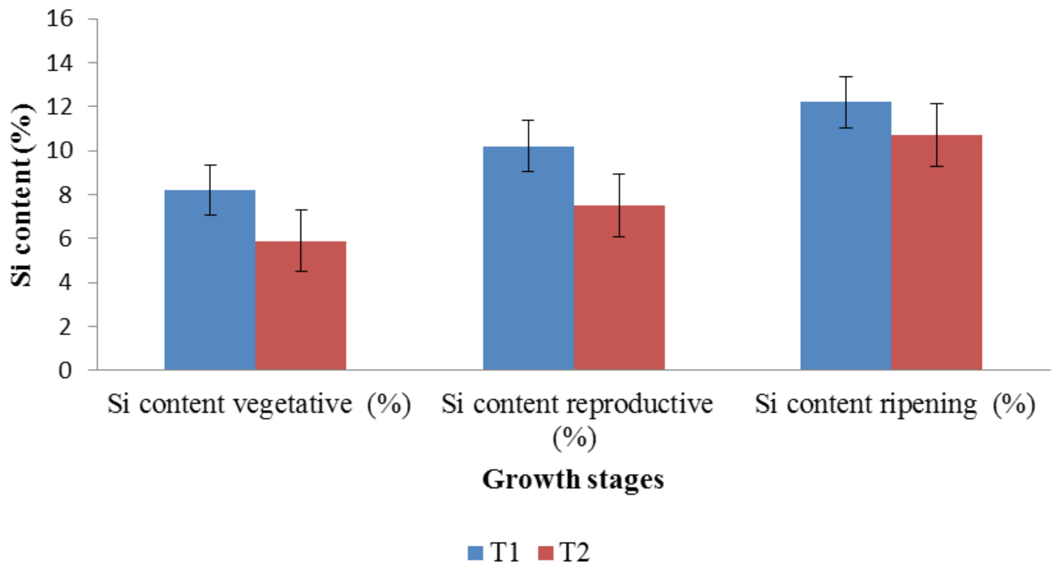

Figure 9: Si content (%) in rice plant leaves during the dry season (*vuli*)

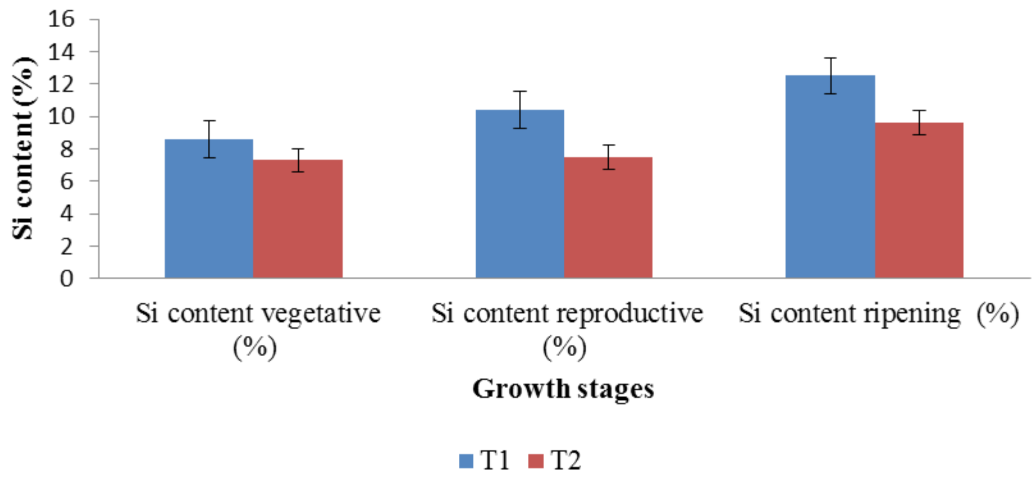

Figure 10: Si content (%) in rice plant leaves during the wet season (*masika*)

4.4.1 Silicon status in rice plant leaves at vegetative stage

The highest Si content in rice plant leaves was observed in treatment T_1 (8.38%) whereas the lowest value was observed in treatment T_2 (6.6%) (Figure 9 and 10). The highest Si content in rice plants grown under SRI was mainly attributed to alternating wetting and drying field conditions which enhance higher uptake of Si from the soil. This situation contributed much to the strength of plants to withstand stresses due to wind and water.

4.4.2 Si status in rice plant leaves at reproductive stage

There was an increase in Si content in rice plant leaves due to higher uptake of Si from the soil which results into the formation of thick cuticle double layer in the epidermal layer around cell walls of leaves and stems as suggested by Raven (2001) and Rao *et al.* (2017). Treatment T_1 recorded the highest Si content (10.27%) in rice plant leaves. In comparison, the lowest Si content was observed in treatment T_2 (7.54%) (Figure 9 and 10).

4.4.3 Si status in rice plant leaves at ripening stage

Similarly, at the ripening stage there was increase in Si content in rice plant leaves whereby treatment T_1 recorded the highest Si content (12.37%). Meanwhile, the lowest Si content was observed in treatment T_2 (10.15%) (Figure 9 and 10). The higher value of Si content in rice plant leaves which was observed in treatment T_1 were attributed to higher uptake of Si from the soil. This was also attributed to proper maintenance of water applied in the rice field under SRI practices.

Similar observations were reported way back by Nayar *et al.* (1982). It was reported that the Si content in rice plant (the leaf blade, culm and whole plant) increases with the age of the plant from transplanting to harvest. The lower values were observed during vegetative growth stage while the higher values were observed after flowering stage.

These results agree with those observed by Rajamani (2012) in India who conducted a study to evaluate Si content in index leaves of various rice genotypes. It was reported that the Si content in index leaves were increasing from tillering to harvest stage with values being 2.76%, 3.09% and 3.56% rated as critical value considering Si content of < 5% as critical level in rice plant as suggested by Shivay and Dinesh (2009) and Rao *et al.* (2017). This might be attributed to leaching of nutrients including Si above the root zone of the plant due to water flowing into the rice fields (Datnoff *et al.*, 2005).

4.5 Growth and Yield Parameters of Rice

4.5.1 Plant height

There was significant difference ($p < 0.05$) in plant heights among the treatments. It was observed that plant height increased as soil Si content increased from vegetative to ripening stage (Figure 11). At harvest, treatment $T_1$with higher Si content in soils (242.5 mg kg^{-1}) recorded higher plant height (146.5 cm). Meanwhile, the lower plant height (128.9 cm) was recorded in treatment $T_2$with lower (231.2 mg $kg^{-1)}$ soil Si content (Figure 11).

