EFFECTS OF INTEGRATING DEFICIT IRRIGATION AND CARBONATE FOLIAR FERTILIZER APPLICATION INTO THE SYSTEM OF RICE INTENSIFICATION

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A DISSERTATION SUBMITED 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.

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EXTENDED ABSTRACT

Introduction

Rice plays a key role in food availability and the economy of Tanzania. However, the rice yield gap of over 87% indicates that there are challenges of inadequate management practices for enhancing its production. In literature, there are recommendations on the use of the System of Rice Intensification (SRI) as one of the means to enhance rice yield by improving water productivity. Further, deficit irrigation is profound in increasing water productivity while having minimal or no impact on yield. Other studies have emphasized the use of the conventional fertilizers, while recent developments have recommended the use of foliar fertilizers at the various growth stages in order to enhance rice productivity. Individually, deficit irrigation, SRI and foliar fertilizer application have proved to be effective in enhancing rice yield and water productivity. However, the information on their combined effects is limitedly known. Therefore, a study was conducted to assess the effects of integrating deficit irrigation and carbonate foliar fertilizer (Lithovit) application into the System of Rice Intensification (SRI) on rice growth, yield and water productivity in addition to economic implications.

Methodology

This study was conducted in Mkindo Irrigation scheme in Mvomero, Morogoro, Tanzania during the dry and wet season (October 2020 to June 2021). The experiment was laid out in a split plot design with three levels of irrigation for main plots which were 100% of the irrigation water requirement (40mm) imitating the SRI alternate wetting and drying pattern and induced deficit irrigation applied at 80% and 50% of the irrigation water requirement as IR_{100}, IR_{80} and IR_{50}, respectively. Irrigation was carried out at the appearance of soil cracks in IR_{100}. The sub-plot fertilizer treatments were five in number namely: (A) Diammonium Phosphate (DAP) and Urea (normal practice), (B) DAP, Urea and 100% of recommended foliar fertilizer (Lithovit Standard), (C) DAP and 50% (Lithovit and Urea), (D) Lithovit Standard only and (E) no fertilizer. The combined irrigation and fertilizer treatments tested were $IR_{100}A$, $IR_{100}B$, $IR_{100}C$, $IR_{100}D$, $IR_{100}E$, $IR_{80}A$, $IR_{80}B$, $IR_{80}C$, $IR_{80}D$, $IR_{80}E$, $IR_{50}A$, $IR_{50}B$, $IR_{50}C$, $IR_{50}D$, and $IR_{50}E$. The data was analyzed using IBM SPSS version 20 at 5% probability level and mean separation done using Duncan’s multiple range test.

Results and discussion

The integration of deficit irrigation and carbonate foliar fertilizer application into SRI enhanced rice growth, yield and water productivity in addition to increasing benefit cost ratio (BCR). Treatment IR_{80} had the best overall performance followed by IR_{100} and $IR_{50.}$ However, there was no significant difference among the water applications IR_{100}, IR_{80} and IR_{50} for all growth and yield attributes due to disruption of water regimes by heavy rainfall in both seasons. Fertilizer treatment B had the highest yield followed by A, C and D while E had the least. It was found that, $IR_{100}B$ attained the highest yield of 11.10 t/ha followed by $IR_{80}B$ (10.90t/ha) and ($IR_{50}B$ and $IR_{100}A$) with 9.40 t/ha for the dry season. For the wet season, $IR_{80}B$ (6.93 t/ha) had the highest yield followed by $IR_{50}B$ (6.68 t/ha) and $IR_{100}B$ (6.6 t/ha). The least yield was attained by $IR_{50}E$ with 7.10 and 3.78 t/ha for the dry and wet seasons respectively. The foliar treatments (C and D) performed as good as the conventional fertilizer treatment A due to the impact of the calcium carbonate foliar fertilizers. Lithovit supplies higher concentrations of carbon dioxide than in the atmosphere especially during water stress periods thereby aiding photosynthesis hence increasing crop growth and yield.

Treatment B had the highest water productivity (WP) followed by A, C, D and E. The highest and lowest WP was 0.851 kg/m^3 and 0.562 kg/m^3 attained by $IR_{80}B$ and $IR_{80}E$ respectively for the dry season. For the wet season, the highest and lowest WP was attained by $IR_{50}B$ (0.540 kg/m^3) and $IR_{50}E$ (0.306 kg/m^3). The high WP is attributed to the impact of alternate wetting and drying practice under SRI that heavily cuts down on unproductive water losses. In addition, Lithovit foliar fertilizer that acts as a long term reservoir for carbon dioxide especially during water stress periods played a key role on yield enhancement of foliar treatments. Across water regimes, the highest benefit-cost ratio (BCR) for the dry and wet seasons was 2.81 and 1.67 respectively attained by IR_{100}. Among fertilizer treatments, the highest BCR was attained by D (3.45) and C (1.74) for the dry and wet seasons respectively. Treatment A had the least BCR of 1.96 and 1.06 for the dry and wet season respectively. Combination $IR_{100}D$ had the highest BCR of 3.82 and 2.08 for the dry and wet season respectively. All BCR >1 except $IR_{80}A$ and $IR_{50}A$ each with a BCR of 0.97. For all growth, yield, water productivity and BCR, the dry season performed better than the wet season.

Conclusion

The integration of deficit irrigation and carbonate foliar fertilizers into SRI enhanced growth, yield, water productivity and BCR. Among water regimes, IR_{80} had the best overall performance. Also, the combination of foliar and basal fertilizers had the best overall growth, yield and WP performance. Foliar treatments also performed as good as the conventional basal practice due to the impact of calcium carbonate fertilizers which enhanced production following the good yield attained. In terms of BCR, foliar treatments had the best performance. Generally, the dry season performed better than the wet season for all growth, yield and water productivity attributes due to the low temperatures in the wet season that affected crop growth and development. Therefore, incorporating deficit irrigation and carbonate foliar fertilizers into SRI farming practices is capable of enhancing growth, yield and water productivity.

DECLARATION

I **ASERU GLORIA**, 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 before nor being concurrently submitted to any other institution.

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DEDICATION

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ABBREVIATIONS AND SYMBOLS

Al	Aluminium
Ca	Calcium
$CaCO_3$	Calcium carbonate
CaO	Calcium oxide
CO_2	Carbondioxide
DAT	Days after Transplanting
D_p	Deep percolation
ET	Evapotranspiration
FAO	Food and Agriculture Organization
Fe	Iron
IRRI	International Rice Research Institute
IWMI	International Water Management Institute
K	Potassium
Mg	Magnesium
MgO	Magnesium oxide
Mn	Manganese
MSE	Mean Standard Error
N	Nitrogen
OC	Organic Carbon
P	Phosphorus
r	Pearson’s correlation coefficient
R^2	Coefficient of determination
S	Sulphur
S.D	Standard Deviation
s.e	Standard error
SRI	System of Rice Intensification
t/ha	Tonnes per hectare
TRT	Treatment
UN	United Nations
USDA	United States Department of Agriculture
WAP	Water application
WP	Water productivity
WRI	World Resources Institute

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

1.1.1 General Introduction

Globally, about 26% of the population (2 billion) lack regular access to safe, nutritious and sufficient food (Food and Agriculture Organization (FAO) *et al.*, 2019). According to United States Department of Agriculture (USDA) (2019), the global population of food insecure people is expected to fall from 19.3 to 9.2% between 2019 and 2029. On the contrary, Sub-Saharan Africa (SSA) is predicted to be the epicenter of global food insecurity by 2029 with 22.5% of its population being food insecure (USDA, 2019). This calls for more food production to meet this global target while curbing the aggravating situation of SSA. Rice, wheat and maize are the three most essential cereals critical for the daily survival of a vast population globally (FAO, 2016). According to FAO (2016), daily consumption of cereals is expected to have increased by 390 million tonnes between 2014 and 2024. By 2050, annual demand for rice, wheat and maize is predicted to reach 3.3 billion tonnes (FAO, 2016).

Rice (*Oryza sativa L*) is the primary staple food for over half of the world's population (FAO, 2013) while sustaining livelihoods of more than 100 million people in Sub-Saharan Africa (SSA). Globally, rice ranks third after wheat and maize in terms of production (FAOSTAT, 2014) with a daily consumption of more than three billion people (Global Rice Science Partnership (GRiSP), 2013). Nearly 11% of the world's cultivated land is occupied by rice covering an area of about 158 million hectares with over 527 million tonnes as annual production (Raut *et al.*, 2019). Rice also contributes about 21% of human's calorific energy and about 14% of their dietary protein (International Rice Research Institute (IRRI), 2019). As the world population is projected to increase to 8.27 billion in 2030 (United Nations (UN), 2015), correspondingly, there will be increase in rice demand. The global rice demand is projected to increase from 439 - 555 million tonnes (milled rice) between 2010 and 2035 (GRiSP, 2013). Other studies such as Shamshiri *et al.* (2018); Dinesh *et al.* (2019); Raut *et al.* (2019) are all in agreement concerning increased rice production following the increase in rice demand.

In Tanzania, rice is the third most important food crop after maize and cassava consumed by about 30% of the households (FAO, 2015). Also, about 20% of farmers are involved in rice production (Mtaki, 2018) with 80% of these being small scale farmers (Katambara *et al.,* 2016). Tanzania is also the lead rice producer in Eastern and Southern Africa while accounting for about 9% of the total 30.8 million tonnes of African rice production (FAOSTAT, 2014). However, the rice yield gap for Tanzania is over 87% (Senthilkumar *et al.*, 2018). This is attributed to the generally low rice yields ranging from 1.1 t/ha under rainfed lowland conditions to 3.5 t/ha under irrigated conditions (System of Rice Intensification-Rice (SRI-Rice), 2020) which is below the world's average yield of 4.31 t/ha (FAO, 2015). Despite its central role in food security and economic development, rice production in Tanzania is faced with a number of constraints such as low rice yielding varieties, weed infestation, prevalence of pests and diseases with water scarcity and poor/low fertilizer application being of major concern.

About 80% of the available water supply globally is withdrawn for agriculture, industries and urban areas (World Resources Institute (WRI), 2019) with agriculture taking the biggest share (70%) (World Bank, 2020). However, water scarcity is still among the major challenges facing rice production (Abdellatif, 2018). Nearly 25% of the world's population is facing water crisis (WRI, 2019) and about 52% of the world's projected 10 billion people are expected to live in water stressed areas by 2050 (Massachusetts Institute of Technology (MIT), 2014). This is majorly attributed to increased population and socio-economic development exacerbated by climate change (WRI, 2019). Rice production is also considered most eco- unfriendly (Uphoff and Dazzo, 2016). This is attributed to the fact that rice requires about 50% of the available fresh water resources (Badawi *et al*., 2013) compared to other sectors (Uphoff and Dazzo, 2016). Field water use for rice is about 2500 mm (Bouman, 2009) which is two to three times higher than other cereals (Materu *et al.,* 2018). It is predicted that of the World's 79 million hectares of irrigated rice lowlands (which provide three quarters of the World's rice supply), about 15-20 million are expected to suffer water scarcity by 2025 (International Water Management Institute (IWMI), 2008).

The biggest part of Tanzania is semi-arid with erratic rains (Kihupi *et al*., 2015) yet over 90% of rice grown in Tanzania is under continuous flooding (Kangile *et al*., 2018). Deficit irrigation, the practice of supplying less water than is required for optimal crop growth is considered as one of the measures that could be undertaken to ensure optimal water utilization while maximizing production (Materu *et al.,* 2018; Sahoo and Verma, 2019). Therefore yield reduction under deficit irrigation is deemed insignificant compared to the benefits attained (Materu *et al.,* 2018; Shammout *et al.,* 2018). Alternate wetting and drying (AWD) practice is among the agronomic practices carried out under the system of rice intensification (SRI). SRI has been found essential in optimizing water for production (Dahiru, 2018; Shamshiri *et al.,* 2018; Dinesh *et al.,* 2019; Sahoo and Verma, 2019) which implies more yield per water applied. SRI practice has also been reported to increase yields ranging from 6-8 tonnes per hectare (t/ha) while saving water up to 25% (Katambara *et al.,* 2013; Materu *et al.,* 2018). According to Tuong and Bouman (2009), a 10% reduction in water used in irrigated rice would avail 150 000 million metric cubics of water for other non-agricultural activities. Therefore, increasing water productivity is a right step in the direction of addressing water scarcity.

In order to achieve more production per unit area, fertilization is an essential practice in crop production (Hashem, 2019; Gowele *et al.,* 2020). Moreover, micronutrients are also very essential in the production of rice (Khan and Iqbal, 2018; Gowele *et al.,* 2020). However, the use of low or excess amount of fertilizers compromises the soil quality and crop yield in addition to high production costs (Raut *et al.,* 2019). In addition, the methods of fertilizer application have a significant impact on the growth and yield attributes (Raut *et al*., 2019). Foliar application, the technique of spraying liquid fertilizers (macro or micro nutrients) directly onto the leaves of crops is considered key in attaining maximum and quality yields (Khalil and Hussein, 2015; Jakab-gábor and Komarek, 2017; Buczek, 2017; Kaleri *et al.,* 2019; Kumar and Nagesh, 2019; Aljutheri *et al.,* 2020) while alleviating inhibition due to water stress (Badawi *et al.,* 2013). While deficit irrigation, SRI and foliar fertilization have proved to be effective in enhancing rice production, their integration effects on growth, yield and water productivity of rice is limitedly known.

1.1.2 Rice cultivation under deficit irrigation

Rice cultivation is the highest water user accounting for about 50% of total water usage in Agriculture (Badawi *et al*., 2013). Therefore, the call for improved water productivity in rice production has increased. Deficit irrigation is fast becoming one of the approaches being adopted in both arid and semi-arid Regions (Mulu and Alamirew, 2018). Deficit irrigation is deemed profound in increasing water productivity of rice while reducing water losses (Materu *et al.*, 2018). This involves inducing marginal stress save for critical growth stages. A critical phase is one where water stress causes comparatively greater reduction in yield. When it comes to rice, the critical growth stages include tillering, panicle initiation, heading and flowering. Favourable water supply at earlier or later stages cannot compensate the loss at these stages therefore water must be at saturation level. Since deficit irrigation affects growth and yield of rice, it is imperative to identify the extent of deficit irrigation that can be applied without causing major losses to crop yield.

Badawi *et al*. (2013) cautioned that in order to obtain considerable grain and straw yields, water deficit at both panicle and heading stages should be avoided. Rice is not considered an aquatic crop (Isnawan *et al.*, 2020) therefore its growth is not hampered when exposed to limited water especially during the vegetative stage (Uphoff, 2014). Ndayitegeye *et al*. (2020) stated that deficit irrigation coupled with irrigation intervals could be an essential method of saving water without affecting vegetative growth while having no significant impact on yield. Dolatabadian *et al.* (2010) reported that final yield was more affected when plants were stressed at reproductive phase than vegetative phase. Intermittent drying also stimulates tiller growth while improving soil (Dahiru, 2018). Basha and Sarma (2017) emphasized that moisture stress at tillering and reproductive phases leads to 30% and 50-60% yield reduction respectively. Materu *et al.* (2018) observed that 80% of the normal SRI irrigation water depth (32mm) is capable of increasing rice production by 1.5 million tonnes annually in addition to conserving water for other users. According to Basha and Sarma (2017), ponding depth should be less than 50 mm so as to minimize losses due to percolation and seepage. The practice of alternate wetting and drying is capable of reducing crop water requirements while increasing crop yields. This is through reducing on evaporation therefore less demand of water makes more water available for other purposes.

1.1.3 Water productivity

Increasing water productivity (WP) is one of the imminent methods of managing water without increasing water allocations to agriculture (Scheierling *et al.*, 2016). Water productivity is simply a performance indicator that describes the ratio of any output to water supplied. High WP implies conditions of near optimal use of water implying that less water is used to attain certain yield (Mulu and Alamirew, 2018). Unver *et al.* (2017) reported that increase in crop yield results in higher crop evapotranspiration rates, however, with better water management practices, unproductive evapotranspiration is reduced thereby increasing water productivity in the long run. Djaman (2016) mentioned that water productivity increases under deficit irrigation at the expense of full irrigation. According to Scheierling *et al.* (2016), focusing on increasing water productivity avails a bigger opportunity of saving water. Unver *et al.* (2017) emphasized further that increasing agricultural production per unit volume of water is unprecedented in managing water demand.

1.1.4 The System of Rice Intensification (SRI)

1.1.4.1 Background

The system of rice intensification originated from Madagascar in the 1980s (Uphoff, 2014). SRI was introduced with the aim of sustaining agricultural production through optimum use of capital, improved water productivity and less input costs (Uphoff, 2014; Dahiru, 2018). Across Asia and Sub- Saharan Africa, SRI is becoming profound over time (Katambara *et al.,* 2013). This is cognizant of the fact that SRI is associated with higher yields (Katambara *et al.*, 2013; Uphoff, 2014; Reuben *et al.*, 2016a, b ; Dinesh *et al.*, 2019; Isnawan *et al.*, 2020) regardless of the rice varieties used (Dahiru, 2018). SRI is being practiced in a number of countries and has been attributed to increased yield by about 50 – 100%, and 200-300% where the initial level of production was low (Uphoff, 2002), reduced water use by 44% (Sato and Uphoff, 2015) while increasing the productivity of land.