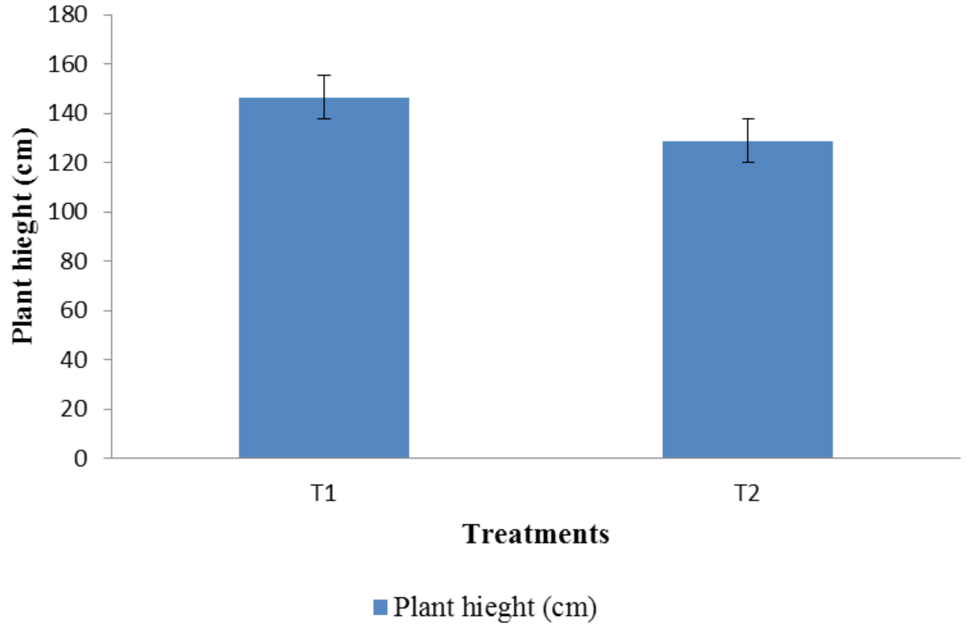

Figure 11: Plant height (cm) at ripening stage

T_1: Treatment 1 using SRI technology and T_2: Treatment 2 under continuous flooding

4.5.2 Number of tillers per hill

As observed in plant height, the number of tillers per hill also increased with the age of plants after two weeks of transplanting till ripening stage. Also there was significant difference at $p < 0.05$ in number of tillers per hill among the treatments (Figure 12). Plots with higher soil Si contents observed to have higher number of tillers per hill. For instance, treatment T_1 with higher soil Si content (242.5 mg kg^{-1}) observed to have higher number of tillers per hill (54.1). Meanwhile, T_2 with lower soil Si content (231.2 mg kg^{-1}) observed to have lower number of tillers per hill (26.6) during the ripening stage (Figure 11).

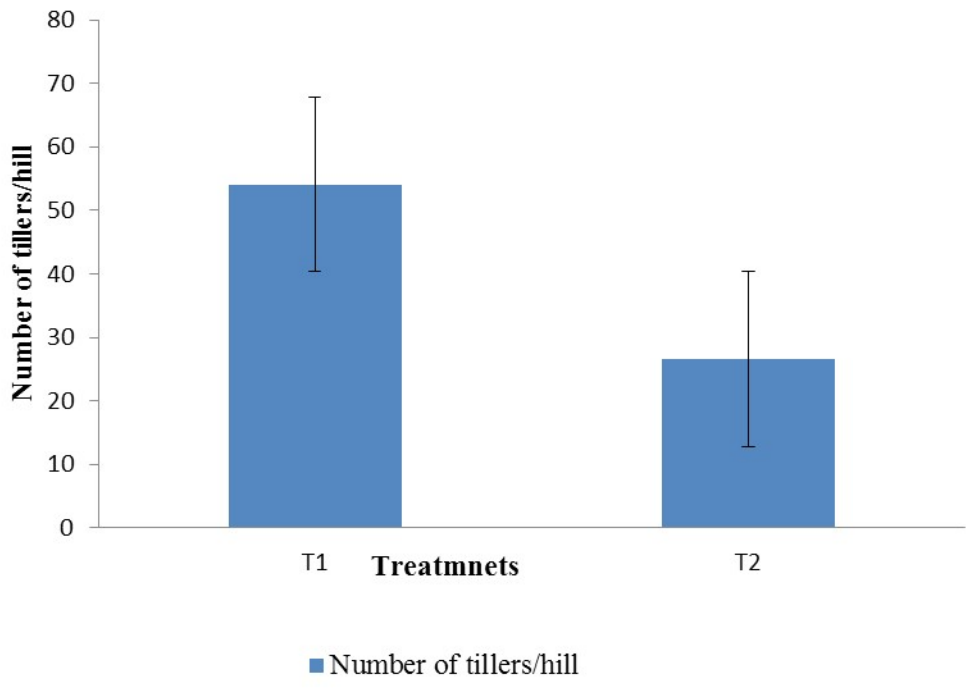

Figure 12: Number of tillers/hill at ripening stage

T_1: Treatment 1 using SRI technology and T_2: Treatment 2 under continuous flooding

4.5.3 Number of productive tillers per hill

There was significant variation at ($p < 0.05$) in number of productive tillers per hill between treatments. Similarly to number of tillers per hill, treatment T_1 with higher soil Si content (242.5 mg kg^{-1}) recorded higher number of productive tillers per hill (46.1) whereas, the lowest number of productive tillers per hill was observed in treatment T_2(21.5) with lower soil Si content (231.2 mg kg^{-1}) (Figure 13). The higher number of tillers and productive tillers per hill observed in rice plants grown under SRI was attributed to proper maintenance of water, younger seedlings used and wider plant spacing.

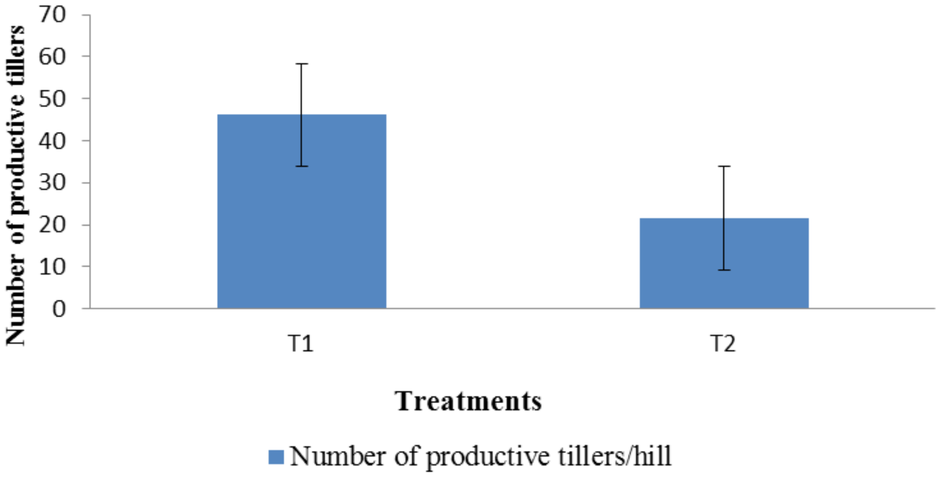

Figure 13: Number of productive tillers/hill during ripening stage

T_1: Treatment 1 using SRI technology and T_2: Treatment 2 under continuous flooding

4.5.4 Number of panicles per hill

There was significant variation at ($p < 0.05$) in number of panicles per hill between the treatments. Higher number of panicles per hill was observed in treatment T_1 (30.6) with higher soil Si content (242.5 mg kg^{-1}). Meanwhile, the lowest value was observed in treatment T_2 (27.3) with lower soil Si content (231.2 mg kg^{-1}) (Figure 14).

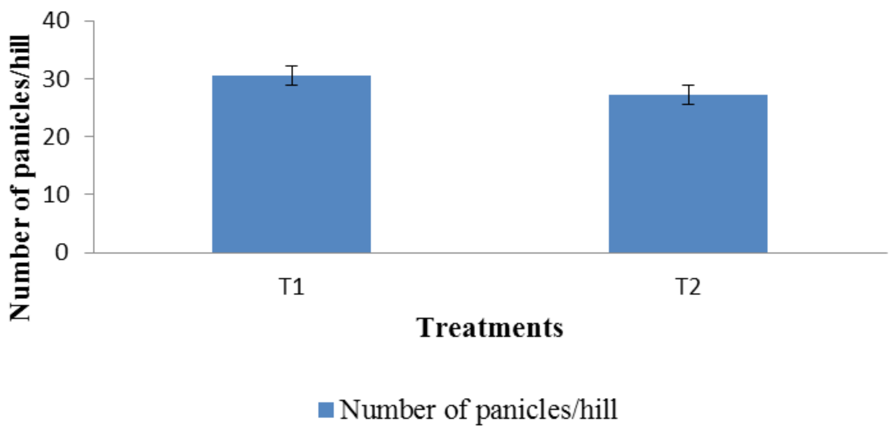

Figure 14: Number of panicles/hillduring ripening stage

T_1: Treatment 1 using SRI technology and T_2: Treatment 2 under continuous flooding

4.5.5 Grain yield

There was significant difference at ($p < 0.05$) in grain yield between the treatments. Higher grain yield was recorded in treatment T_1 (7.9 tons ha^{-1}) with higher soil Si content (242.5 mg kg^{-1}) and higher Si content in rice grains (8.7%) while the lowest grain yield was recorded in treatment T_2 (3.4 tons ha^{-1}) with lower soil Si content (231.2 mg kg^{-1}) and lower Si content in rice grains (7.1%) (Figure 14). The higher grain yield observed in T_1 under SRI was attributed to higher uptake of Si from rice field, proper maintenance of water, younger seedlings used and wider plant spacing.

These results concurs with the findings observed by Jawahar and Vaiyapuri (2010) who reported higher plant height, number of tillers per hill, number of panicles per hill and grain yield in plots with higher Sulphur and Si content. These results are also in conformity with those observed by Rajaman (2012) who reported significantly higher mean grain yield (6779 kg ha^{-1}) in rice genotype JGL-3855 with higher Si content compared to rice genotype RNR-235(46460 kg ha^{-1}) with lower Si content.

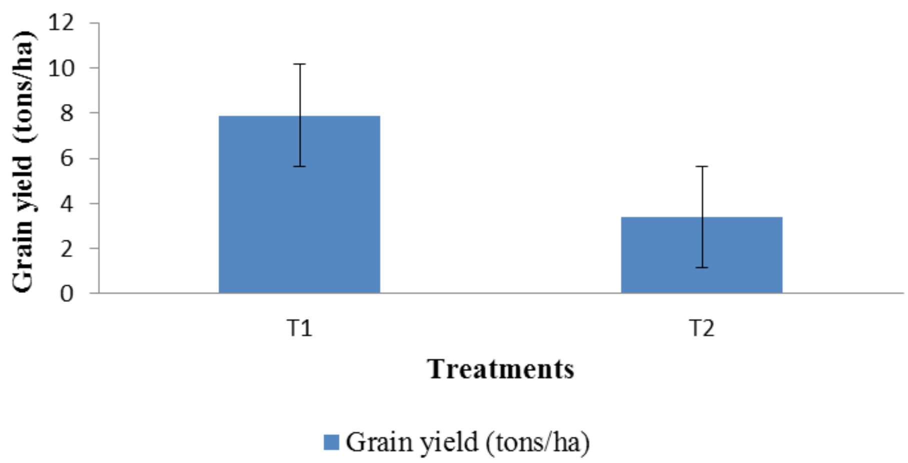

Figure 15: Grain yield (tons/ha) during ripening stage

T_1: Treatment 1 using SRI technology and T_2: Treatment 2 under continuous flooding

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following are the conclusions

i) The soils of the study area had sufficient amount of Si content for proper rice growth which ranged between 230.58 to 240.42 mg kg^{-1} hence it is suitable for rice cultivation.

ii) Rice variety SARO 5 (TXD 306) used in this experiment had an acceptable range of Si content (6.76%), which was observed prior to the experiment. Also this variety showed higher ability to take up more Si from the soil. At harvest, it was seen that the produced rice grains had an optimum level of Si which range of 10.15-12.37%.

iii) Si content in rice plant leaves was increasing significantly from vegetative to ripening stage, and it was within an acceptable range for proper rice growth ranges between 4-20%.

iv) Moreover, SRI plants recorded the highest Si content in rice grains and rice plant leaves compared to continuous flooding. This indicates that the alternating wetting and drying field conditions enhances plants to take up more Si from the soil compared to continuous flooding.

v) Growth and yield parameters of rice grown under SRI and continuous flooding practice were observed to increase significantly from vegetative to ripening stage. However, treatment T_1 using SRI technologies showed higher growth and yield parameters compared to treatment T_2 under continuous flooding.

5.2 Recommendations

The following are the recommendations

i) Mkindo farmers were encouraged to adopt the SRI technology since it enhances higher uptake of Si which in turn improves growth and rice yields.

ii) There is a need for introducing Si sources such as rice husks and straws in rice fields in order to improve rice productivity.

iii) This study should be conducted in other places for the purpose of assessing Si content in different soils and environment conditions around the country.

iv) Further studies should be conducted to assess the effect of different Si sources on growth and yield parameters of rice as well as water productivity.

v) Further studies should also be undertaken to assess the available Si content of other rice varieties produced in Mkindo area and other areas around the country for instance local varieties such as *mbawambili*, *cherehani* and *kulanabwana*.

REFERENCES

Aarekar, S. A. (2012). *Effect of sources and levels of silicon on yield of paddy*. Thesis for Award of MSc Degree at Maharashtra (India). 94pp.

Ali, R. M. (2015). *Evaluation of the performance of system of rice intensification in Bumbwisudi rice irrigation scheme, Zanzibar*. Dissertation for Award of MSc Degree at Sokoine University of Agriculture, Morogoro, Tanzania. 115pp.