It is also indicated that about 25 – 50% of water could be saved under alternate wetting and drying without any adverse effect on rice yields (Dahiru, 2018). Further, about 80 – 90% of seed rate is saved under SRI (Dahiru, 2018) as it requires about 4 -10 kg (Abdellatif, 2018) of seed per hectare while planting unlike conventional flooding that takes between 30 – 60 kg. Consequently, SRI contributes towards environmental sustainability as continuous submergence of soil as in continuous flooding leads to anaerobic decomposition of organic matter which facilitates the production of methane- a greenhouse gas (Tuong and Bouman, 2009). However, the SRI practice of alternate wetting and drying avails temporary soil aeration which can reduce the emission of methane. Despite the positive attributes, SRI is faced with a number of challenges. Weed infestation is among the major challenges faced under SRI in addition to its labour intensity. Therefore early and rampant weeding is an essential practice.

1.1.4.2 Principles of SRI

The underlying principles of SRI include; (a) Transplanting seedlings at a much younger age (8-12 days) to reduce transplant shock and facilitate higher growth and development (Shamshiri *et al.*, 2018). (b) Transplanting few seedlings (one or two) so as to reduce on the competition for nutrients among plants (Dahiru, 2018). (c) Using organic fertilizer to perk up microbial activity and soil aeration so as to enhance rice growth and productivity. However, in situations where manure supply is scanty, yield improvements can be made using chemical fertilizers. (d) Alternate wetting and drying practice carried out during the vegetative phase on the onset of cracks. (e) Wider plant spacing which gives better access to solar radiation and other nutrients essential for photosynthesis and root development. Reuben *et al.* (2016b) recommended a spacing of 25 x 25 cm as it was found to perform much higher than other spacings. (f) Early and regular mechanical weeding to reduce on the competition between plants and weeds for nutrients. The AWD practice facilitates rampant weed growth due to ample aeration.

1.1.5 SRI practice in Tanzania

Rice plays an essential role in the economy of Tanzania as it is the most cultivated food and commercial crop after maize while accounting for over 80% of total production in Eastern Africa (Rugumamu, 2014). About 681 000 hectares of rice are under cultivation representing about 18% of the cultivated land (SRI-Rice, 2020). Conventional flooding is the most common method (90%) used in rice growing (Kangile *et al.,* 2018) hence justifying the generally very low yields of about 1-1.5 t/ha. First introduced to Tanzania in 2006 by Kilombero Plantations Limited (Katambara *et al.*, 2013), SRI is one of the strategies being capitalized upon by both government and the private sector to improve rice productivity. Since 2013, SRI has spread to other areas such as Mkindo and Dakawa in Morogoro Region and in the Mwanza and Kilimanjaro Regions (SRI-Rice, 2020). Over time, farmer acceptability and adoption of SRI in Tanzania has increased given its profitability, simplicity and compatibility with existing farming practices. Kahimba *et al.* (2014) indicated that SRI resulted into higher grain yield of about 4.7 – 6.3 t/ha unlike conventional practice with about 3.8

t/ha. SRI also demonstrated water saving of up to 63.72% for Mkindo area in Morogoro Region (Kahimba *et al.,* 2014). Maximizing yield per unit of water is deemed better than maximizing yield per unit of land. However, given the limited land and water scarcity, there is need to produce more rice per unit of land using limited water.

1.1.6 Relevance of foliar fertilizer application

Rice requires sufficient nutrients to produce ample yields (Kumar *et al.*, 2019). Nhamo *et al.* (2014) reported that a relative yield gain of 52%, equivalent to 948 kg /ha of rice grain can be obtained in Eastern and Southern Africa from the use of fertilizers. Senthilvalavan and Ravichandran (2019) recommended the integration of organic and inorganic fertilizers as essential in enhancing the growth and physiological attributes of rice. This calls for the need for efficient fertilization. Rice fields require slow release of fertilizers (Tarigan *et al.*, 2019) yet large volumes of fertilizers are lost through leaching and fixation following basal fertilizer application (Raut *et al*., 2019). On the contrary, nutrients supplied through foliar spray are rapidly absorbed by plants (Kumar and Nagesh, 2019; Raut *et al.*, 2019). Fageria *et al.* (2009) observed that crop response to foliar fertilizers takes about two days with basal fertilizers taking between five to six days. Foliar fertilizer application is also tolerant to unfavourable weather conditions (Kumar and Nagesh, 2019) while using less fertilizers thereby saving on farmers' income (Hashem, 2019; Kaleri *et al.,* 2019).

Foliar fertilizers are reported to have significant impact on the growth and yield of paddy rice (Kumar and Nagesh, 2019; Raut *et al.*, 2019). Hashem (2019) recommended the use of foliar fertilizer application together with the conventional fertilizers at the various growth stages in order to enhance rice productivity. Badawi *et al.* (2013) affirmed that the interaction between foliar fertilizer application and irrigation treatments had significant impact on the yield of rice. Raut *et al.* (2019) reported significantly higher number of growth and yield attributes following foliar fertilizer application on rice compared to other fertilizer application methods. Nassef *et al.* (2013); Shallan *et al.* (2016); Morsy *et al.* (2018) and Mostafa (2019) attributed the significant increase of plant growth attributes following application of Lithovit fertilizers. Lithovit is also a natural 100% organic calcium carbonate fertilizer extracted from natural limestone deposits suitable for organic farming. Lithovit consists of nano-particles that are readily absorbed through the stomata and can considerably increase the photosynthesis rate, reduce crop water requirement and increase crop yield (Farouk, 2015).

1.2 Problem statement

Due to the existing constraints facing rice production in Tanzania such as low rice yielding varieties, weed infestation, prevalence of pests and diseases, water scarcity and poor/low fertilizer application, various researchers have been engaged in assessing the capacity of the system of rice intensification (SRI) to curb these constraints (Katambara *et al.,* 2013; Reuben *et al.,* 2016a, b; Kangile *et al.,* 2018; Materu *et al*., 2018). SRI has been profound in reducing the amount of water used for production through the alternate wetting and drying mechanism in addition to other factors such as increasing yield and food security (Katambara *et al.,* 2013; Reuben *et al.,* 2016a, b; Kangile *et al.,* 2018; Materu *et al*., 2018). Materu *et al.* (2018) focused on irrigation management alternatives for water and rice production in Tanzania where it was affirmed that high yields could be attained following reduction in total irrigation volume.

A number of studies have also been carried out on the impact of foliar fertilizer application on various crops (such as rice, maize, potatoes, wheat) and parameters such as evapotranspiration, water use efficiency, growth and yield in addition to specific macro and micro nutrients (Siddique *et al.,* 2015; Naseri and Hatami, 2016; Noaema and Sawicka, 2016; Buczek, 2017; Jakab-gábor and Komarek, 2017; Hanaa and Safaa, 2019; Kumar and Nagesh, 2019; Ramesh *et al.,* 2019). Foliar fertilizer application is associated with fertilizer and water use efficiency, correcting nutrient deficiencies, ease of application, uniform fertilizer application and lower costs (Noaema and Sawicka, 2016; Steiner *et al*., 2018; Hanaa and Safaa, 2019; Ramesh *et al.,* 2019). Toromanova and Georgieva (2017) reported a 13.1% increase in productive tillering capacity of rice following application of Lithovit fertilizer which was the highest among other foliar treatments used. However, most of these studies on foliar fertilizer application have been carried out on rice under continuous flooding and hardly done under SRI. Further, there is limited information on the effects of integrating deficit irrigation and carbonate foliar fertilizer application into SRI. The aim of this study was to determine the effect of integrating deficit irrigation and carbonate foliar fertilizer application into SRI on rice growth, yield, water productivity and economic implications.

1.3 Justification

The existing rice yield gap in Tanzania, requires prompt actions that would enhance its reduction. Deficit irrigation, SRI and foliar fertilizer application have proved to be effective in enhancing rice yield and water productivity individually, however, the information on their combined effects is limited. Therefore, the aim of this study was to assess the effects of integrating deficit irrigation and carbonate foliar fertilizer application into SRI and determine how much yield would be attained in addition to increasing water productivity. Increasing yield and water productivity will not only improve farmers' earnings but also reduce on the costs of production given that foliar fertilizer application is deemed cheaper than the conventional existing practices.

1.4 Objectives

1.4.1 Main objective

The main objective of this study was to evaluate the effects of integrating deficit irrigation and carbonate foliar fertilizer (Lithovit) application into the System of Rice Intensification (SRI) on rice growth, yield and water productivity in addition to economic implications.

1.4.2 Specific objectives

The specific objectives of this study included to;

i. Evaluate the effect of integrating deficit irrigation and carbonate foliar fertilizer application into SRI on growth and yield of rice,
ii. Evaluate the effect of integrating deficit irrigation and carbonate foliar fertilizer application into SRI on water productivity of rice and
iii. Assess the economic implications in integrating deficit irrigation and carbonate foliar fertilizer application into SRI.

1.5 Outline of the dissertation

This dissertation comprises three papers that address three objectives as chapters two, three and four. Chapters two, three and four constitute the effects of integrating deficit irrigation and carbonate foliar fertilizers into the system of rice intensification on growth and yield, water productivity and economic analysis respectively. Chapter five gives the general conclusions and recommendations.

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CHAPTER TWO

Paper One

Effects of integrating deficit irrigation and carbonate foliar fertilizers into the System of Rice Intensification on growth and yield

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Abstract

Rice plays a key role in food availability and the economy of Tanzania. However, the rice yield gap of over 87% indicates that there are challenges of inadequate management practices for enhancing its production. There are recommendations on the use of the System of Rice Intensification (SRI) as one of the means to enhance rice yield. Recent developments have also recommended the use of foliar fertilizers at the various growth stages in order to enhance rice productivity. Individually, SRI and foliar fertilizer application have proved to be effective in enhancing rice yield, however, the information on their combined effects is limitedly known. Further, existing literature stresses on the advantages of deficit irrigation in improving water productivity while having minimal or no impact on yield. However, there is limited information integrating deficit irrigation and foliar fertilizer application into SRI. Therefore, a study was conducted to evaluate the effects of integrating deficit irrigation and carbonate foliar fertilizer (Lithovit) application into SRI on rice growth and yield. This study was conducted in Mkindo Irrigation scheme in Mvomero, Morogoro, Tanzania during the dry and wet season (October 2020 to June 2021). The experiment was laid out in a split plot design with three levels of irrigation for main plots which were 100% of the irrigation water requirement (40mm) imitating the SRI alternate wetting and drying pattern and induced deficit irrigation applied at 80% and 50% of the irrigation water requirement as IR_{100}, IR_{80} and IR_{50}, respectively. Irrigation was carried out at the appearance of soil cracks in IR_{100}. The sub-plot fertilizer treatments were five in number namely: (A) Diammonium Phosphate (DAP) and Urea (normal practice), (B) DAP, Urea and 100% of recommended foliar fertilizer (Lithovit Standard), (C) DAP and 50% (Lithovit and Urea), (D) Lithovit Standard only and (E) no fertilizer. The combined irrigation and fertilizer treatments tested were IR_{100}A, IR_{100}B, IR_{100}C, IR_{100}D, IR_{100}E, IR_{80}A, IR_{80}B, IR_{80}C, IR_{80}D, IR_{80}E, IR_{50}A, IR_{50}B, IR_{50}C, IR_{50}D, and IR_{50}E. The data was analyzed using IBM SPSS version 20 at 5% probability level in order to ascertain if any significant differences between the various treatment combinations existed.

It was found that, IR_{100}B attained the highest yield of 11.10 t/ha followed by IR_{80}B (10.90t/ha) and (IR_{50}B and IR_{100}A) with 9.40 t/ha for the dry season. For the wet season, IR_{80}B (6.93 t/ha) had the highest yield followed by IR_{50}B (6.68 t/ha) and IR_{100}B (6.6 t/ha). The least yield was attained by IR_{50}E with 7.10 and 3.78 t/ha for the dry and wet season respectively. The foliar treatments performed as good as the conventional fertilizer treatment. This is due to the fact that Lithovit supplies higher concentrations of carbon dioxide than in the atmosphere thereby aiding photosynthesis hence increasing crop growth and yield. Generally, the dry season performed better than the wet season for all growth and yield attributes.

Key words: System of Rice Intensification (SRI), deficit irrigation, carbonate foliar fertilizer, growth, yield

2.1 Introduction

Globally, about 26% of the population (2 billion) lack regular access to safe, nutritious and sufficient food (FAO *et al*., 2019). According to United States Department of Agriculture (USDA) (2019), the global population of food insecure people is expected to fall from 19.3 to 9.2% between 2019 and 2029. On the contrary, Sub-Saharan Africa (SSA) is predicted to be the epicenter of global food insecurity by 2029 with 22.5% of its population being food insecure (USDA, 2019). This calls for more food production to meet this global target while curbing the aggravating situation of SSA. Rice, wheat and maize are the three most essential cereals critical for the survival of a vast population globally (FAO, 2016). According to FAO (2016), daily consumption of cereals is expected to increase by 390 million tonnes between 2014 and 2024. By 2050, an annual demand for rice, wheat and maize is predicted to reach 3.3 billion tonnes (FAO, 2016).

Rice (*Oryza sativa L*) is the primary staple food for over half of the world's population while sustaining livelihoods of more than 100 million people in Sub-Saharan Africa (SSA) (FAO, 2013). Globally, rice ranks third after wheat and maize in terms of production (FAOSTAT, 2014) with a daily consumption of more than three billion people (GRiSP, 2013). Nearly 11% of the world's cultivated land is occupied by rice covering an area of about 158 million hectares with over 527 million tonnes as annual production (FAO *et al*., 2019). Rice also contributes about 21% of human's calorific energy and about 14% of their dietary protein (IRRI, 2019). As the world population is projected to increase to 8.27 billion in 2030 (UN, 2015), correspondingly, there will be increase in rice demand. The global rice demand is projected to increase from 439 - 555 million tonnes (milled rice) between 2010 and 2035 (GRiSP, 2013). Other studies such as Shamshiri *et al.* (2018); Dinesh *et al.* (2019); Raut *et al.* (2019) are all promoting increase in rice production following the increase in rice demand.

In Tanzania, rice is the third most important food crop after maize and cassava and is consumed by about 30% of the households (FAO, 2015). About 20% of farmers are involved in rice production (Mtaki, 2018) with 80% of these being small scale farmers (Katambara *et al.,* 2016). Tanzania is also the lead rice producer in Eastern and Southern Africa while accounting for about 9% of the total 30.8 million tonnes of African rice production (FAOSTAT, 2014). However, the rice yield gap for Tanzania is over 87% (Senthilkumar *et al.,* 2018). This is attributed to the generally low rice yields ranging from 1.1 t/ha under rainfed lowland conditions to 3.5 t/ha under irrigated conditions (SRI-Rice, 2020) which is below the world's average yield of 4.31 t/ha (FAO, 2015). Despite its central role in food security and economic development, rice production in Tanzania is faced with a number of constraints such as low rice yielding varieties, weed infestation, prevalence of pests and diseases with water scarcity and poor/low fertilizer application being of major concern.

Various studies have been carried out to assess the capacity of the System of Rice Intensification (SRI) as a means to curb rice production constraints and improve the yields in Tanzania (Katambara *et al.,* 2013; Reuben *et al.,* 2016a, b; Kangile *et al.,* 2018; Materu *et al*., 2018; Gowele *et al.,* 2020). SRI has been profound in boosting yields between 6-8 t/ha and water productivity by saving water of up to 25% as compared to conventional flood irrigation (Katambara *et al.,* 2013; Reuben *et al.,* 2016a, b; Kangile *et al.,* 2018; Materu *et al*., 2018). Despite SRI success, the potential rice yields have not been achieved in Tanzania. Another study by Nhamo *et al.* (2014) reported that a relative yield gain of 52%, equivalent to 948 kg /ha of rice grain can be obtained in Eastern and Southern Africa from the use of fertilizers. This highlights the inadequacy of nutrients availability (fertilization) to the plants that limits more production per unit area to consequently close the yield gap (Khan and Iqbal, 2018; Hashem, 2019; Kumar *et al.,* 2019). Evidently, rice requires sufficient nutrients to produce ample yields (Kumar *et al.*, 2019). Senthilvalavan and Ravichandran (2019) reported that integration of organic and inorganic fertilizers is essential in enhancing the growth and physiological attributes of rice. Moreover, micronutrients are also very essential in the production of rice (Khan and Iqbal, 2018; Raut *et al*., 2019; Gowele *et al.,* 2020). However, the use of low or excess amount of fertilizers compromises the soil quality and crop yield in addition to high production costs (Raut *et al.,* 2019).

In addition, the methods of fertilizer application have a significant impact on the growth and yield attributes (Raut *et al*., 2019). Rice fields require slow release of fertilizers (Tarigan *et al.,* 2019) yet large volumes of fertilizers are lost through leaching and fixation following basal fertilizer application (Raut *et al*., 2019). Foliar application, the technique of spraying liquid fertilizers (macro or micro nutrients) directly onto the leaves of crops is considered key in attaining maximum and quality yields (Khalil and Hussein, 2015; Buczek, 2017; Jakab-gábor and Komarek, 2017; Kaleri *et al.,* 2019; Kumar and Nagesh, 2019; Aljutheri *et al.,* 2020) while alleviating inhibition due to water stress (Badawi *et al.*, 2013).

Foliar fertilizers are reported to have significant impact on the growth and yield of paddy rice (Badawi *et al*., 2013; Toromanova and Georgieva, 2017; Hashem, 2019; Raut *et al.*, 2019). Hashem (2019) recommended the use of foliar fertilizer application together with the conventional fertilizers at the various growth stages in order to enhance rice productivity. Badawi *et al.* (2013) affirmed that the interaction between foliar fertilizer application and deficit irrigation had significant impact on the yield of rice. Toromanova and Georgieva (2017) reported that foliar fertilizer application played a positive effect on rice productivity with a 13.1% increase in productive tillering capacity following application of Lithovit fertilizer which was the highest among other foliar treatments used. Lithovit is a natural 100% organic calcite carbonate fertilizer extracted from natural limestone deposits suitable for organic farming (Nassef *et al.,* 2013; Morsy *et al*., 2018; Zorovski *et al*., 2021). Lithovit consists of nano-particles that are directly absorbed through the stomata and can considerably increase the photosynthesis rate, reduce crop water requirement and increase crop yield (Farouk, 2015).