Amuri, N., Semoka, J., Ikerra, S., Kulaya, I. and Msuya, B. (2013). Enhancing use of phosphorus fertilizers for maize and rice production in small scale farming in Eastern and Northern zones, Tanzania. Department of Soil Science and Department of Agricultural Education and Extension, Sokoine University of Agriculture. A Paper presented at the 27th Soil Science Society of East Africa-6th African Soil Science Society Conference, 21st to 25th October 2013, Nakuru, Kenya.1-12pp.

Berthelsen, S., Noble, A. D., Kingston, G., Hurney, A., Rudd, A. and Garside, A. (2003). Improving yield and CCS in sugarcane through the application of silicon based amendments. *Final Report, Sugar Research and Development Corporation Project* CLW009.

Bremmer, J. M. and Malvaney, C. S. (1982). Total nitrogen. In: *Methods of Soil Analysis*, Part 2. (Edited by A. L., Miller, R. H. and Keeney, D. R.). American Society of Agronomy. Madison Wisconsin. pp 149 – 157.

CIIFAD (2015). System of Rice Intensification (SRI). International Network and Resources Centre, (SRI-Rice), Cornell International Institute for Food and Agriculture Development (CIIFAD), Cornell University, Ithaca, New York.

[http://sri.ciifad.cornell.edu/aboutsri/methods/index.html] site visited on 21/1/2019.

Datnoff, L. E., Asha, M., Brunings and Rodrigues, F. A. (2005). Silicon effects on components of host resistance: an overview and implications for integrated disease management. *In Proceedings of III silicon in agriculture conference,* 22-26 October 2005, Uberlandia, Brazil. 26-32pp.

Datnoff, L. E., Asha, M., Brunings, P. and Rodrigues, F. A. (2005). Silicon effects on components of host resistance: An overview and implications for integrated disease management. In Proceedings of III silicon in agriculture conference, 22-26 October 2005, Uberlandia, Brazil.26-32.

Dunand, R. and Saichuk, J. (2014). Rice growth and development. In: *Louisiana Rice Production Handbook. 4thedition. Chapter 4.* (Edited by Johnny Saichuk). 41-53pp.

FAO (2008). *Climate change, water and food security. Technical background document from the expert consultation*. Food and Agriculture Organization, Rome, Italy. 18pp.

Gascho, G. J. (2001). Silicon sources for agriculture. In: Datnoff, L.E., Snyder, G.H., Korndorfer, G. H. (Eds.) *Silicon in agriculture.* Elsevier, Amsterdam.197-207pp.

Gee, G. W. and Bauder, J. W. (1986). Particle-size analysis. In: *Methods of Soil Analysis,* Part 1. *Physical and Mineralogical Methods*. Agronomy series No 9. (Edited byKlute, A.), American Society of Agronomy Madison Wisconsin, USA. 383 – 409pp.

Hesse, P. R. (1971). *A Text Book of Soil Chemical Analysis.* John Murray, London. 560pp.

International Rice Research Institute (IRRI) (2007). Growth stages of the rice plant [http://www.knowledgebank.irri.org/ericeproduction/0.2._Growth_stages_of_the_rice_plant.htm] site visited on 8/10/2021.

International Rice Research Institute (IRRI) (2018). Silicon deficiency. *Rice knowledge bank*. [http://www.knowledgebank.irri.org/training/fact-sheets/nutrient-management/deficiencies-and-toxicities-fact sheet/item/silicon-deficiency] site visited on 21/1/2019.

Ismail, A. M., Johnson, D. E., Ella, E. S., Vergara, G. V. and Balthazar, A. M. (2012). Adaptation to flooding during emergence and seedling growth in rice and weeds, and implications for crop establishment. AoB Plants, pls019.

Jawahar, S. and Vaiyapuri, V. (2010). Effect of sulphur and silicon fertilization on growth and yield of rice.Department of Agronomy, Faculty of Agriculture, Annamalai University, Annamalai Nagar-608002, Tamil Nadu, India. *International Journal of Current Research* 2010(9): 036-038pp.

Jinger, D., Devi, M. T., Dhar, S., Dass. A., Rajanna, G. A., Upadhaya, P. and Raj, R. (2017). Silicon in mitigating biotic stresses in rice (*Oryza sativa L.*): A review *Annual Agriculture Research* 38(1): 1-14.

Joseph, E. K. (2009). *Assessing the silicon status of rice* (*Oryza sativa*). Thesis for Award of MSc Degree at Louisiana State University of Agriculture, Mechanical College. 55pp.

Kahimba, F. C., Kombe, E. E. and Mahoo, H. F. (2014). The potential of system of rice intensification to increase rice water productivity: A case of Mkindo irrigation scheme in Morogoro Region, Tanzania. *Tanzania Journal of Agricultural Sciences* 12(2): 10 – 19.

Kangile, R. J., Ng'elenge, H. S. and Busindeli, I. M. (2018). Socio-economic and field performance evaluation of different rice varieties under system of rice intensification in Morogoro, Tanzania. *Agricultural Research and Technology Open Access Journal* 2018: 2471 – 6774.

Katambara, Z., Kahimba, F. C., Mahoo, H. F., Mbungu, W. B., Mhenga, F., Reuben, P., Maugo, M. and Nyarubamba, A. (2013). Adopting the system of rice intensification in Tanzania: A review. *Agricultural Sciences* 4(08): 369 – 375.

Katambara, Z., Mng'ong'o, M., Chambi, C. and Malley, Z. (2016). Characteristics of rice produced under direct and indirect SRI practices in Chimala area in Mbarali District Tanzania. *Journal of Agriculture and Sustainability* 9(01): 15-30.

Kombe, E. E. (2012). *The system of rice intensification as a strategy for adapting to the effects of climate change and variability: A case study of Mkindo irrigation scheme in Morogoro, Tanzania.* Dissertation for Award of MSc Degree at Sokoine University of Agriculture, Morogoro, Tanzania. 76pp.

Landon, J. R. (2014). *Booker Tropical Soil Manual. A hand book for soil survey and agricultural land evaluation in the tropics and subtropics*. Longman Scientific and Technical Publishers, Essex. 474pp.

Liang, Y.C., Sun, W.C., Zhu, Y.G. and Christie, P. (2007). Mechanisms of silicon-mediated alleviation of abiotic stresses in higher plants: A review. *Environmental Pollution* 147: 422-428.

Lindsay, W. L. and Norvell, W. A. (1978). Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of American Journal* 42: 421-428.

Ma, J. F. (2004). Role of silicon in enhancing the resistance of plants to biotic and abiotic stresses. *Soil Science and Plant Nutrition* 50: 11-18.

Ma, J. F. and Takahashi, E. (2002). Silicon uptake and accumulation in higher plants. In: *Soil, fertilizer and plant silicon research in Japan*. Elsevier Science, Amsterdam. The Netherlands 11(8): 50-60.

Ma, J. F. and Yamaji, N. (2008). Functions and transport of silicon in plants. *Cellular and Molecular Life Sciences* 65(19): 3049 – 3057.