Deficit irrigation, SRI and foliar fertilizer application have proved to be effective in enhancing rice growth and yield individually. However, the information on their combined effects is limitedly known. Therefore, this study evaluates the effects of integrating deficit irrigation and carbonate foliar fertilizer application into SRI on rice growth and yield. The specific objectives of this study include to evaluate the impact of integrating deficit irrigation and carbonate foliar fertilizer application into SRI on growth and yield attributes under (1) different water applications (2) different fertilizer applications and (3) the interaction between the water and fertilizer applications.

2.2 Materials and Methods

2.2.1 Description of the Study Area

The study was conducted at Mkindo farmer managed irrigation scheme in Morogoro, Tanzania. This choice was made given that the scheme is among the few farmer-based schemes which practices SRI. Small scale irrigation schemes are considered essential in improving the livelihoods of majority of small scale farmers in Tanzania (Fundi and Kinemo, 2018). Mkindo irrigation scheme is located in Mkindo village, Mvomero District, Morogoro Region in eastern Tanzania between latitude $6^0$16’ and $6^0$18’ South, and longitude $37^0$32’ and $37^0$36’ East as shown in Fig. 2.1. Its altitude ranges between 345 m and 365 m above mean sea level and is about 85 km from Morogoro Municipality (Kahimba *et al.*, 2014). The major crop grown in the area is rice under surface irrigation supplied by Mkindo Perennial River.

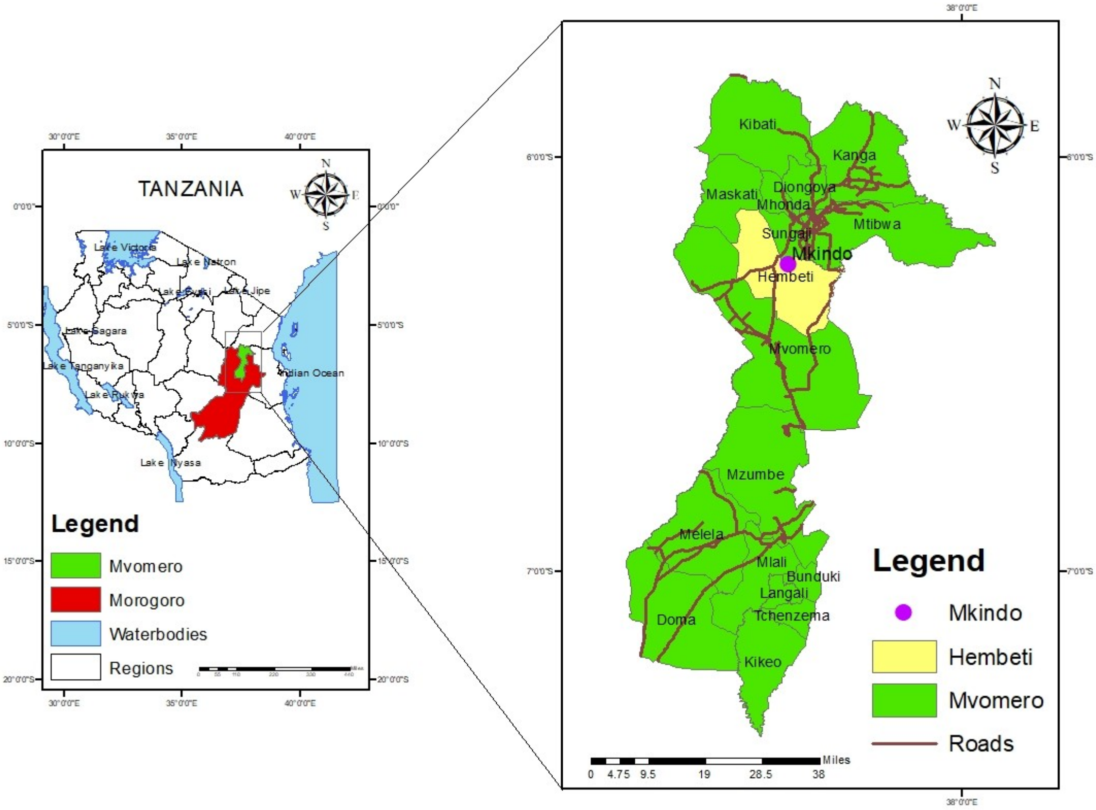

Figure 2.1: Location of the Study area

The study area is characterized by an average annual temperature of 24.95˚C, with a minimum temperature of 15.8˚C in July and a maximum temperature of 33.8˚C in February as shown in Fig. 2.2. The study area has a bimodal rainfall regime which determines the two rice growing seasons- dry season (*vuli*) with short rains starting in October to December and wet season (*masika*) with long rains starting from March to May. Rainfall in Mkindo usually starts in October with an increased trend until May with peak rainfall in April. The trend then decreases from May until July where the least rainfall is attained. The average annual total rainfall ranges between 700 and 1600 mm (Mtibwa Sugar Estate Meteorological Station).

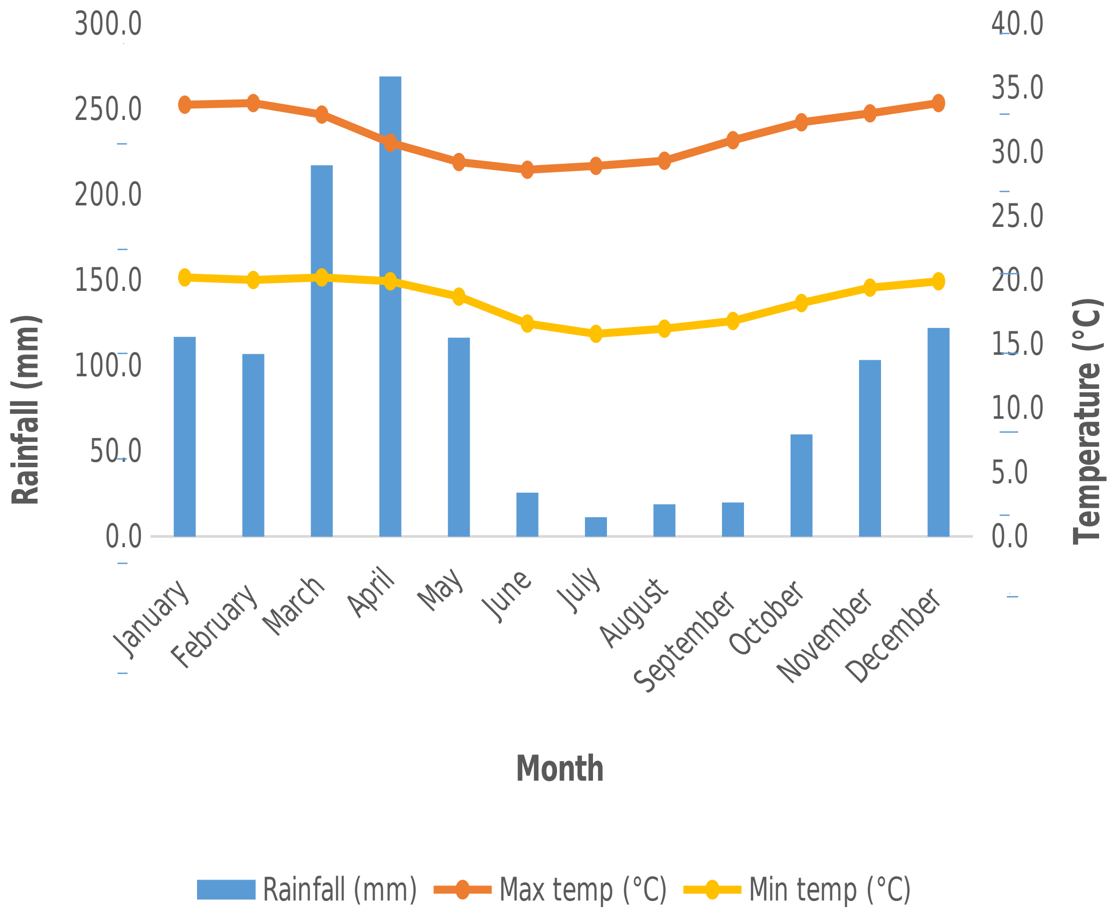

Figure 2.2: Average Monthly Rainfall, Maximum and Minimum temperature from 2000-2020

Source: Mtibwa Sugar Estate Meteorological Station

The soils of the study area are sandy clay loam (69.12%, 23.6% and 7.28%) with pH of 5.54 (medium acidic soils), electrical conductivity (EC) of 87.7 µS/cm (acceptable range), total nitrogen (N) and organic carbon of 0.09% (very low) and 1.26% (medium) respectively. Other properties include: available phosphorus (P) of 7.11 mg/kg (medium) with Cation Exchange Capacity (CEC) of 8.0 Cmol/kg (low) and exchangeable Ca, Mg, K, Na of 3.29 (medium), 1.44 (medium), 0.16 (medium) and 0.21 (low) Cmol/kg respectively Msanya (2012). These soils are deemed suitable for rice cultivation according to Msanya (2012) and Shamshiri *et al.* (2018) as they facilitate root proliferation, aeration, water infiltration and water holding capacity, soil nutrients retention and drainage.

2.2.2 Experimental design

The experiment was laid out in a split plot design with three levels of irrigation for main plots which were 100% of the irrigation water requirement (40mm) imitating the SRI alternate wetting and drying pattern and induced deficit irrigation applied at 80% and 50% of the irrigation water requirement as IR_{100}, IR_{80} and IR_{50}, respectively. Irrigation was carried out at the appearance of soil cracks in IR_{100}. The sub-plot fertilizer treatments were five in number namely: (A) Diammonium Phosphate (DAP) and Urea (normal practice), (B) DAP, Urea and 100% of recommended foliar fertilizer (Lithovit Standard), (C) DAP, 50% (Lithovit and Urea), (D) Lithovit Standard only and (E) no fertilizer. The combined irrigation and fertilizer treatments tested were $IR_{100}A$, $IR_{100}B$, $IR_{100}C$, $IR_{100}D$, $IR_{100}E$, $IR_{80}A$, $IR_{80}B$, $IR_{80}C$, $IR_{80}D$, $IR_{80}E$, $IR_{50}A$, $IR_{50}B$, $IR_{50}C$, $IR_{50}D$ and $IR_{50}E$.

All the treatments were randomly allocated and replicated three times. An individual plot size was 4 m × 2 m (8 m^2) each separated from the other by 0.5 m buffer zone to prevent lateral movement of water from one plot to another as shown in Fig. 2.3.

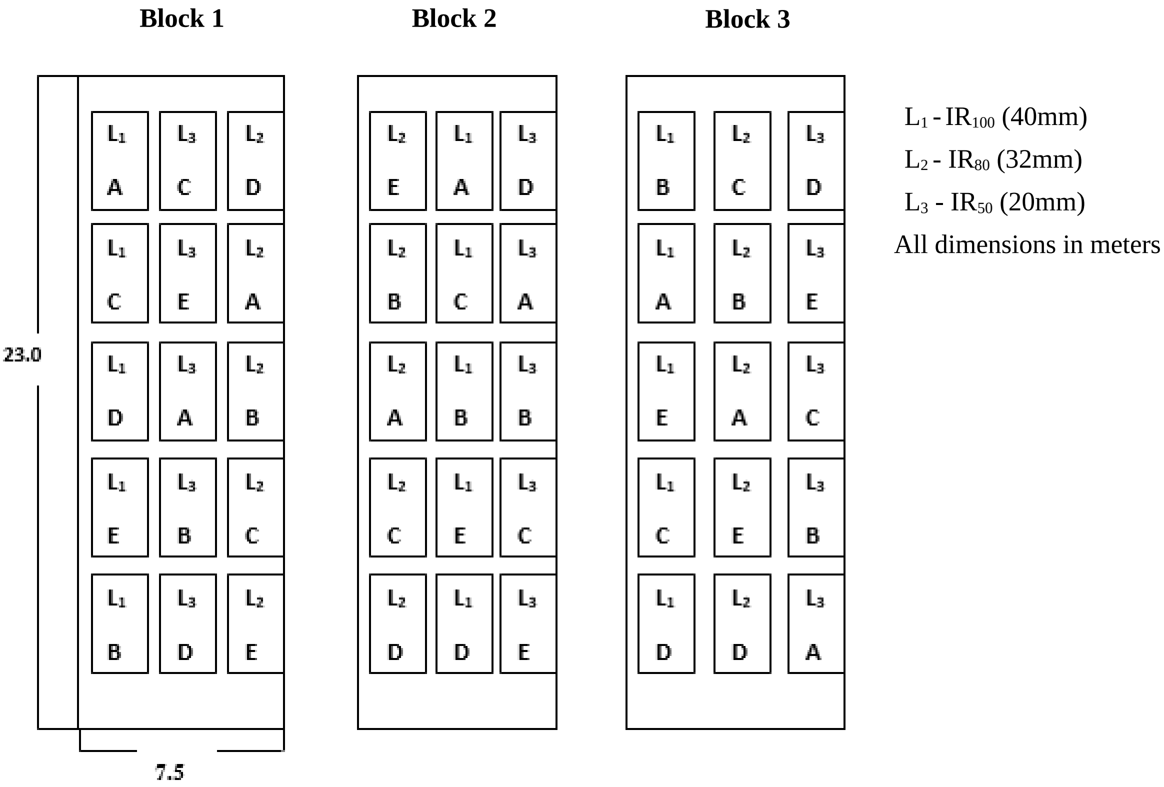

Figure 2.3: Set up of the experiment

2.2.3 Agronomic practices

The agronomic practices that were carried out include nursery and field preparation, transplanting, fertilizer application and weeding. During land preparation, the field was properly puddled using a power tiller. Levelling was also carried out to aid uniform wetting of the soil. Proper drainage was maintained to facilitate water discharge especially during the rainy period. The SARO (TXD 306) rice variety was used as it is well suited to the conditions of Mkindo and was recommended by the Ministry of Agriculture, Tanzania (Kahimba *et al.*, 2014). During nursery preparation, only viable seeds were used and were identified by submerging all the seeds in a salty solution in which an egg would float. All the seeds that floated were considered inferior and were discarded. Seed priming was then done by soaking the seeds in clean water to enhance the rate of seedling emergence and germination.

One seedling per hill was transplanted at the age of 10 days using 25 cm × 25 cm spacing (Reuben *et al.*, 2016b). While considering particular sub-plots with their respective treatments, DAP was applied only once on the second day after transplanting (DAT), Urea was applied at two different times (30 and 60) DAT while all foliar fertilizers were applied at 30, 60 and 81 DAT. Urea and DAP were applied at a rate of

125kg/ha while all foliar treatments at 1kg/ha in 100 litres of water. The fertilizer compositions are as shown in Table 2.1.

Table 2.1: Fertilizer composition for the various treatments

S/N	Fertilizers	Composition
1.	DAP	Nitrogen, N (18%) Phosphate, PO_4 (46%)
2.	Urea	Nitrogen (46%)
3.	Lithovit Standard	Calcium carbonate, $CaCO_3$ (60%) Calcium oxide, CaO (35%) Silicon dioxide, SiO_2 (12%) Magnesia, Mg (2%) Iron, Fe (1%) Manganese, Mn (0.02%)
4.	Lithovit and Urea (50%)	Calcium Carbonate (33%) Nitrogen (21%) Calcium oxide (18.5%) Silicon dioxide (6.5%) Magnesia (1.2%) Iron (0.5%) Manganese (0.01%)

Weeding and spraying of pesticides against white fly infestation was carried out four and two times in the dry and wet season respectively. Before harvesting, a 14 days dry period was observed to allow for maximum transfer of nutrients to the grains. The rice was harvested manually with serrated edged sickles at 112 days when about 90% of the panicles had ripened spikelets and threshed using wooden sticks.

2.2.4 Measurement of plant attributes

2.2.4.1 Growth attributes

Areas (one square meter) with average uniformly growing representative plants were randomly selected and labelled from each field plot for measurements of five plants that were carried out after every two weeks. The variables that were measured after every two weeks include; plant height, number of leaves and total number of tillers. Plant height was measured using a tape measure while number of leaves and total number of tillers were measured manually by counting.

2.2.4.2 Yield attributes

At harvest, the number of productive tillers, length of panicles, biomass, yield and dry weight of 1000 grains were measured. Length of panicles was measured using a tape measure while the number of productive tillers was measured manually by counting. Dry weight of 1000 grains was measured by randomly picking two grain panicles from 10 plant samples within each sub plot excluding the boundary crops. The panicles were then air dried and 100 grains were manually counted off and weighed using a digital electronic balance. The weight was then projected to 1000 grains. Biomass and grain yield were measured by randomly harvesting one square meter of rice from each plot. Thereafter the grains were separated from the straw by manual threshing. The weight of the grains was determined after winnowing and one kilogram of straw was also measured off for further drying. Air drying was then carried out until constant weight was attained for both the straw and grains. A digital electronic balance was used to measure the grain and straw weights.

2.2.5 Data analysis

Analysis of Variance (ANOVA) was used ($p<0.05$) to determine the existence of any differences between both the main and sub plot treatments for the growth and yield attributes. Data was analyzed using IBM SPSS version 20 which is best recommended for split plot nature of experiments. Duncan’s multiple range test was used to determine if any significant difference existed between the various treatment combinations.

2.3 Results and Discussion

2.3.1 Seasonal trend of growth and yield under foliar-deficit-SRI integration

2.3.1.1 Plant height

There was rapid increase in plant height in the vegetative (28-56 DAT) and reproductive phases (84 DAT) which became constant during maturity stage (112 DAT). The trend of growth of plant height throughout the entire dry and wet season under IR_{100}, IR_{80} and IR_{50} for fertilizer treatments A, B, C, D and E at 28, 56, 84 and 112 DAT is as shown in Fig. 2.4. There was also slight variation in plant height at the different growth stages between the different fertilizer treatments with E having the least plant height.

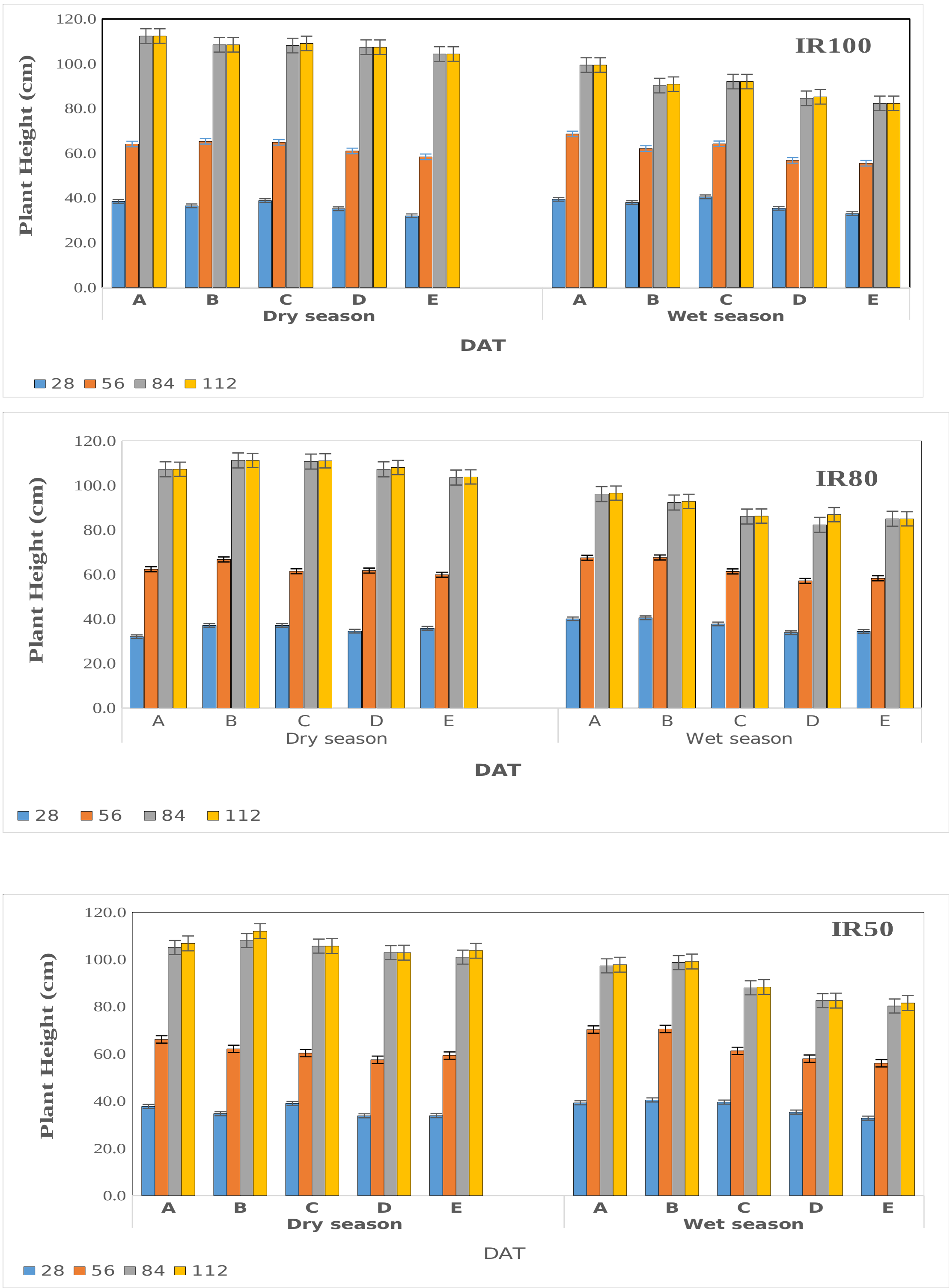

Figure 2.4: Plant height for water regimes IR_{100}, IR_{80} and IR_{50} for the dry and wet seasons

Generally, the dry season performed better than the wet season. Growth and panicle initiation occurs during the vegetative and reproductive phases. In addition, all fertilizer applications were carried out before the reproductive phase hence the rapid increase in plant height which became constant during maturity is due to ample supply of nutrients during these phases. A similar trend was also observed by Thakur *et al.* (2014); Hidayati *et al.* (2016) and Yoga *et al.* (2020). The variation in plant height between the different water applications is attributed to the variation in water depth as also observed by Materu *et al.* (2018). The variation in plant height between the conventional and foliar fertilizer treatments is due to the impact of Lithovit foliar fertilizers. Lithovit contains Calcium carbonate ($CaCO_{3)}$ and Magnesium carbonate ($MgCO_3$) which rapidly penetrates into plant tissues and aids in biological and physiological processes hence increase in plant height. This is in agreement with Morsy *et al.* (2018) and Zorovski *et al.* (2021).

2.3.1.2 Leaves

Across all water application treatments, IR_{100}, IR_{80} and IR_{50}, there was rapid increase in the total number of leaves during the vegetative and reproductive phase which became constant during maturity phase. The trend of growth of leaves after every 28 DAT for fertilizer treatments A, B, C, D and E under $IR_{100,}$ IR_{80} and IR_{50} water regimes for the entire dry and wet seasons is as shown in Fig. 2.5. There was variation in the number of leaves among the different fertilizer treatments. At every growth stage, either treatment A or B had the highest number of leaves followed by C, D while the no fertilizer treatment E had the least number of leaves.

A similar trend of growth of leaves was observed by Materu *et al.* (2018). The variation in the number of leaves among fertilizer treatments was due to the impact of Lithovit fertilizers which penetrate rapidly into plant tissues through the stomata and play vital roles in biological and physiological processes (Nassef *et al.*, 2013; Morsy *et al.*, 2018).

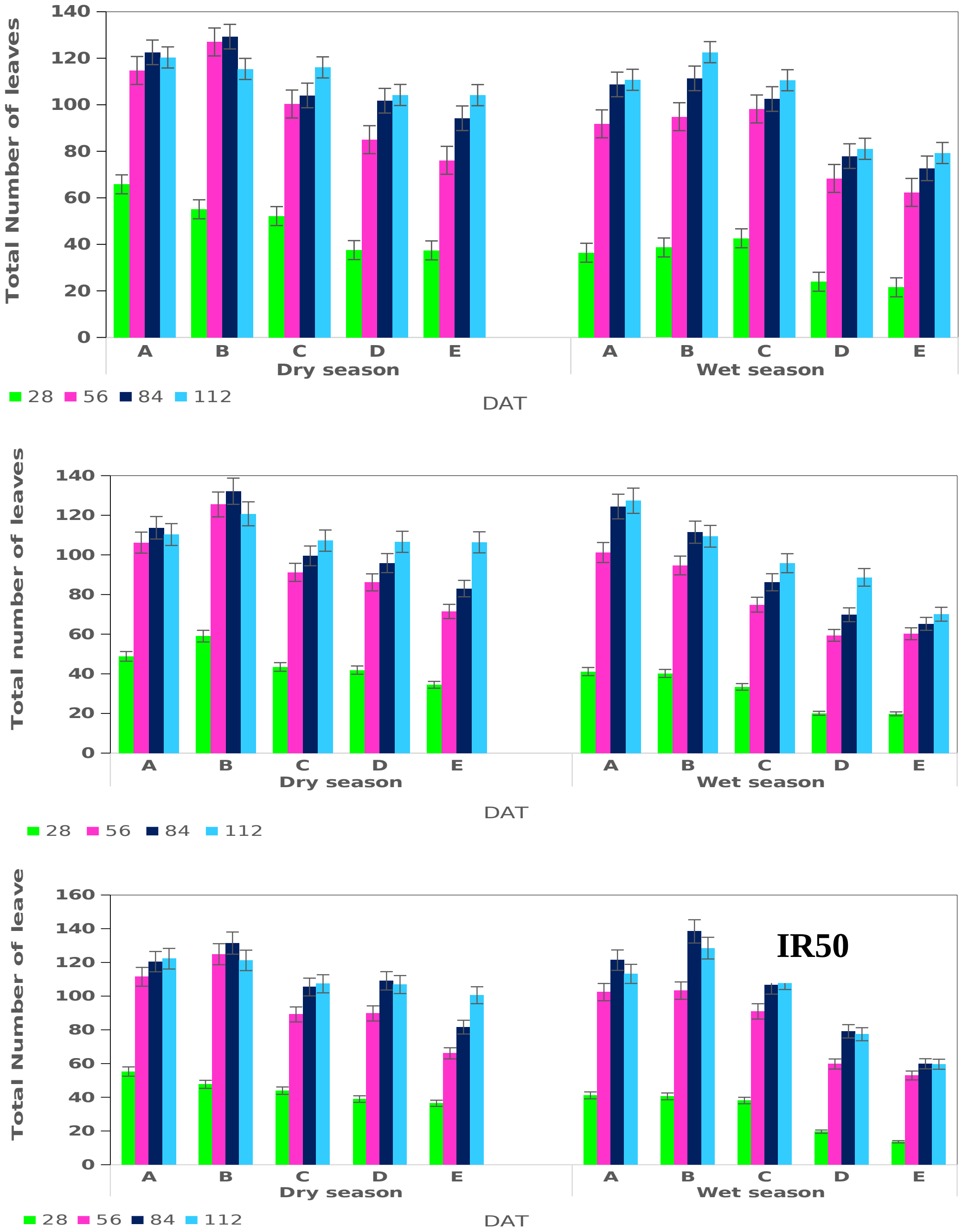

Figure 2.5: Total number of leaves for IR100, IR80 and IR50 for the dry and wet seasons

The variation in water depth also facilitated the variation in the total number of leaves for the different water level applications.

2.3.1.3 Total and productive tillers

For both the dry and wet season, the mortality of tillers was not significant ($p>0.05$). Fig. 2.6 shows the dry season variation between total tillers (TT) and productive tillers (PT) (tiller mortality) for the different fertilizer treatments A, B, C, D and E at IR_{100}, IR_{80} and IR_{50}. IR_{100} had higher tiller mortality rate compared to IR_{80} and IR_{50}. Treatment $IR_{100}C$, $IR_{80}C$, $IR_{50}C$ and $IR_{100}E$ had the highest tiller mortality rate (8%) followed by $IR_{100}A$, $IR_{100}B$ and $IR_{80}C$ with 6% while the rest of the treatments had no mortality rate.

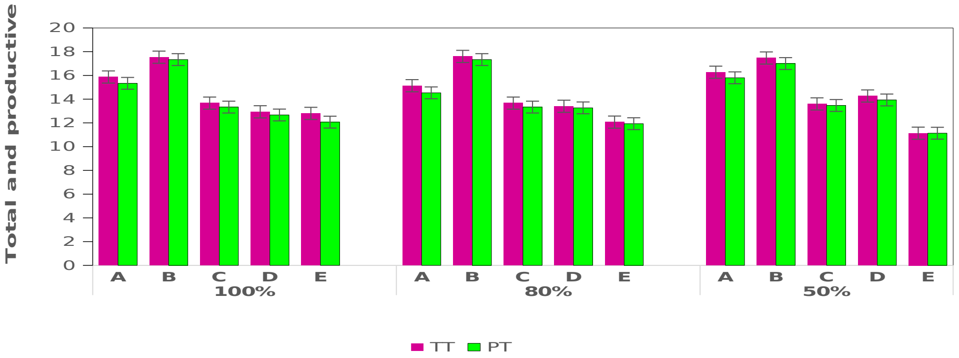

Figure 2.6: Dry season total tillers (TT) and productive tillers (PT) for 1R100, 1R80 and 1R50

Figure 2.7 shows the wet season variation between total and productive tillers for the different fertilizer treatments A, B, C, D and E under IR_{100}, IR_{80} and IR_{50} water applications (WAP).

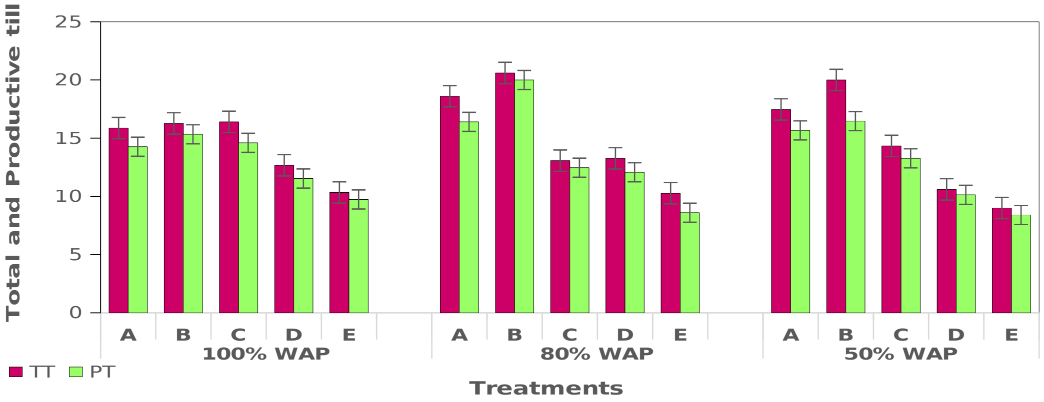

Figure 2.7: Wet season total and productive tillers for 1R100, 1R80 and 1R50

The highest and least tiller mortality rate was registered under $IR_{50}B$ (25%) and $IR_{100}E$ (0%) respectively. The tiller mortality rate across all water applications for all fertilizer treatments for both the dry and wet seasons was not significant ($p>0.05$). Similar findings were observed by Reuben *et al.* (2016a). The wet season had more tiller mortality rate compared to the dry season indicating that the cropping season (variation in rainfall) may have had an impact on the tillering efficiency. This is in agreement with Materu *et al.* (2018) and Zoundou *et al.* (2019).

2.3.2 Effect of water application levels on rice growth and yield

There was no significant difference ($p>0.05$) among the different water applications for plant height, leaves, total and effective tillers, panicle length and straw for both the dry and wet season in addition to dry season 1000 grain weight and yield. However, there was significant difference between the different water applications ($p<0.05$) for 1000 grain weight (dry season) and yield (wet season). The effect of the different water levels, IR_{100}, IR_{80} and IR_{50} on plant height, number of leaves, total and effective tillers, panicle length, dry weight of 1000 grains, straw and yield for both the dry and wet seasons is as shown in Table 2.2.

Table 2.2: Water regimes dry and wet season analysis for growth and yield attributes

Season	Water level	Plant Height (cm)	Leaves	Total tillers	Effective tillers	Panicle length (mm)	1000 grain weight (g)	Straw (g)	Yield (t/ha)
Dry season	IR_{100}	109.1a	112a	15a	14a	261.5a	31.01a	0.51a	9.02a
	IR_{80}	109.2a	110a	14a	14a	262.6a	31.16a	0.53a	8.75a
	IR_{50}	107.2a	112a	15a	14a	268.0a	32.21b	0.52a	8.22a
Wet season	IR_{100}	89.3b	101b	14b	13b	228.9b	30.08c	0.51b	5.76b
	IR_{80}	89.4b	98b	15b	14b	230.7b	30.26c	0.50b	5.41bc
	IR_{50}	89.1b	98b	14b	13b	228.9b	30.63c	0.49b	5.13c

(Mean values followed by different letters within similar columns differ significantly at $p< 0.05$ according to Duncan's Multiple-range test)

The highest 1000 grain weight for the dry season was recorded under IR_{50} followed by IR_{80} and IR_{100} with 32.21, 31.16 and 31.01g respectively but with no significant difference between IR_{80} and IR_{100}. While considering yield for the wet season, there was a significant difference between IR_{100} and IR_{50} with a 12% difference in yield while IR_{100} had 6.5% more yield than IR_{80}.

Dry season 1000 grain weight is contrary to Zoundou *et al*. (2019) who recorded the highest 1000 grain weight with IR_{100} and the least with IR_{50} but with no significant difference ($p>0.05$). The plant heights recorded are higher than in Materu *et al.* (2018) who observed mean values of 44.0, 40.0 and 30.0 cm for $IR_{100,}$ IR_{80} and IR_{50} respectively. The total and productive tillers for the dry and wet seasons fall within the range of Kissou and Wang (2017) whose range was between 16 and 18 tillers. The panicle lengths are in agreement with Ndiiri *et al.* (2017) and Kissou and Wang (2017) who observed panicle length between 213 - 252 mm and 194.2 - 271.5 mm respectively. The panicle lengths for both the dry and wet seasons were higher than those observed by Zoundou *et al.* (2019) who recorded 197.5, 195.0 and 177.5 mm as the highest panicle length under IR_{50}, IR_{80} and IR_{100} respectively.

The yield falls within the range of Materu *et al.* (2018) who recorded yield of (11.5-7.5 t/ha) and (6.0-5.0 t/ha) for the dry and wet seasons respectively. However, less yield than attained in this study of 6.3 t/ha and 8.5 t/ha was reported for the same area location by Kombe (2012) and Reuben *et al.* (2016a) respectively indicating the impact of foliar fertilizers in enhancing yield performance. The no significant difference in growth and yield attributes between the water regimes was due to heavy rainfall during the second (November 2020) and first month (March 2021) of the vegetative phase for both the dry and wet seasons respectively which disrupted water regimes. This was also reported by Materu *et al.* (2018).