Ma, J. F., Tamai, K., Yamaji, N., Mitani, N., Konishi, S., Katsuhara, M., Ishiguro, M., Murata, Y. and Yano, M. (2006).A silicon transporter in rice. *Nature* 440(7084): 688 – 691.

Ma, J. F., Tamai, M., Ichii, M. and Wu, K. (2001). A rice mutant defective in active silicon uptake. *Plant Physiology* 130: 2111-2117.

Ma, J. F., Yamaji, N., Mitani, N., Tamai, K., Konishi, S., Fujiwara, T., Katsuhara, M. andYano, M. (2007).An efflux transporter of silicon in rice. *Nature* 448(7150): 209 – 212.

Mali, M. and Aery, A. N. C. (2008). Silicon effects on nodule growth, dry-matter production, and mineral nutrition of cowpea (*Vignaunguiculata*). *Journal of Plant Nutrition and Soil Science* 171(6): 835 – 840.

Marschner, H. (1995). *Mineral Nutrition of Higher Plants*. *Second Edition*. Academic Press. 899pp.

Massawe, I. H., Rwehumbiza, F. B. and Msanya, B. M. (2017). Effect of water management systems with different nutrient combinations on performance of rice on soils of Mvumi, Kilosa District, Tanzania. *International Journal of Current Research in Biosciences and Plant Biology* 4(2): 34 – 44.

Materu, S. T., Shukla, S., Sishodia, R. P., Tarimo, A. and Tumbo, S. D. (2018). Water use and rice productivity for irrigation management alternatives in Tanzania. *Water* 10(8): 1-15.

Mbaga, H. R. (2015). *Response of rice to nitrogen and phosphorus applied to the dominant soil type at the Dakawa irrigation scheme, Morogoro, Tanzania.* Dissertation for Award of MSc Degree at Sokoine University of Agriculture, Morogoro, Tanzania. 122pp.

Mboyerwa, P. A., Kibret, K., Mtakwa, P. W. and Aschalew, A. (2021). Evaluation of growth, yield, and water productivity of paddy rice with water-saving irrigation and optimization of nitrogen fertilization. *Agronomy* 11(8): 1-22.

McLean, E. O. (Eds) (1982). Soil pH and lime requirement. In: *Methods of Soil Analysis,* Part 2, *Chemical and Mineralogical Properties*. (Edited by Page, A. L., Miller, R. H. and Keeny, D. R.). American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin.199 – 223pp.

Mghase, J. J., Shiwachi, H., Nakasone, K. and Takahashi, H. (2010). Agronomic and socioeconomic constraints to high yield of upland rice in Tanzania. *African Journal of Agricultural Research* 5(2): 150-158.

Ministry of Agriculture, Food Security and Cooperatives (MAFSC) (2009). National rice development strategy final draft. The United Republic of Tanzania. 32pp.

Miyake, Y. (1993). Silica in soils and plants. On the environmental condition and nitrogen source to appearance of silicon deficiency of the tomato plant. *Scientific Reprint of the faculty of Agriculture Okayama University* 81: 27-35.

Msanya, B. M., Kimaro, D. N., Kileo, E. P., Kimbi, G. G. and Mwango, S. B. (2001). Land suitability evaluation for the production of food crops and extensive grazing: a case study of Wami Plains in Morogoro Rural District, Tanzania. Soils and Land Resources of Morogoro Rural and Urban Districts, Volume 1. Department of Soil Science, Faculty of Agriculture, Sokoine University of Agriculture Morogoro Tanzania. 73pp.

Nayar, P. K., Misra, A. K. and Patnaik, S. (1982). Silica in rice (*Oryza sativa L*) and flooded rice soils: Effects of flooding on the extractable silica in soils and its relation with uptake by rice. *Oryza* 19: 34-42.

Nelson, D. W. and Sommers, L. E. (1982).Total organic carbon. In: *Methods of Soil Analysis*, Part 2. *Chemical and Microbiological Properties* (Edited by Page, A. L., Miller, R. H. and Keeney, D. H.). American Society of Agronomy. Madison Wisconsin. 539-579pp.

Oikeh, S. O., Nwilene, F. E., Agunbiade, T. A., Oladimeji, O., Ajayi, O., Semon, M., Tsunematsu, H. and Samejima, H. (2008). *Growing Upland Rice: a Production Handbook*, Africa Rice Center (WARDA), Cotonou, Benin. 44pp.

Paye, W. S. (2016). *Silicon fertilization in rice: Establishment of critical silicon level and its impact on availability of nutrients in soils of Louisiana*. Thesis for Award of MSc Degree at Louisiana State University (Liberia). 97pp.

Pereira, H. S., Korndörfer, G. H., Vidal, A. A. and Camargo, M. S. (2004). Silicon sources for rice crop. *Science Agriculture* 61(5): 522-528.

Rajamani, K. (2012). *Effect of silica on rice* (*Oryza Sativa L.*) *yield and its uptake under different levels of nitrogen application.* Thesis for Award of PhD Degree at Acharya N. G. Ranga Agricultural University. 242pp.

Rao, B. G., Yadav, P. I. and Syriac, E. K. (2017). Silicon nutrition in rice: A review. *Journal of Pharmacognosy and Phytochemistry* 6(6): 390 – 392.

Raven, J. A. (2001). Silicon transport at the cell and tissue level. In:Datnoff, L. E., Snyder, G. H. and Korndorfer, G. H. (eds.) - *Studies in plant science, 8: Silicon in agriculture*. Elsevier Science, Amsterdam, the Netherlands. 41–55pp.

Reuben, P., Katambara, Z., Kahimba, F. C., Mahoo, H. F., Mbungu, W. B., Mhenga, F., Nyarubamba, A. and Maugo, M. (2016). Influence of transplanting age on paddy yield under the system of rice intensification. *Agricultural Sciences* 7: 154 – 163.

Rhoades, J. D. (1996). Salinity: Electrical conductivity and total dissolved solids. In: *Methods of Soil Analysis* 3: 417 – 435.

Ricepedia. (2015). *The online authority on rice*. [http://ricepedia.org/rice-as-a-plant/growth-phases] site visited on 10/06/2020.

Rubinos, R. G., Jalipa, A. T. and Bayacag, P. (2007). Comparative economic study of organic and conventional rice farming in Magsaysay, Davao Delsur.10th National Convention on Statistics, EDSA Shangri-La Hotel, Davao City. 17pp.

Sahebi, M., Hanafi, M. M., Akmar, A. S. N., Rafii, M. Y., Azizi, P., Tengoua, F. F. and Azwa, J. N. M. (2015).Importance of silicon and mechanisms of biosilica formation in plants. *Bio Med Research International* 2015: 1-16.

Savant, N. K., Datnoff, L. E. and Snyder, G. H. (1997). Depletion of plant available silicon in soils: A possible cause of declining rice yields. *Communication in Soil Science and Plant Analysis* 28: 1245 - 1252.