2.3.3 Effect of fertilizer applications on growth and yield

There was significant difference ($p<0.05$) among the different fertilizer applications for all growth and yield attributes except for dry season panicle length and straw weight. The effect of the various fertilizer treatments A, B, C, D and E on plant height, leaves, total and effective tillers, panicle length, 1000 grains weight, straw and yield for both the dry and wet seasons is as shown in Table 2.3.

Table 2.3: Subplot (fertilizer treatment) analysis

Season	TRT	Plant Height (cm)	Leaves	Total tillers	Effective tillers	Panicle length (mm)	1000 grain weight (g)	Straw (g)	Yield (t/ha)
Dry Season	A	110.0a	118a	16a	15a	263.8a	32.08a	0.52a	9.41a
	B	109.4ab	119a	17b	17b	268.1a	32.07a	0.51a	11.09b
	C	108.2ab	110b	14c	13c	262.4a	31.04ab	0.50a	8.19c
	D	108.1ab	106bc	14c	13c	264.9a	31.37ab	0.54a	8.16c
	E	106.7b	104c	12d	12d	260.9a	30.75b	0.52a	7.26c
Wet season	A	97.0c	117d	17e	15e	242.7b	30.78cd	0.57b	6.05de
	B	91.9d	120d	19e	17e	234.4bc	31.71c	0.53bc	6.74d
	C	88.6de	105d	15f	13f	223.9ce	30.33d	0.53bc	5.70e
	D	84.7ef	82e	12g	11g	230.6c	29.98d	0.46cd	4.38f
	E	82.5f	70e	10g	9h	215.8e	28.81e	0.40d	4.10f

(Mean values followed by different letters within similar columns differ significantly at $p < 0.05$ according to Duncan's Multiple-range test)

2.3.3.1 Plant height and leaves

For the dry season, the highest plant height was attained by A (110.0 cm) followed by B (109.4 cm), C (108.2 cm) and D (108.1 cm) while E had the least plant height of 106.7 cm. A similar trend was observed under the wet season with plant heights of 97.0, 91.9, 88.6, 84.7 and 82.5 cm for treatments A, B, C, D and E respectively.

For the dry season, B had 1%, 8%, 12% and 14% more leaves than treatments A, C, D, and E respectively. However, there was no significant difference between treatment B and A while a high significant difference ($p<0.01$) existed between treatments (B, C), (B, D) and (B, E). For the wet season, B had the highest number of leaves (120) while E had the least (70). There was no significant difference among treatments A, B and C with B having only 3% and 14% more leaves than A and C respectively. Treatment D had 17% more leaves than E but with no significant difference ($p>0.05$).

2.3.3.2 Total and effective tillers

Treatment B had the highest number of total and productive tillers followed by A, C, D and E in both seasons. For the dry season, B had 13% more effective tillers than A, 31% than (C and D) and 42% than E. The post-hoc results indicate no significant difference between treatments C and D while the rest of the fertilizer applications were significantly different ($p<0.05$). For the wet season, treatments B, A, C and D had 90%, 70%, 50% and 20% more total tillers than E. While considering effective tillers, there was no significant difference between treatments A and B while the rest of the treatments were significantly different.

2.3.3.3 Panicle length and straw weight

For the dry season, panicle length ranged between 268.1 and 260.9 mm with B and E having the highest and least panicle length respectively. For the wet season, A had the highest panicle length of 242.7 mm while E had the least panicle length of 215.8 mm. There was a significant difference between treatments (A, B), (B, C), (C, D) and (C, E). Dry season straw weight ranged between 0.50 and 0.54 g with the highest and least weight being attained by D and C respectively with no significant difference ($p>0.05$) between the various fertilizer applications. For the wet season, treatments A and E had the highest (0.57g) and least (0.40g) straw weight respectively. Treatment A had 8%, 24% and 43% more straw than (B and C), D and E respectively.

2.3.3.4 Dry weight of 1000 grains and yield

For the dry season, A had the highest 1000 grain weight of 32.08g while E had the least of 30.8g. However, there was no significant difference between treatments (A, B), (C, D) and (D, E). For the wet season, treatment B had the highest average 1000 grain weight (31.7g) while E had the least (28.8g). There was no significant difference between treatments (A, B), (A, C) and (C, D).

For the dry season, Treatment B had the highest yield (11.09 t/ha) followed by A, C, D and E with 9.41, 8.19, 8.16 and 7.26 t/ha respectively. Treatment B had 18% more yield than the conventional treatment A while treatment C had 13% less yield than A hence justifying the no significant difference between treatment A and C. Treatment B had 53% more yield than E and there was no significant difference between E and D. A similar trend was followed by the wet season with B having the highest average yield of 6.74 t/ha followed by A, C, D and E with 6.05, 5.70, 4.38 and 4.10 t/ha respectively.

Treatment B had the best yield performance attributed to the combination of both basal and foliar fertilizers. This is in agreement with Hashem (2019) who recommended combining basal and foliar fertilizers as a form of rice yield enhancement. Treatment E had the least performance as no fertilizers were applied throughout the entire growing period. However, its overall performance was still better than the conventional continuous flooding with average yield of 3.83 t/ha (Kombe, 2012) due to the impact of SRI. The practice of alternate wetting and drying (AWD) facilitates about 80% of free living bacteria and other microbes in and around rice roots (Berkelaar, 2007) which have nitrogen fixing ability thereby supplying nutrients such as nitrogen, phosphorus and potassium in addition to micronutrients such as calcium, sulphur, iron, copper, manganese and zinc to the soil hence the better performance. Further, AWD creates a moist but unsaturated soil condition that facilitates deeper root growth in the search for water hence aiding crop growth and yield. This is in agreement with Materu *et al.* (2018) and Dinesh *et al*. (2019). In addition, the large plant spacing under SRI (25 x 25 cm) creates ample aeration therefore less competition for nutrients hence more growth. This is in agreement with Kahimba *et al.* (2014) and Reuben *et al.* (2016b).

The dry season had more yield than the wet season due to the differences in the cropping seasons. This was also observed by Materu *et al.* (2018). Further, actual yield of rice depends on the amount of starch that fills the spikelets especially during the ripening stage. Low temperatures affect crop development at the various growth stages and can lead to spikelet sterility where no grain is produced (Ndiiri *et al*., 2017). Ndiiri *et al.* (2017) reported that minimum temperatures below 16 °C yielded 100% sterility. The average minimum temperatures in this study for the wet season were 14.8 °C and 13.5 °C for the months of May and June, the reproductive and ripening stages respectively which are most prone to sterility. This therefore justifies the cause of the lower yields in the wet season than the dry season. However, the maximum yield attained in both the dry and wet seasons was greater than the yield obtained by Kombe (2012) and Reuben *et al.* (2016a) who reported a maximum yield of 6.3 t/ha and 8.5 t/ha respectively under SRI with 25 x 25 cm spacing for Mkindo area. The increase in yield is attributed to the effect of foliar fertilizers. Lithovit fertilizers contain calcium carbonate ($CaCO_3$) (80%) which decomposes to calcium oxide (CaO) and carbon dioxide (CO_2) in the stomata of the leaves which accelerates photosynthesis hence leading to increased carbon intake and assimilation.

2.3.4 Interaction effect between water and fertilizer applications on growth and yield

The effect of combining the different water levels IR$_{100}$, IR$_{80}$ and IR$_{50}$ with fertilizer treatments A, B, C, D and E on plant height, number of leaves, total and effective tillers, 1000 grain weight, panicle length, straw and yield for the dry season is as shown in Table 2.4.

Table 2.4: Dry season interaction between water and fertilizer applications on growth and yield

Water application	TRT	Plant height (cm)	Leaves	Total tillers	Productive tillers	1000 Grains weight (g)	Panicle length (mm)	Straw (g)	Yield (t/ha)
IR$_{100}$	A	112.6	120	16	15	31.8	251.1	0.52	9.40
	B	108.7	115	18	17	32.3	264.8	0.49	11.10
	C	108.3	116	14	13	30.3	264.8	0.45	8.70
	D	109.2	104	13	13	30.2	262.6	0.53	8.90
	E	106.4	104	13	12	30.6	264.1	0.40	7.50
IR$_{80}$	A	109.7	110	15	15	31.7	271.7	0.51	9.00
	B	110.8	122	17	17	31.3	266.6	0.54	10.90
	C	108.8	107	14	13	30.3	250.0	0.55	8.10
	D	109.2	107	14	13	32.0	268.1	0.53	8.10
	E	107.4	106	12	12	30.4	256.5	0.52	7.20
IR$_{50}$	A	107.6	120	16	16	32.8	268.7	0.49	9.00
	B	108.7	121	17	17	32.6	272.8	0.53	9.40
	C	107.6	107	14	14	32.6	272.3	0.51	7.80
	D	106.2	107	14	14	32.0	264.0	0.49	7.50
	E	106.0	101	11	11	31.2	262.2	0.52	7.10
p value		0.840	0.24	0677	0.953	0.434	0.255	0.337	0.829

From Table 2.4, the highest and least plant height was attained by IR$_{100}$A and IR$_{50}$E with 112.6 and 106.0 cm respectively. The highest number of leaves was attained by IR$_{80}$B followed by IR$_{50}$B and IR$_{100}$A with 122, 121 and 120 leaves respectively while IR$_{50}$E had the least number of leaves (101). For the dry season, the highest number of total tillers was attained under IR$_{100}$B with only 6% less tillers than both IR$_{80}$B and IR$_{50}$B while IR$_{50}$E had the least total and effective tillers. The highest and least 1000 grain weight was attained under IR$_{50}$A (32.8g) and IR$_{80}$E (30.4g). IR$_{50}$B had the highest panicle length followed by IR$_{50}$C and IR$_{80}$A with 272.8, 272.3 and 271.7 mm respectively while IR$_{80}$C had the least panicle length of 250.0 mm. The highest and least straw weight was attained by IR$_{80}$C (0.55g) and IR$_{100}$E (0.40g) respectively.

The highest and least yield was attained by IR$_{100}$B (11.10 t/ha) and IR$_{50}$E (7.10 t/ha) respectively. IR$_{100}$B performed 18% better than IR$_{100}$A while IR$_{100}$C performed as good as the conventional fertilizer treatment IR$_{100}$A with only 8% less yield. Further, the foliar treatment IR$_{100}$D also performed considerably well especially in the dry season compared to the conventional treatment IR$_{100}$A with only 6% less yield. A similar trend was followed by both IR$_{80}$ and IR$_{50}$. IR$_{80}$B had 21% more yield than IR$_{80}$A while IR$_{80}$A had 11% more yield than IR$_{80}$C and IR$_{80}$D. IR$_{50}$B had 4% more yield than IR$_{50}$A while IR$_{50}$A had 15% more yield than IR$_{50}$C and 20% more yield than IR$_{50}$D. Table 2.5 shows the effect of combining the different water levels IR$_{100}$, IR$_{80}$ and IR$_{50}$ with fertilizer treatments A, B, C, D and E on plant height, number of leaves, total and effective tillers, 1000 grain weight, panicle length, straw weight and yield for the wet season.

Table 2.5: Wet season interaction between water and fertilizer treatments on growth and yield

Water levels	TRT	Plant height (cm)	Leaves	Total tillers	Productive tillers	1000 Grains weight (g)	Panicle length (mm)	Straw (g)	Yield (t/ha)
IR$_{100}$	A	98.4	111	16	14	30.6	243.13	0.59	6.52
	B	87.9	123	16	15	30.8	228.63	0.51	6.60
	C	91.9	111	16	15	30.4	224.23	0.62	6.33
	D	85.2	81	13	12	30.0	233.27	0.42	4.97
	E	82.2	79	10	10	28.6	214.90	0.38	4.37
IR$_{80}$	A	95.3	127	19	16	31.0	242.93	0.56	5.82
	B	89.0	109	21	20	31.7	238.93	0.63	6.93
	C	85.9	96	13	12	30.3	217.17	0.51	5.28
	D	86.8	89	13	12	30.0	243.50	0.44	4.28
	E	85.0	70	10	9	28.4	211.00	0.38	4.15
IR$_{50}$	A	97.3	113	17	16	30.8	242.17	0.56	5.82
	B	98.1	128	20	16	32.7	235.67	0.46	6.68
	C	88.0	109	14	13	30.3	230.17	0.47	5.48
	D	82.2	77	11	10	29.9	215.13	0.54	3.88
	E	80.3	60	9	8	29.4	221.43	0.43	3.78
p value		0.137	0.685	0.278	0.242	0.775	0.104	0.077	0.832

From Table 2.5, the highest and least plant height was attained by $IR_{100}A$ and $IR_{50}E$ with 98.4 and 80.3 cm respectively. The highest number of leaves of 128, 127 and 123 was attained by $IR_{50}B$, $IR_{80}A$, and $IR_{100}B$ respectively. The least number of leaves was 60 attained by $IR_{50}E$. $IR_{80}B$ had the highest number of total tillers with only 5% difference with $IR_{50}B$ while $IR_{50}E$ had the least number of total and effective tillers. $IR_{100}A$ had the highest panicle length followed by $IR_{80}A$ and $IR_{50}A$ with 243.13, 242.93 and 242.17 mm respectively while $IR_{80}E$ had the least panicle length of 211.0 mm. The highest and least 1000 grains weight was attained by $IR_{50}B$ (32.7g) and $IR_{80}E$ (28.4g) respectively.

The highest and least yield was attained by $IR_{80}B$ (6.93 t/ha) and $IR_{50}E$ (3.78 t/ha) respectively. $IR_{100}B$ performed 1% better than $IR_{100}A$. $IR_{100}C$ performed as good as the conventional fertilizer treatment $IR_{100}A$ with only 3% less yield. The foliar treatment $IR_{100}D$ had only 31% less yield than $IR_{100}A$. A similar trend was followed by both IR_{80} and IR_{50}. $IR_{80}B$ had 19% more yield than $IR_{80}A$ while $IR_{80}A$ had 10% more yield than $IR_{80}C$ and 36% more yield than $IR_{80}D$. $IR_{50}B$ had 15% more yield than $IR_{50}A$ while $IR_{50}A$ had 6% more yield than $IR_{50}C$ and 50% more yield than $IR_{50}D$.

However, the interaction between water applications and fertilizer treatments for both seasons across all growth and yield attributes was not significant ($p > 0.05$). These findings are similar to Zhang *et al.* (2012) who found no significant interaction among rice varieties, water management and fertilizer application under AWD of rice.

The variation between the conventional and foliar fertilizer applications is due to the impact of Lithovit foliar fertilizers. Lithovit supplies higher concentrations of carbon dioxide than in the atmosphere thereby aiding photosynthesis hence increasing crop growth and yield. In addition, other macronutrients are availed which increase enzymatic activity and growth. Further, Lithovit consists of nano-particles that are also slowly and efficiently availed to plants unlike conventional fertilizers.

For all growth and yield attributes, the dry season performed better than the wet season due to the low temperatures that affected crop growth and development. The temperatures in the wet season were 14.8 °C (May 2021) and 13.5 °C (June 2021)

(Mtibwa Meteorological Station) during the reproductive and ripening stages respectively which are most prone to sterility. This was also observed by Materu *et al.* (2018).

2.4 Conclusion

Generally, integrating deficit irrigation and carbonate foliar fertilizers into SRI had a positive impact on growth and yield attributes. The IR_{80} had the best performance in terms of plant height, panicle length, total number of leaves, total and effective tillers and yield. Treatment B had the best performance in terms of total number of leaves, total and effective tillers, panicle length and yield. Treatment A had the highest plant height and weight of 1000 grains which however was not any significantly different from treatment B. Therefore, combining foliar treatments with conventional fertilizers played a key role in the performance enhancement of treatment B. Foliar treatments C and D performed considerably as good as the conventional fertilizer treatment A. Treatments C and D also had 15% less yield than A for dry season while C had 6% less yield than A for the wet season. The good performance of the foliar treatments is attributed to the influence of Lithovit foliar fertilizer which accelerates physiological and biological processes, avails micronutrients and reduces on impact of water stress. Treatment E had the least performance in terms of all growth and yield attributes as no fertilizers were applied throughout the entire growing period. However, its overall performance was still better than the conventional continuous flooding due to the impact of SRI. The practice of AWD facilitates about 80% of free living bacteria and other microbes in and around rice roots which have nitrogen fixing ability thereby supplying nutrients to the crops hence the better performance.

The interaction between water and fertilizer applications was not significant. However, $IR_{80}B$ had the best performance in terms of growth and yield attributes followed by $IR_{50}B$. Further, the dry season performed better than the wet season for all growth and yield attributes. This is due to the low temperatures below 16°C as average minimum temperatures in this study for the wet season were 14.8 °C and 13.5 °C for the months of May and June respectively - the reproductive and ripening stages which are most prone to sterility hence justifying the low performance.

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CHAPTER THREE

Paper two

Effects of integrating deficit irrigation and carbonate foliar fertilizers into the System of Rice Intensification on water productivity

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Abstract

The use of the System of Rice Intensification (SRI), deficit irrigation and foliar fertilizer application have proved to be effective in enhancing water productivity (WP) individually. However, the information on their combined effects is limitedly known. Therefore this study evaluated the effects of integrating deficit irrigation and carbonate foliar fertilizer (Lithovit) application into SRI on water productivity. The study was conducted in Mkindo Irrigation scheme in Mvomero, Morogoro, Tanzania during the dry and wet seasons (October 2020 to June 2021). The experiment was laid out in a split plot design with three levels of irrigation for main plots which were 100% of the irrigation water requirement (40mm) imitating the SRI alternate wetting and drying pattern and induced deficit irrigation applied at 80% and 50% of the irrigation water requirement as IR_{100}, IR_{80} and IR_{50}, respectively. Irrigation was carried out at the appearance of soil cracks in IR_{100}. The sub-plot fertilizer treatments were five in number namely: (A) Diammonium Phosphate (DAP) and Urea (normal practice), (B) DAP, Urea and 100% of recommended foliar fertilizer (Lithovit Standard), (C) DAP and 50% (Lithovit and Urea), (D) Lithovit Standard only and (E) no fertilizer. The combined irrigation and fertilizer treatments tested were $IR_{100}A$, $IR_{100}B$, $IR_{100}C$, $IR_{100}D$, $IR_{100}E$, $IR_{80}A$, $IR_{80}B$, $IR_{80}C$, $IR_{80}D$, $IR_{80}E$, $IR_{50}A$, $IR_{50}B$, $IR_{50}C$, $IR_{50}D$, and $IR_{50}E$. The data was analyzed using IBM SPSS version 20 and mean separation was done using Duncan's multiple range test ($p<0.05$). The treatment B had the highest WP followed by A, C, D and E. The highest and lowest WP was 0.851 kg/m^3 and 0.562 kg/m^3 by $IR_{80}B$ and $IR_{80}E$ respectively for the dry season. For the wet season, the highest and lowest WP was 0.540 kg/m^3 and 0.306 kg/m^3 by $IR_{50}B$ and $IR_{50}E$ respectively. The high WP is attributed to the impact of induced deficits into SRI that heavily cuts down on the water losses and Lithovit that acts as a long term reservoir for carbon dioxide especially during water stress periods.

Key words: System of rice Intensification (SRI), carbonate foliar fertilizer application, deficit irrigation, water productivity

3.1 Introduction

Nearly 25% of the global population is facing water crisis (World Resources Institute (WRI), 2019) and about 52% of the world's projected 10 billion people are expected to live in water stressed areas by 2050 (MIT, 2014). This is mainly attributed to increase in population and socio-economic development exacerbated by climate change (WRI, 2019). Further, about 80% of the available water supply globally is withdrawn for agriculture, industries and urban areas (WRI, 2019) with agriculture taking the biggest share (70%) (World Bank, 2020). Rice (*Oryza sativa L*) is the primary staple food for over half of the world's population while sustaining livelihoods of more than 100 million people in Sub-Saharan Africa (SSA) (FAO, 2013). However, water scarcity is still among the major challenges facing rice production (Abdellatif, 2018). Rice production is considered most eco- unfriendly (Uphoff and Dazzo, 2016). This is attributed to the fact that rice requires about 50% of the available fresh water resources (Badawi *et al*., 2013) compared to other sectors (Uphoff and Dazzo, 2016). Field water use for rice is about 2500 mm (Bouman, 2009) which is two to three times higher than other cereals (Materu *et al.*, 2018). It is predicted that of the World's 79 million hectares of irrigated lowland rice (which provide three quarters of the World's rice supply), about 15-20 million are expected to suffer water scarcity by 2025 (IWMI, 2008). This calls for more sustainable farming practices.

In Tanzania, rice is the third most important crop consumed by about 30% of the households (FAO, 2015). About 20% of farmers are involved in rice production (Mtaki, 2018) with 80% of these being small scale farmers (Katambara *et al.*, 2016).

Tanzania is also the lead rice producer in Eastern and Southern Africa while accounting for about 9% of the total 30.8 million tonnes of African rice production (FAOSTAT, 2014). However, the biggest part of Tanzania is semi-arid with erratic rains (Kihupi *et al.*, 2015) yet over 90% of rice grown is under continuous flooding (Kangile *et al.*, 2018). Therefore, water scarcity still poses a big threat to rice production.

Deficit irrigation, the practice of supplying less water than is required for optimal crop growth is considered as one of the measures that could be undertaken to ensure optimal water utilization while maximizing production (Badawi *et al.*, 2013; Ashouri, 2014; Chai *et al.*, 2016; Materu *et al.*, 2018; Mulu and Alamirew, 2018; Ndayitegeye *et al.*, 2020). Alternate wetting and drying (AWD) is among the agronomic practices carried out under the System of Rice Intensification (SRI). SRI has been found essential in optimizing water for production (Katambara *et al.*, 2013; Reuben *et al.*, 2016a, b; Aini *et al.*, 2017; Dahiru, 2018; Kangile *et al.*, 2018; Materu *et al.*, 2018; Shamshiri *et al.*, 2018; Dinesh *et al.*, 2019; Sahoo and Verma, 2019) which implies more yield per water applied (Ashouri, 2014). Materu *et al.* (2018) deemed deficit irrigation profound in increasing water productivity of rice while reducing water losses. This involves inducing marginal stress except for critical growth stages. Isnawan *et al.* (2020) emphasized how rice is not considered an aquatic crop therefore its growth is not hampered when exposed to limited water. Badawi *et al.* (2013) cautioned against water deficit at both panicle and heading stages in order to obtain considerable grain and straw yields. According to Uphoff (2014), water stress for rice was best applied during the vegetative phase. Katambara *et al.* (2013) and Materu *et al.* (2018) reported water saving of up to 25% under SRI while Kahimba *et al.* (2014) reported 63.72% for Mkindo area in Morogoro Region. According to Tuong and Bouman (2009), a 10% reduction in water used in irrigated rice would avail 150,000 million metric cubics of water for other non-agricultural activities. Scheierling *et al.* (2016) recommended increasing WP as one of the imminent methods of managing water without increasing water allocations to agriculture. Therefore, increasing water productivity is a right step in the direction of addressing water scarcity.

Fertilizer application is an essential practice in crop production (Hashem, 2019; Raut *et al.*, 2019; Tarigan *et al.*, 2019; Gowele *et al.*, 2020). Moreover, rice requires sufficient nutrients to produce ample yields (Kumar *et al.*, 2019; Gowele *et al.*, 2020).

Senthilvalavan and Ravichandran (2019) recommended integration of organic and inorganic fertilizers for enhancing the growth and physiological attributes of rice. Further, rice fields require slow release of fertilizers (Tarigan *et al.*, 2019) yet large volumes of fertilizers are lost through leaching and fixation following basal fertilizer application (Raut *et al*., 2019). On the contrary, nutrients supplied through foliar spray are rapidly absorbed by plants (Nagula and Prabhakar, 2016; Kumar and Nagesh, 2019; Raut *et al.,* 2019). In addition, foliar fertilizer application is associated with fertilizer and water use efficiency, correcting nutrient deficiencies, ease of application, uniform fertilizer application and lower costs (Badawi *et al.,* 2013; Kumara *et al.,* 2019; Kumar and Nagesh, 2019; Raut *et al.,* 2019; Narayan *et al.,* 2020). Zhang *et al*. (2012) analyzed water use efficiency and physiological response of rice cultivars and observed that AWD availed higher water productivity than continuous flooding as a result of proper water and fertilizer management. Hashem (2019) recommended the use of foliar fertilizer application together with the conventional fertilizers at the various growth stages in order to enhance rice productivity. Ndayitegeye *et al.*(2020) recommended deficit irrigation coupled with irrigation intervals as an essential method of saving water without affecting vegetative growth while having no significant impact on yield. Toromanova and Georgieva (2017) reported a 13.1% increase in productive tillering capacity following application of calcium carbonate (Lithovit) foliar fertilizer which was the highest among other foliar treatments used.

Individually, deficit irrigation, SRI and foliar fertilization have been associated with increasing water productivity. However, there is limited information on their combined impact. Therefore this study evaluates the effect of integrating deficit irrigation and carbonate foliar fertilizer application into SRI on consumptive use and water productivity of rice under (1) different water applications, (2) different fertilizer applications and (3) the interaction between the water and fertilizer applications.

3.2 Materials and Methods

3.2.1 Description of the Study Area

The study was conducted at Mkindo farmer managed irrigation scheme in Morogoro, Tanzania. This choice was made given that the scheme is among the few farmer-based schemes which practices SRI. Small scale irrigation schemes are considered essential in improving the livelihoods of majority of small scale farmers in Tanzania (Fundi and

Kinemo, 2018). Mkindo irrigation scheme is located in Mkindo village, Mvomero District, Morogoro Region in eastern Tanzania between latitude 6^{0}16’ and 6^{0}18’ South, and longitude 37^{0}32’ and 37^{0}36’ East as shown in Fig. 3.1. Its altitude ranges between 345 m and 365 m above mean sea level and is about 85 km from Morogoro Municipality (Kahimba *et al.*, 2014). The major crop grown in the area is rice under surface irrigation supplied by Mkindo Perennial River.

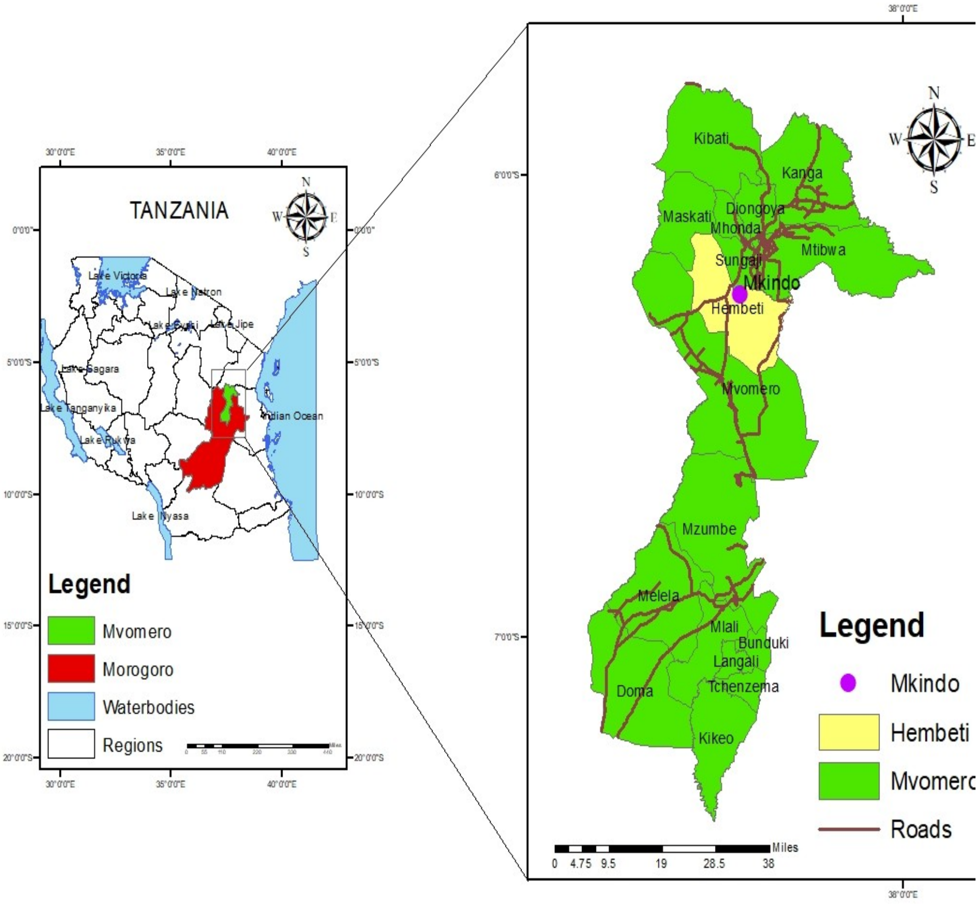

Figure 3.1: Location of the study area

The study area is characterized by an average annual temperature of 24.95˚C, with a minimum temperature of 15.8˚C in July and a maximum temperature of 33.8˚C in February as shown in Fig. 3.2. The study area has a bimodal rainfall regime which determines the two rice growing seasons- dry season (*vuli*) with short rains starting in October to December and wet season (*masika*) with long rains starting from March to May. Rainfall in Mkindo usually starts in October with an increased trend until May with peak rainfall in April. The trend then decreases from May until July where the least rainfall is attained. The average annual total rainfall ranges between 700 and 1600 mm (Mtibwa Sugar Estate Meteorological Station).

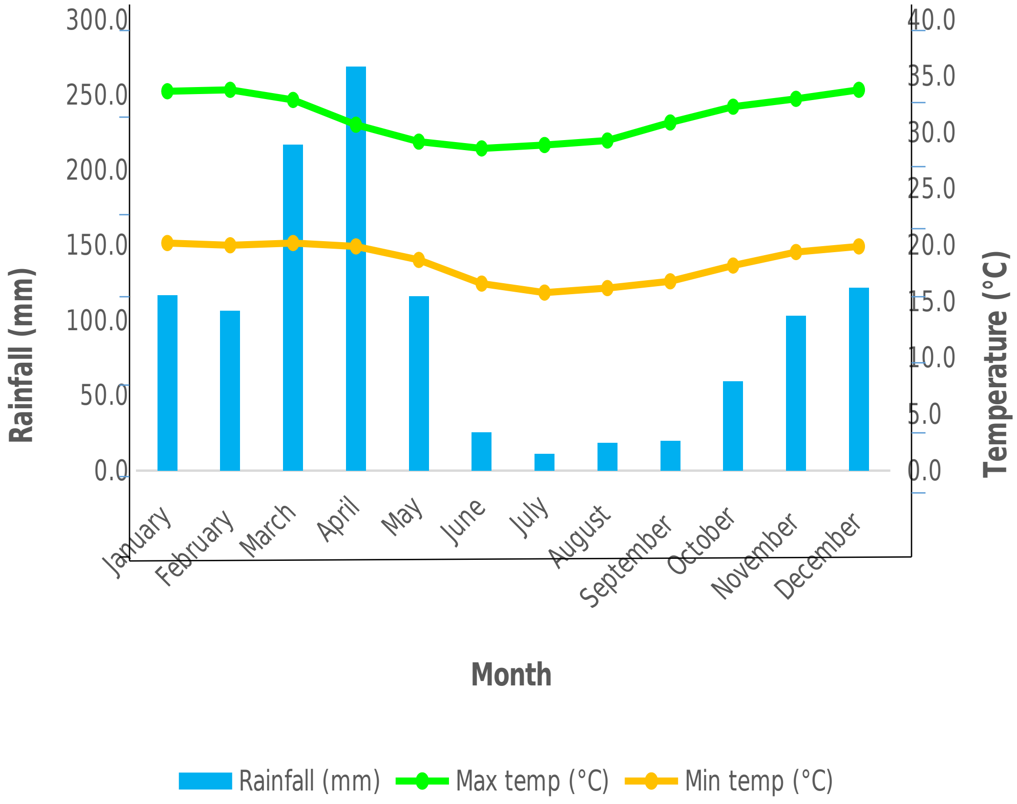

Figure 3.2: Monthly Rainfall, Maximum and Minimum temperature from 2000-2020

Source: Mtibwa Sugar Estate Meteorological Station

3.2.2 Experimental design and lay out

The experiment was laid out in a split plot design with three levels of irrigation for main plots which were 100% of the irrigation water requirement (40mm) imitating the SRI alternate wetting and drying pattern and induced deficit irrigation applied at 80% and 50% of the irrigation water requirement as IR_{100}, IR_{80} and IR_{50}, respectively. Irrigation was carried out at the appearance of soil cracks in IR_{100}. The sub-plot fertilizer treatments were five in number namely: (A) Diammonium Phosphate (DAP) and Urea (normal practice), (B) DAP, Urea and 100% of recommended foliar fertilizer (Lithovit Standard), (C) DAP, 50% (Lithovit and Urea), (D) Lithovit Standard only and (E) no fertilizer. The combined irrigation and fertilizer treatments tested were $IR_{100}A$, $IR_{100}B$, $IR_{100}C$, $IR_{100}D$, $IR_{100}E$, $IR_{80}A$, $IR_{80}B$, $IR_{80}C$, $IR_{80}D$, $IR_{80}E$, $IR_{50}A$, $IR_{50}B$, $IR_{50}C$, $IR_{50}D$ and $IR_{50}E$. All the treatments were randomly allocated and replicated three times. An individual plot size was 4 m × 2 m (8 m^2) each separated from the other by 0.5 m buffer zone to prevent lateral movement of water from one plot to another as shown in Fig. 3.3.