Shio, K. (1996). Phosphorus. In: *Methods of Soil Analysis,* Part 3.*Chemical Methods of Soil Analysis*. *Soil Science Society of America. Book Series* 5: 864 – 920.

Shivay, Y. S. and Dinesh, K. (2009). Importance and management of silicon deficiency in rice. *Indian Farming* 58(5): 34-36.

Stoop, A. W., Uphoff, N. and Kassam, A. (2002). A review of agricultural research issues raised by the system of rice intensification (SRI) from Madagascar: Opportunities for improving farming systems for resource-poor farmers. *Agricultural Systems* 71(3): 249-274.

Sudhakar, P. C., Singh, J. P., Singh, Y. and Singh, R. (2006). Effect of graded fertility levels and silicon sources on crop yield, uptake and nutrient-use efficiency in rice (*Oryza sativa* L.). *Indian Journal of Agronomy* 51(3): 186 – 188.

Sumner, M. E. and Miller, W. P. (1996). Cation exchange capacity. In: *Methods of Soil Analysis.* Part 3, *Chemical Methods*. *Soil Science Society of America* 5: 475 – 490.

Tamai, K. and Ma, J. F. (2003). Characterization of silicon uptake by rice roots. *New Phytologist* 158(3): 431 – 436.

Tubana, B. S., Babu, T. and Datnoff, L. E. (2016). A review of silicon in soils and plants and its role in US agriculture: history and future perspectives. *Soil Science* 181(9/10): 393-411.

United Republic of Tanzania (URT) (2009). *The National Irrigation Policy.* Ministry of Water and Irrigation, Dar es Salaam, Tanzania. 55pp.

United States Department of Agriculture (USDA) (1975). Soil taxonomy. *A Basic System of Soil Classification for Making and Interpreting Soil Surveys.* Soil survey staff, soil Conservation Service, Washington DC. 754pp.

Uphoff, N. (2007). The system of rice intensification: using alternative cultural practices to increase rice production and profitability from existing yield potentials. *International Rice Commission Newsletter*, Number 55, UN. Food and Agriculture Organization, Rome. 11pp.

Uphoff, N. (2015). The system of rice intensification (SRI). *Responses to frequently asked questions*. SRI-RICE, Cornell University, Ithaca, New York 14853, USA. First Edition. 224pp.

Wilson, R. T. and Lewis, I. (2015). *The Rice Value Chain in Tanzania, a Report from the Southern Highlands. Food Systems Programme.* Food and Agriculture Organization of the United Nations, Rome, Italy. 15pp.

Yamaji, N., Sakurai, G., Mitani-Ueno, N. and Ma, J. F. (2015). Orchestration of three transporters and distinct vascular structures in node for intervascular transfer of silicon in rice. *Proceedings of the National Academy of Sciences* 112(36): 11401 – 11406.

Yao, M., Wang, D. and Zhao, M. (2015). Element Analysis Based on Energy-Dispersive X-ray Fluorescence. *Advances in Materials Science and Engineering* 2015: 1-8.

Zhu, Z., Wei, G., Li, J., Qian, Q. and Yu, J. (2004). Silicon alleviates salt stress and increases antioxidant enzymes activity in leaves of salt-stressed cucumber (*Cucumissativus* L.). *Plant Science* 167(3): 527 – 533.

PUBLICATIONS

From this study two papers have been submitted to Tanzania Journal of Agricultural Sciences for publication. One paper has been published and the other has been accepted for publication.

Title for the published paper:

Comparison of Silicon Status in Rice Grown Under the System of Rice Intensification and Flooding Regime in Mkindo Irrigation Scheme, Morogoro, Tanzania

G. E. Gowele*[1], H. F. Mahoo[1] and F. C. Kahimba[2]

https://www.ajol.info › index.php › tjags › article › view

Title for the paper accepted for publication:

Silicon uptake and its effect on growth and yield of rice under the system of rice intensification and continuous flooding in Mkindo Irrigation Scheme, Morogoro, Tanzania

G. E. Gowele*[1], H. F. Mahoo[1] and F. C. Kahimba[2]

APPENDICES

Appendix 1: Weather data of Mkindo Irrigation Scheme collected at Mtibwa Sugar Meteorological Station year 1999-2019

a) Rainfall data

Year	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	TOTAL
1999	82.3	45.3	304.9	325.5	77.7	45.5	38.1	52.7	40.5	12.7	54.6	120.3	1 200.10
2000	51.3	40.9	177.5	297.2	66.8	43.4	12.2	27.2	11.6	4.4	152.6	184.8	1 069.70
2001	193.5	143.1	196.6	293.6	148.9	27.2	12.4	1.7	4.5	9.2	5.8	21.3	1 157.70
2002	112.1	82.6	277.4	372	51.4	0.9	14.6	40.4	53.4	110.6	59.3	107.4	1 281.90
2003	159.9	88.5	94.1	137.9	105.3	18.1	13	10.7	33.5	27.1	7.4	59.9	755.2
2004	186.6	87.5	167.8	250	9.6	24.7	1.5	4.6	3	76.2	98.2	220.7	1 130.30
2005	65.3	79.9	226.7	216.2	128.4	26.1	2.3	29.2	10.7	3.8	49.6	6.4	844.4
2006	81.4	59.5	207	326.1	106.5	62.6	25.4	25.7	65.3	58.4	176.6	234	1 428.40
2007	124	95	229.8	230.6	176.2	57.3	6.4	45.4	6.3	35.8	112.8	34	1 153.40
2008	18	198.4	191.5	315	64.2	22.5	15.4	6.6	22.2	29.9	141.1	45.7	1 070.40
2009	25.7	153.5	190	176	101	31	6.6	4	0.2	64.1	122.1	87.1	961.3
2010	162.9	82.9	115.7	157.6	128.7	2.1	0.4	4.3	10.4	3	28.8	72.3	769
2011	127.5	59.1	210.7	219.5	100.9	13.4	1	1.9	23.6	57.6	66	296.2	1 177.40
2012	101.2	97.5	146.3	87.3	124.3	7	0.2	21	4.7	1.3	75.2	73.3	739.4
2013	21.5	14.4	167.7	228.2	61.2	5.8	2.4	13.4	11.2	78	64.6	48	716.5
2014	120	162	342.5	216.8	103.5	22.5	6.6	10.1	46.8	19.5	115.1	153.7	1 319.10
2015	117.1	9	178.7	294.3	139.7	-	31.8	15.2	-	26.8	121.4	83.8	1 017.80
2016	119.6	90.7	190.5	466.2	46.5	33.2	5	-	13	3	9.1	53.7	1 030.50
2017	118.2	84.3	393.3	309.9	227.4	68.5	-	16.7	26.1	98.8	103.8	56.5	1 503.50
2018	126	48	298	188	118	19	12	4	28	13.3	37	87.7	979
2019	130.3	24.9	64.9	147.7	278.6	2.2	1.5	42.4	2.4	371.4	203	288.9	1 558.20
Average	**106.9**	**83.2**	**208.2**	**250.3**	**112.6**	**25.4**	**9.9**	**18**	**19.9**	**52.6**	**85.9**	**116**	**1 088.70**

b) Data for average monthly minimum and maximum temperature of Mkindo Irrigation Scheme collected at Mtibwa Sugar Meteorological Station from year 1999-2019