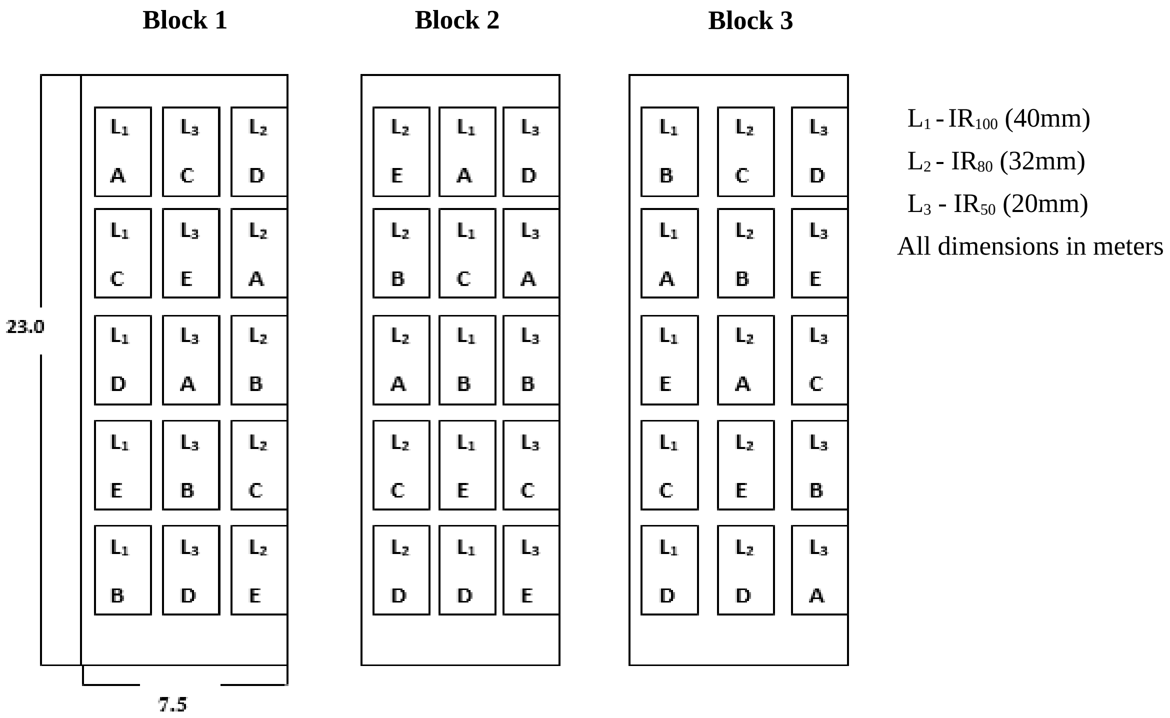

Figure 3.3: Set up of the experiment

3.2.3 Agronomic practices

The agronomic practices that were carried out include nursery and field preparation, transplanting, fertilizer application and weeding. During land preparation, the field was properly puddled using a power tiller. Levelling was also carried out to aid uniform wetting of the soil. Proper drainage was maintained to facilitate water discharge especially during the rainy period. The SARO (TXD 306) rice variety was used as it is well suited to the conditions of Mkindo and was recommended by the Ministry of Agriculture, Tanzania (Kahimba *et al.*, 2014). During nursery preparation, only viable seeds were used and were identified by submerging all the seeds in a salty solution in which an egg would float. All the seeds that floated were considered inferior and were discarded. Seed priming was then done by soaking the seeds in clean water to enhance the rate of seedling emergence and germination.

One seedling per hill was transplanted at the age of 10 days using 25 cm × 25 cm spacing (Reuben *et al.*, 2016b). While considering particular sub-plots with their respective treatments, DAP was applied only once on the second day after transplanting

(DAT), Urea was applied at two different times, 30 and 60 DAT while all foliar fertilizers were applied at 30, 60 and 81 DAT. Urea and DAP were applied at a rate of 125kg/ha while all foliar treatments at 1kg/ha in 100 litres of water. The fertilizer compositions are as shown in Table 3.1.

Table 3.1: Fertilizer composition for the various treatments

S/N	Fertilizers	Composition
1.	DAP	Nitrogen, N (18%) Phosphate, PO_4 (46%)
2.	Urea	Nitrogen (46%)
3.	Lithovit Standard	Calcium carbonate, $CaCO_3$ (60%) Calcium oxide, CaO (35%) Silicon dioxide, SiO_2 (12%) Magnesia, Mg (2%) Iron, Fe (1%) Manganese, Mn (0.02%)
4.	Lithovit and Urea (50%)	Calcium Carbonate (33%) Nitrogen (21%) Calcium oxide (18.5%) Silicon dioxide (6.5%) Magnesia (1.2%) Iron (0.5%) Manganese (0.01%)

Weeding and spraying of pesticides against white fly infestation was carried out four and two times during the dry and wet seasons respectively. Before harvesting, a 14 days dry period was observed to allow for maximum transfer of nutrients to the grains. The rice was harvested manually with serrated edged sickles at 112 days when about 90% of the panicles had ripened spikelets and threshed using wooden sticks.

3.2.4 Consumptive use

Consumptive use of the various treatments was estimated using the water balance method (James, 1988). Water balance involves assessing the difference between the inflow and outflow of water during a specific period of time as shown in Eq. 3.1 (James, 1988).

$$ET = I + P + C_p - D_p \pm \Delta S - R_f \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

Where, ET is the evapotranspiration (mm), I is the depth of irrigation water (mm), P is precipitation (mm), C_p is the capillary rise (mm), D_p is the water loss by seepage + percolation (mm), ΔS is the change in the soil moisture content and R_f is runoff loss (mm).

Capillary rise was considered negligible due to the flat nature of the field and low intensity irrigation (Todorovic *et al.,* 2020; Biswas *et al.,* 2021). Runoff was also considered negligible due to the existing bunds. The principal water losses in rice fields are evapotranspiration, seepage + percolation, therefore, the equation was reduced to Eq. 3.2;

$$ET = I + P - D_p \pm \Delta S \ldots\ldots\ldots\ldots \quad (3.2)$$

The depth of irrigation was pre-determined as IR_{100}, IR_{80} and IR_{50} with water depths of 40, 32 and 20 mm respectively. Precipitation data for the two seasons was obtained from Mtibwa Sugar Estate Meteorological Station and effective rainfall was determined using the Soil Conservation Service of the United States Department of Agriculture (USDA SCS) method with the aid of CROPWAT 8.0 software.

Soil samples were collected at the start and end of the experiment from which soil moisture content was determined using gravimetric method. The soil samples were placed in an oven for 24 hours at 105°C and the amount of water in the soil was determined by subtracting the oven dry weight from the initial field soil weight. Moisture content was then computed by converting the gravimetric Eq. 3.3 into volumetric Eq. 3.4 and 3.5 (Mulu and Alamirew, 2018).

$$\theta_m = \frac{M_w}{M_S} x\, 100 \ldots\ldots\ldots\ldots \quad (3.3)$$

Where θ_m is water content on mass basis (%), M_w is mass of water (g) and M_s is mass of soil after oven drying (g)

$$\theta_v = \theta_m\, x\, \rho_b \ldots\ldots\ldots\ldots \quad (3.4)$$

Where θ_v is water content on volume basis (%) and ρ_b is soil bulk density (g/cm^3)

$$TAW = \theta_V\, x\, 10 \ldots\ldots\ldots\ldots \quad (3.5)$$

Where *TAW* is total available water in *mm/m*

Seepage + Percolation losses (D_p) were determined using an improvised lysimeter (Singha *et al.,* 2014 and Biswas *et al.,* 2021) where a 200L water drum was cut into two equal parts as shown in Fig. 3.4. The closed part (A) of the drum was used to estimate evapotranspiration (ET_A) while the hollow part (B) was used to determine D_p with evapotranspiration (ET_B). Water level readings were taken at the same time on a daily basis for a month. Seepage + percolation was obtained as the difference between Eq. 3.6 and Eq. 3.7. (James, 1988).

For the closed part (A): $I+P=ET_A$………………………………………………… (3.6)

For the hollow part (B): $I+P=ET_B-D_p$…………………………………………… (3.7)

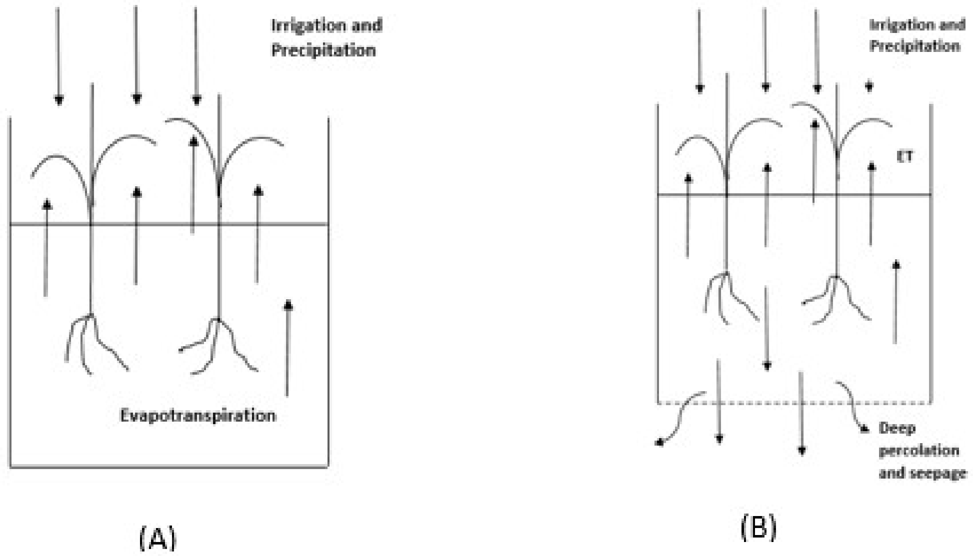

Figure 3.4: (A) Closed end lysimeter, (B) Open end lysimeter

3.2.5 Water productivity

Grain yield was attained by randomly harvesting one square meter of rice from each plot which was manually threshed, air dried to constant weight and measured using a digital electronic balance. Water productivity (WP) was determined using Eq. 3.8 (Zoundou *et al.,* 2019).

$$\wp = \frac{Yield\left(kg/m^2\right)}{Total\,water\,applied\left(m\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.8)$$

3.2.6 Data analysis

Analysis of Variance (ANOVA) for water productivity was done using IBM SPSS version 20 at 5% probability level and Duncan's multiple range test was used for mean separation. Correlation and regression analysis was done to ascertain the relationship of direct and indirect influence between yield and water productivity.

3.3 Results and Discussion

3.3.1 Water balance components

3.3.1.1 Irrigation, precipitation and change in soil moisture

Irrigation applied for IR_{100}, IR_{80} and IR_{50} for the dry season was 960, 936 and 900 mm respectively while 1080, 1032 and 960 mm was applied for the wet season respectively. Effective precipitation for the dry and wet season was 345.2 and 277.5 mm respectively indicating that the wet season received 20% less rainfall than the dry season. The seasonal variation could be attributed to the impact of climate change. The change in soil moisture ranged between (167.0- 290.4 mm) and (200.7- 266.0 mm) for the dry and wet seasons respectively.

3.3.1.2 Deep percolation and seepage

The dry and wet season average deep percolation and seepage (D_p) rate was 1.20 and 1.10 mm/day respectively with an average D_p of 1.15 mm/day. The D_p values fall in the range of Singha *et al.* (2014) who observed that D_P varied from 1 to 8.50 mm/day. Further, according to Chapagain and Hoeskstra (2010), percolation loss varies from 2 – 6 mm/day for clay and sandy soils respectively. The low D_p values are as a result of AWD under SRI that drastically cuts down on unproductive water outflows. This is in agreement with Tuong and Bouman (2009) and Ashouri (2014). Basha and Sarma (2017) also recommended less than 50mm as standing water depth in rice fields in order to minimize percolation losses which is in agreement with this study.

3.3.2 Consumptive use

Consumptive use (ET) is a key indicator for reliability, equity and adequacy in water use. Table 3.2 shows the dry and wet season responses of the different water applications IR_{100}, IR_{80} and IR_{50} and fertilizer treatments A, B, C, D and E on consumptive use.

Table 3.2: Consumptive use for the water and fertilizer treatments in the dry and wet seasons

		Consumptive use (mm)	
WAP	**TRT**	**Dry season**	**Wet season**
IR_{100}	A	1337.8	1487.3
	B	1461.2	1500.3
	C	1402.8	1492.3
	D	1445.4	1435.0
	E	1444.0	1445.0
IR_{80}	A	1280.4	1388.7
	B	1379.1	1399.1
	C	1332.4	1392.7
	D	1366.5	1346.9
	E	1365.4	1354.9
IR_{50}	A	1194.3	1240.8
	B	1256.0	1247.3
	C	1226.8	1243.3
	D	1248.1	1214.7
	E	1247.4	1219.7

For the dry season, across all water regimes, B had the highest ET followed by D, E, C and A. Consumptive use for the dry season ranged between (1337.8-1461.2 mm), (1280.4-1379.1 mm) and (1194.3-1256.0 mm) for IR_{100}, IR_{80} and IR_{50} respectively. IR_{100}B had the highest ET while IR_{50}A had the least ET of 1461.2 and 1194.3 mm respectively. For the wet season, across all water regimes, B had the highest ET followed by C, A, E and D. Consumptive use ranged between (1435.0-1500.3 mm), (1346.9-1399.1 mm) and (1214.7-1247.3 mm) for IR_{100}, IR_{80} and IR_{50} respectively. IR_{100}B had the highest ET while IR_{50}D had the lowest ET of 1500.3 and 1214.7 mm respectively.

The findings of this study are in consonance with Bouman (2009) who highlighted that total water input varies between 700 and 5300 mm with 1500-2000 mm being water input for especially lowland areas. Also El-sayed and El-monem (2017) reported consumptive use values in the range of 901.3 and 1000 mm at different soil moisture levels close to the findings of this study. However, ET attained was higher than Zhao *et al.* (2010) who reported consumptive use of 898.3 mm under SRI.

3.3.3 Water productivity

3.3.3.1 Effect of water applications on water productivity

The impact of the different water regimes IR_{100}, IR_{80} and IR_{50} on water productivity was statistically non-significant ($p>0.05$) in both seasons. Fig. 3.5 shows the water productivity of IR_{100}, IR_{80} and IR_{50} water regimes for both the dry season (DS) and wet season (WS). The highest WP of 0.6921 kg/m^3 and 0.4241 kg/m^3 was attained by IR_{100} in the dry and wet seasons respectively.

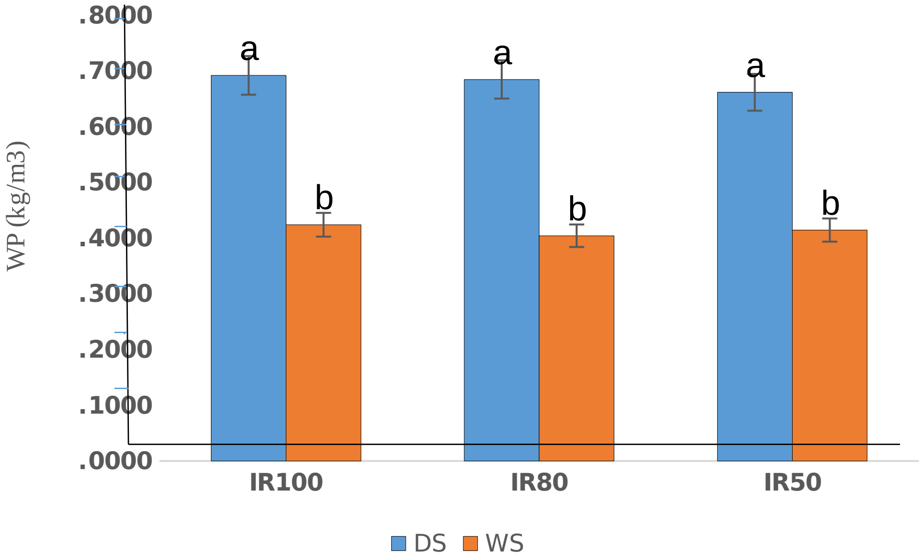

Figure 3.58: Water productivity of IR_{100}, IR_{80} and IR_{50} for the dry and wet seasons

The lowest WP in the dry and wet seasons was 0.6617 (IR_{50}) and 0.4042 (IR_{80}) respectively. The dry season had greater WP than the wet season. The no significant difference in water productivity among the water treatments was due to heavy rainfall during the second month (November 2020) and first month (March 2021) of the vegetative phase for both the dry and wet seasons respectively which disrupted water regimes. This was also observed by Materu *et al.* (2018).

3.3.3.2 Effect of fertilizer applications on water productivity

The impact of different fertilizer applications A, B, C, D and E on water productivity was significantly different ($p<0.05$) in both seasons as shown in Fig. 3.6. In both seasons, B had the highest WP followed by A, C and D while E had the least.

The highest WP in both the dry and wet seasons was 0.808 kg/m^3 and 0.519 kg/m^3 respectively. The lowest WP in both the dry and wet season was 0.569 kg/m^3 and 0.315 kg/m^3 respectively. The dry season had higher WP than the wet season.

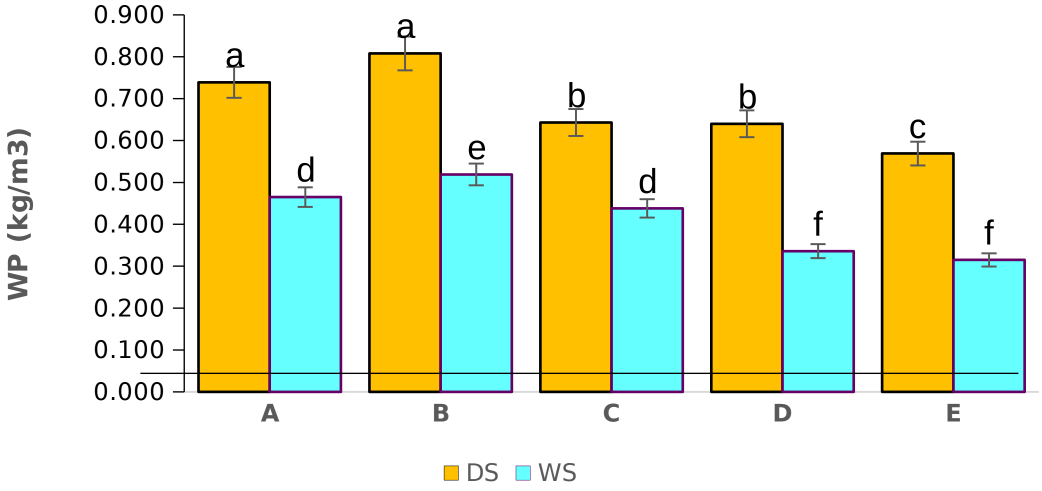

Figure 3.6: Dry and wet season water productivity for treatments A, B, C, D and E

(Mean values followed by different letter within columns differ significantly at p < 0.05 according to Duncan's Multiple-range test).