	January		February		March		April		May		June		July		August		September		October		November		December	
Year	**Max**	**min**	**Max**	**min**	**Max**	**min**	**Max**	**min**	**Max**	**min**	**Max**	**Min**	**Max**	**min**	**Max**	**min**	**Max**	**min**	**Max**	**min**	**Max**	**min**	**Max**	**min**
1999	34.1	20.9	35	20.4	32.2	21.2	29.3	19.9	28.6	19.3	26.6	16.8	26.6	16.1	26.9	17.3	29	17.2	31	19.3	32.7	19.5	31.8	19.3
2000	34.3	20.3	35.1	19.4	32	20.6	30.1	20.1	28.7	19.2	27.9	17.6	27.8	15.9	28.6	17.4	30.4	17.6	32.9	18	33.6	21.9	31.8	22
2001	30.8	21.9	35.1	22.3	32.3	22.9	30.3	22.7	28.9	22.1	27.6	20.4	27	19.3	28.8	19.3	30.7	21	32.5	22.4	34.6	23.8	34.7	25.2
2002	32.8	25.1	35.1	24.6	32	25.2	31.8	25	29.9	23.2	28.4	16.3	28.9	16.5	28.2	17.9	29.6	18.3	31.1	19.8	32.3	20.4	34.1	21.2
2003	33.1	21	35.1	21.1	35.3	21.6	31.8	21.6	29.9	20.3	28.6	18.6	28	17.2	29.2	16.5	30.4	18.5	31.6	19.2	35	21.1	35.4	21.5
2004	34	21.8	35.1	21.2	31.7	21.7	30.4	20.7	29.7	18.9	28.6	17	29	16.3	29.8	17	31.3	18.5	32.1	20	32.3	20.5	32.4	20.8
2005	34.1	20.8	35.1	21.2	32.6	21.1	31	21.3	29.5	19.2	28.3	18.5	28.4	17	29.1	17.2	30.8	17.6	32.6	18.3	34	20.3	35.8	21.2
2006	35.2	21.2	35.1	21.1	32.1	20.6	30.3	20.1	29.3	19.3	28	16.8	27.7	15.8	28.4	16.7	29.8	17.7	30.5	19	30.7	20	31.1	20.4
2007	32.2	20.6	35.1	19.9	32.1	19.6	31	20.2	29.4	19.5	28.4	16.2	34.6	16.5	29	16.7	31.3	17.1	32.6	18.2	32.9	19.3	34	19.6
2008	35.5	20.4	35.1	19.7	32.8	20.6	28.7	19.7	28.7	18.7	27.9	16.4	28	15.9	29	17	31.2	16.4	33.1	18.6	34.4	19.7	34	20.6
2009	35.8	20.4	35.1	20.1	33.2	20.5	30.2	20.5	29.4	19.4	29.6	18.7	28.5	16.1	29.2	17.6	31.3	17.3	32.5	19.3	32.4	19.9	33.8	20.9
2010	32.6	20.5	35.1	21.2	34.1	21.3	31.3	21.1	29.8	19.5	29.1	17.9	29.6	16.7	29.6	16.3	30.8	16.6	34	18.2	34.6	19.7	34.7	20.1
2011	34	20	35.1	20.1	33.4	20	31	19.9	29.2	19.1	28.7	17.5	28.8	15.2	29.6	16.4	30.9	16.8	31.4	18.4	32.8	19.6	33.2	19.4
2012	32.3	19.4	35.1	19.2	32.1	19.2	30.8	19.1	29.5	18.1	29	16.4	29.1	15.3	30	16.1	31.8	17.1	33	18.1	33.1	19.6	34	19.7
2013	34.4	20.5	35.1	19.9	33.2	20.3	30.6	19.8	29.3	18.2	29.2	16.5	29.5	15.2	29.1	15.8	31.9	16.6	31.7	17.5	33.6	19	34.7	19.2
2014	36	20.4	35.1	19.1	31.5	19.4	29.7	18.5	28.7	17.8	28.4	16.7	28.7	15.4	29.6	15.9	29.5	16.1	32.7	17.8	32.6	18.2	33	18.5
2015	33.1	18.9	35.1	19.1	33.2	19	31.6	19.1	28.9	18.1	29.1	14.6	28.7	14.9	29.7	15.4	31.8	15.6	33	17.8	32.4	18.7	34.2	18.8
2016	33.5	19.2	35.1	19.3	35.1	19.8	30.5	18.5	29.7	16.2	29.1	14.1	29.3	13	30.4	14.5	30.8	14.6	33.1	15.7	34	17.8	35.7	18.5
2017	36.1	19.1	35.1	17	32.8	18.5	29	17.6	28.3	16.9	27.8	14.8	29.1	14.2	29.5	15	29.3	15.1	32.4	16.4	30.9	16.5	34.4	17.9
2018	31.5	17.2	35.1	17.7	31.3	17.1	30.2	17.2	29.3	16.6	29.4	15.1	28.9	14.3	30.2	14	31.9	15	31.9	32.4	17	17.7	34.4	17.4
2019	34	18	35.1	18	35.6	18	33.3	18.6	27.2	12.5	28.7	13.6	27.5	14.1	30.6	15	31.9	15.1	30.2	16.5	31.8	16.8	31.5	17.2
Average	**33.8**	**20.4**	**35.1**	**20.1**	**32.9**	**20.4**	**30.6**	**20.1**	**29.1**	**18.7**	**28.5**	**16.7**	**28.7**	**15.8**	**29.3**	**16.4**	**30.8**	**16.9**	**32.2**	**19.1**	**32.3**	**19.5**	**33.7**	**20**

c) Average Weather data at Mkindo Village collected at Mtibwa Sugar Meteorological Station year 1999-2019

Month	Average rainfall (mm)	Max temp (^{0}C)	Min temp (^{0}C)
January	106.9	33.8	20.4
February	83.2	35.1	20.1
March	208.2	32.9	20.4
April	250.3	30.6	20.1
May	112.6	29.1	18.7
June	25.4	28.5	16.7
July	9.9	28.7	15.8
August	18.0	29.3	16.4
September	19.9	30.8	16.9
October	52.6	32.2	19.1
November	85.9	32.3	19.5
December	116	33.7	20.0

Appendix 2: Si content (mg kg^{-1}) in soils of the experimental site at various rice growth stages

REP	Season	Treatments	Si content vegetative stage	Average Si content vegetative stage	Si content reproductive stage	Average Si content reproductive stage	Si content ripening stage	Average Si content ripening stage
1	S1	T_1	137	148	229	231	244	248
2	S1	T_1	143		231		245	
3	S1	T_1	164		234		247	
1	S1	T_2	103	101	218	221	232	233
2	S1	T_2	91		227		234	
3	S1	T_2	109		219		234	
1	S2	T_1	170	183	227	229	237	240
2	S2	T_1	184		229		238	
3	S2	T_1	196		231		244	
1	S2	T_2	110	133	216	217	225	229
2	S2	T_2	146		223		229	
3	S2	T_2	143		213		233	

T_1: Treatment 1 using SRI technologies and T_2: Treatment 2; continuous flooding

Treatments	Si content vegetative stage	Si content reproductive stage	Si content ripening stage
T_1	150.82a	230.70a	242.50a
T_2	120.93b	219.80b	231.20b
SE±	0.349	0.1399	0.0694
p-value	0.001	0.002	<.001
LSD (0.05)	1.209	0.4843	0.2401

Appendix 3: Statistical results for Si content (mg kg^{-1}) in soils of the experimental site at different rice growth stages

Different letters within a column means significant difference ($p < 0.05$)
T_1: Treatment 1 using SRI technology and T_2: Treatment 2 under continuous flooding

Appendix 4: Si content in rice seeds and grains at different growth stages

REP	Season	Treatments	Si content (%) start	Si content (%) reproductive stage	Average Si content (%) reproductive stage	Si content (%) ripening stage	Average Si content (%) ripening stage
1	S1	T_1	6.76	12.1	12.7	8.09	8.78
2	S1	T_1		12.8		8.39	
3	S1	T_1		13.3		9.86	
1	S1	T_2		7.59	9.45	6.24	7.1
2	S1	T_2		9.86		7.13	
3	S1	T_2		10.9		7.93	
1	S2	T_1		13.3	13.7	7.83	8.6
2	S2	T_1		13.9		8.28	
3	S2	T_1		13.9		9.83	
1	S2	T_2		8.23	10.1	6.73	7.1
2	S2	T_2		10.6		6.97	
3	S2	T_2		11.6		7.73	

T_1: Treatment 1 using SRI technologies and T_2: Treatment 2; continuous flooding

Appendix 3: Statistical results for Si content in rice grains at various growth stages

Treatments	**Si content (%) reproductive stage**	**Si content (%) ripening stage**
T1	13.2a	8.7a
T2	9.8b	6.5b
SE±	0.3	0.5
p-value	<0.001	0.022
LSD $_{(0.05)}$	1.0	1.8

Different letters within a column means significant difference ($p < 0.05$)
T_1: Treatment 1 using SRI technology and T_2: Treatment 2 under continuous flooding

Appendix 5: **Si content in rice plant leaves at different growth stages**

REP	Season	Treatments	Si content (%) vegetative stage	Average Si content (%) vegetative stage	Si content (%) reproductive stage	Average Si content (%) reproductive stage	Si content (%) ripening stage	Average Si content (%) ripening stage
1	S1	T_1	8.2	8.2	9.48	10.2	11.3	12.2
2	S1	T_1	7.35		10.4		12.5	
3	S1	T_1	8.99		10.6		12.8	
1	S1	T_2	4.68	5.9	6.81	7.5	10.3	10.7
2	S1	T_2	6.85		7.01		10.6	
3	S1	T_2	6.06		8.79		11.1	
1	S2	T_1	8.07	8.6	9.54	10.4	11.3	12.5
2	S2	T_1	8.92		9.87		13.1	
3	S2	T_1	8.74		11.7		13.2	
1	S2	T_2	6.85	7.3	6.98	7.5	8.46	9.6
2	S2	T_2	7.15		7.11		9.02	
3	S2	T_2	7.99		8.51		11.4	

T_1: Treatment 1 using SRI technologies and T_2: Treatment 2; continuous flooding

Appendix 6: Statistical results for Si content in rice plant leaves at different growth stages

Treatments	Si content (%) vegetative stage	Si content (%) reproductive stage	Si content (%) ripening stage
T1	8.38a	10.27a	12.37a
T2	6.6b	7.54b	10.15b
SE±	0.281	0.16	0.256
p-value	0.004	<.001	<.001
LSD $_{(0.05)}$	0.972	0.555	0.886

Different letters within a column means significant difference ($p < 0.05$)

T_1: Treatment 1 using SRI technologies and T_2: Treatment 2; continuous flooding

Appendix 7: Data for growth and yield parameters of rice under SRI and continuous flooding at various rice growth stages

REP	Season	Treatments	stage	Plant height (cm)	Number of tillers/hill	Stage	Plant height (cm)	Number of tillers/hill	Stage	Plant height (cm)	Number of tillers/hill	Number of productive tillers/hill	Number of panicles/hill	Grain yield (tons/ha)
1	S1	T1	vegetative	103.2	47.3	Reproductive	148.3	53.3	Ripening	150.3	54.3	42.7	30.0	7.3
1	S1	T2		98.8	19.0		126.7	24.3		127.5	24.3	19.7	27.7	3.0
1	S2	T1		101.7	35.0		112.7	38.7		136.0	47.0	39.3	27.7	5.0
1	S2	T2		71.0	12.7		83.7	20.7		114.0	21.7	17.3	25.0	1.7
2	S1	T1		109.2	40.7		153.8	54.7		153.2	56.7	50.3	32.0	10.0
2	S1	T2		101.0	27.7		129.7	29.3		133.3	29.3	23.7	29.0	4.3
2	S2	T1		89.3	33.0		119.7	50.7		139.7	52.7	44.3	29.0	6.3
2	S2	T2		77.0	23.0		108.7	27.3		125.7	28.7	22.7	26.3	2.7

3	S1	T1	104.7	48.7	158.5	56.3	160.3	59.0	51.3	34.3	10.7
3	S1	T2	100.8	25.3	130.5	28.3	143.2	27.7	21.7	30.3	5.3
3	S2	T1	93.3	37.0	119.7	50.7	139.3	54.7	48.7	30.3	8.3
3	S2	T2	85.0	22.3	106.7	25.0	129.7	27.7	24.0	25.7	3.7

Appendix 8: **Statistical results for growth and yield parameters of rice under SRI and continuous flooding**

Treatments	**Plant height (cm)**	**Number of tillers/hill**	**Number of productive tillers/hill**	**Number of panicles/hill**	**Grain yield (tons/ha)**
T1	147a	54a	46a	31a	8a
T2	129b	27b	22b	27b	3b
SE±	2.49	1.34	1.56	0.57	0.57
p-value	<.001	<.001	<.001	0.003	<.001
***LSD** $_{(0.05)}$*	7.98	4.28	5	1.82	1.83

Different letters within a column means significant difference ($p< 0.05$)

T_1: Treatment 1 using SRI technology and T_2: Treatment 2 under continuous flooding