For the dry season, treatments A, B, C and D had 30%, 42%, 13% and 12% respectively more WP than E while for the wet season, treatments A, B, C and D had 48%, 65%, 39% and 7% respectively more WP than E. The conventional fertilizer application A had 15% and 6% more WP than foliar treatment C and with only 15% and 38% more WP than foliar treatment D for the dry and wet season respectively. Treatment B had the highest WP attributed to the combination of both basal and foliar fertilizers that led to yield enhancement while treatment E had the least WP as no fertilizers were applied throughout the entire growing period which implied less yield and less WP in the long run.

3.3.4 Interaction between water and fertilizer applications

The interaction between different water and fertilizer treatments was not significant ($p>0.05$). Fig. 3.7 shows the interaction between different water applications IR_{100}, IR_{80} and IR_{50} with the various fertilizer treatments A, B, C, D and E for the dry season (DS) and wet season (WS) on water productivity.

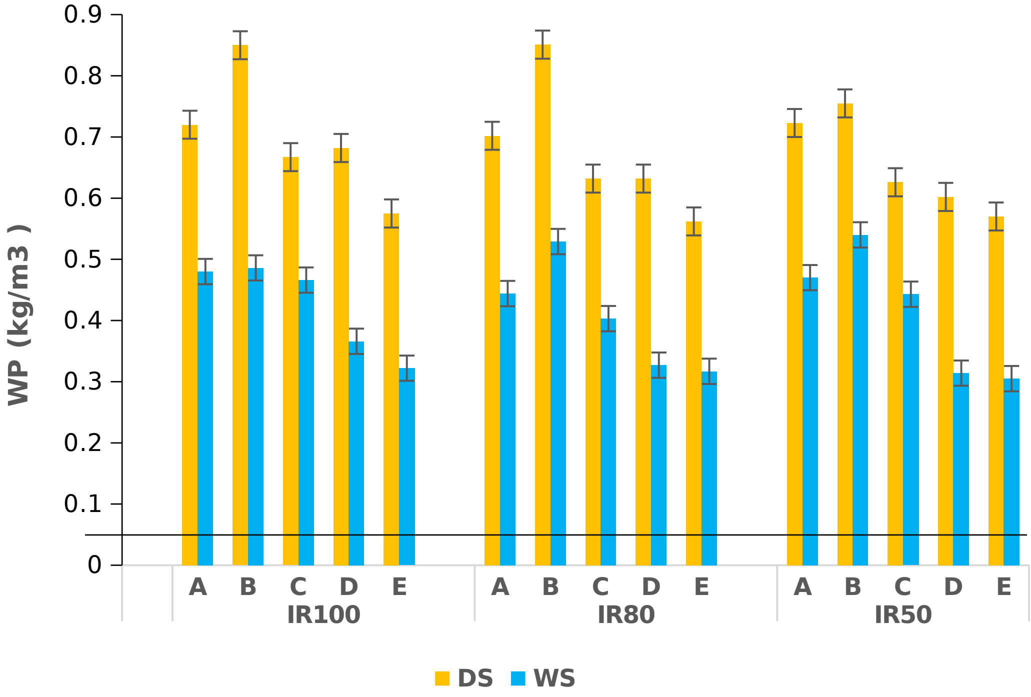

Figure 3.7: Dry and wet season water productivity for water and fertilizer applications interactions

For the dry season, water productivity ranged between 0.575-0.848 kg/m^3, 0.562-0.851 kg/m^3 and 0.570-0.755 kg/m^3 for IR_{100}, IR_{80} and IR_{50} respectively. Water productivity ranged between 0.322-0.486 kg/m^3, 0.317-0.529 kg/m^3 and 0.306-0.540 kg/m^3 for IR_{100}, IR_{80} and IR_{50} respectively for the wet season. Across all water applications, treatments B and E had the highest and lowest WP respectively. The highest and lowest WP under the dry season was 0.851 kg/m^3 and 0.562 kg/m^3 by IR_{80}B and IR_{80}E respectively. The highest and lowest WP under the wet season was 0.540 kg/m^3 and 0.306 kg/m^3 by IR_{50}B and IR_{50}E respectively.

The system of rice intensification is aimed at reducing water input without having any significant impact on yield. The WP values in this study are in agreement with studies done under SRI such as Zhang *et al.* (2012) who observed WP in the range of

0.78 – 1.09 kg/m^3. Ashouri (2014) also observed that WP of lowland rice varied from 0.2 to 1.2 kg/m^3 which is in range with WP of this study. Ndiiri *et al.* (2017) reported average WP of 1.2 kg/m^3 under SRI which is higher than the maximum WP reported in this study.

However, the WP in this study is higher than that reported by Zoundou *et al.* (2019) who observed average values of 0.15, 0.19 and 0.18 kg/m^3 for IR_{100}, IR_{80} and IR_{50} respectively. Too *et al.* (2019) and Biswas *et al.* (2021) also reported WP of 0.5 kg/m^3 and 0.39 kg/m^3 respectively which is lower than WP in this study. Further, Kombe (2012) reported the WP values for Mkindo area to fall within the range of 0.29 - 0.47 kg/m^3 which is less than the WP in this study.

The relatively high water productivity values of rice under this study are attributed to the reduced unproductive losses such as evaporation, seepage and deep percolation (Tuong and Bouman, 2009). Alternate wetting and drying can drastically cut down the unproductive water outflows and increase water productivity since the period of standing water is limited. This is in agreement with Tuong and Bouman (2009) and Ashouri (2014). In addition, the impact of Lithovit foliar fertilizers which act as a long term reservoir for carbon dioxide (CO_2) that enhances growth and productivity of plants even under water stress conditions cannot be under looked. Foliar fertilizers played a key role in enhancing the yield performance of foliar treatments. This is in agreement with Shallan *et al.* (2016).

The dry season had more WP than the wet season due to the differences in the cropping seasons that affected crop growth and development. This was also observed by Materu *et al.* (2018). According to Ndiiri *et al.* (2017), low temperatures below 16 °C affect crop development at the various growth stages and can lead to spikelet sterility where less grain is produced. Moreover, actual yield of rice depends on the amount of starch that fills the spikelets especially during the ripening stage. The average minimum temperatures in this study for the wet season were 14.8 °C and 13.5 °C for the months of May and June 2021, the reproductive and ripening stages respectively which are most prone to sterility. This therefore led to lower yield in the wet season compared to the dry season hence justifying the low water productivity in the wet season.

The relationship between yield and water productivity for the dry and wet seasons is as shown in Fig. 3.8.

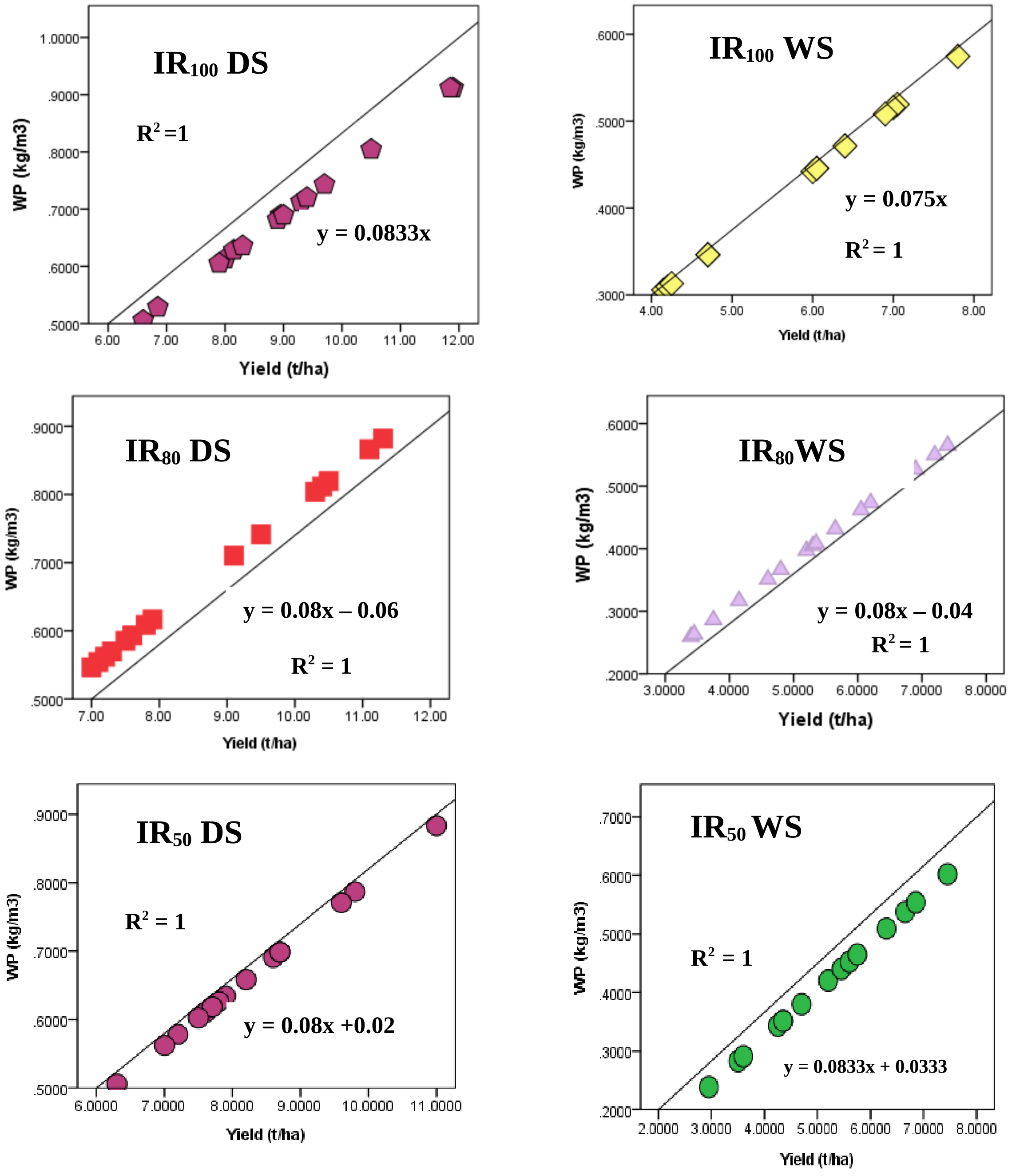

Figure 3.8: Relationship between water productivity (WP) and yield for the dry season (DS) and wet season (WS) for water regimes IR_{100}, IR_{80} and IR_{50}

For both the dry and wet seasons, the coefficient of determination revealed a very strong positive correlation between yield and water productivity of 1.00 which was significant ($p<0.01$). This implies that any variation in yield explains 100% the variation in WP therefore the increase in WP is attributed to the increase in yield. Both conventional and foliar fertilizers played a key role in enhancing the yield performance together with AWD under SRI that reduced on the water requirements.

3.4 Conclusion

Water productivity is very crucial especially in times of diminishing or limited water resources. In this study, water application IR_{100} had the best WP followed by IR_{80} while IR_{50} had the least in both seasons. Among fertilizer applications, B had the highest WP followed by A, C and D while E had the least in both the dry and wet seasons. The interaction between water and fertilizer applications was not significant. Therefore it is deduced that the integration of deficit irrigation and carbonate foliar fertilizers into SRI led to relatively high water productivity. This is attributed to the AWD practice under SRI that cut down on unproductive water losses since there was no standing water for a long period of time. In addition, calcium carbonate fertilizers played a key role in enhancing yield performance of foliar treatments by acting as a long term reservoir for carbon dioxide especially during water stress periods. The general increase in yield therefore led to high WP. Increasing WP will imply more yield per drop of irrigation water used to the farmer and while for the country, it will imply more value for every unit of water used.

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CHAPTER FOUR

Paper three

Economic analysis of integrating deficit irrigation and Carbonate foliar fertilizer application into the System of Rice Intensification

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Abstract

The System of Rice Intensification (SRI), deficit irrigation and foliar fertilizer application have individually been earmarked as one of the cost effective means of enhancing rice productivity. However, the economic information on their combined effects is limitedly known. Therefore, a study was conducted to evaluate the economic implications of integrating deficit irrigation and carbonate foliar fertilizer (Lithovit) application into SRI. This study was conducted in Mkindo Irrigation scheme in Mvomero, Morogoro, Tanzania. The experiment was laid out in a split plot design with three levels of irrigation for main plots which were 100% of the irrigation water requirement (40mm) imitating the SRI alternate wetting and drying pattern and induced deficit irrigation applied at 80% and 50% of the irrigation water requirement as IR_{100}, IR_{80} and IR_{50}, respectively. Irrigation was carried out at the appearance of soil cracks in IR_{100}. The sub-plot fertilizer treatments were five in number namely: (A) Diammonium Phosphate (DAP) and Urea (normal practice), (B) DAP, Urea and 100% of recommended foliar fertilizer (Lithovit Standard), (C) DAP and 50% (Lithovit and Urea), (D) Lithovit Standard only and (E) no fertilizer. The combined irrigation and fertilizer treatments tested were $IR_{100}A$, $IR_{100}B$, $IR_{100}C$, $IR_{100}D$, $IR_{100}E$, $IR_{80}A$, $IR_{80}B$, $IR_{80}C$, $IR_{80}D$, $IR_{80}E$, $IR_{50}A$, $IR_{50}B$, $IR_{50}C$, $IR_{50}D$, and $IR_{50}E$. The data was analyzed using IBM SPSS version 20 at 5% probability level. Water application IR_{100} had the highest benefit-cost ratio (BCR) for the dry and wet seasons of 2.81 and 1.67 respectively. The highest and least BCR among fertilizer treatments was attained by D

(3.45) and A (1.96) respectively (dry season) with C (1.74) and A (1.06) for the wet season. $IR_{100}D$ had the highest BCR of 3.82 and 2.08 for the dry and wet season respectively. All BCR >1 except $IR_{80}A$ and $IR_{50}A$ each with a BCR of 0.97. Foliar treatments had higher BCR than conventional practice due to the impact of calcium carbonate fertilizers which cost effectively enhanced production.

Key words: System of rice intensification (SRI), deficit irrigation, carbonate foliar fertilizer, benefit-cost ratio.

4.1 Introduction

Rice (*Oryza sativa L*) is the primary staple food for over half of the world's population while sustaining livelihoods of more than 100 million people in Sub-Saharan Africa (SSA) (FAO, 2013). Globally, rice ranks third after wheat and maize in terms of production (FAOSTAT, 2014) with a daily consumption by more than three billion people (GRiSP, 2013). In Tanzania, rice is the most important food and commercial crop after maize consumed by about 30% of the households (FAO, 2015) while accounting for over 80% of total production in Eastern Africa (Rugumamu, 2014). Further, about 20% of farmers in Tanzania are involved in rice production (Mtaki, 2018) with 80% of these being small scale farmers (Katambara *et al.*, 2016). However, the rice yield gap for Tanzania is over 87% (Senthilkumar *et al.*, 2018). This is attributed to the generally low rice yields ranging from 1.1 t/ha under rainfed lowland conditions to 3.5 t/ha under irrigated conditions (SRI-Rice, 2020) which is below the world's average yield of 4.31 t/ha (FAO, 2015). Despite its central role in food security and economic development, rice production in Tanzania is faced with a number of constraints such as low rice yielding varieties, weed infestation, prevalence of pests and diseases with water scarcity and poor/low fertilizer application being of major concern.

Due to the existing constraints facing rice production in Tanzania, various researchers have been engaged in assessing the capacity of the System of Rice Intensification (SRI) to curb these constraints (Katambara *et al.*, 2013; Reuben *et al.*, 2016a, b; Kangile *et al.*, 2018; Materu *et al.*, 2018; Gowele *et al.*, 2020). Originally from Madagascar, SRI is becoming profound over time across Asia and Sub-Saharan Africa (Katambara *et al.*, 2013; Uphoff, 2014). This is cognizant of the fact that SRI is associated with optimum use of capital, higher productivity and less input costs (Katambara *et al.*, 2013; Uphoff, 2014; Reuben *et al.*, 2016a, b; Dinesh *et al.*, 2019; Isnawan *et al.*, 2020) regardless of the rice varieties used (Dahiru, 2018). Uphoff (2002) reported yield increase of about 50-100%, and 200-300% where the initial level of production was low and reduced water use by 25–50% (Sato and Uphoff, 2015; Dahiru, 2018). Further, about 80 – 90% of seed rate is saved under SRI (Dahiru, 2018) as it requires about 4-10 kg (Abdellatif, 2018) of seeds per hectare compared to the 30-60 kg needed under conventional flooding.

First introduced to Tanzania in 2006 by Kilombero Plantations Limited (Katambara *et al.*, 2013), SRI is one of the strategies being capitalized upon by both government and the private sector to improve rice productivity. Since 2013, SRI has spread to other areas such as Mkindo and Dakawa in Morogoro Region and in the Mwanza and Kilimanjaro Regions (SRI-Rice, 2020). Over time, farmer acceptability and adoption of SRI in Tanzania has increased given its profitability, simplicity and compatibility with existing farming practices. Kahimba *et al.* (2014) indicated that SRI resulted into higher grain yield of about 4.7 – 6.3 t/ha unlike conventional practice with about 3.8 t/ha. SRI also demonstrated water saving of up to 63.72% for Mkindo area in Morogoro Region (Kahimba *et al.,* 2014). Katambara *et al.* (2013) and Materu *et al.* (2018) reported yield increase ranging from 6-8 t/ha and water saving of up to 25% under SRI. Therefore, SRI has been imminent in efficiently utilizing scarce land, labour, water and capital in addition to being readily accessible to poor farmers (Nayak *et al.,* 2016; Uphoff and Dazzo, 2016; Dinesh *et al.,* 2019).

In order to achieve more production per unit area, fertilization is an essential practice in crop production (Hashem, 2019; Gowele *et al.*, 2020). Rice requires sufficient nutrients to produce ample yields (Kumar *et al.*, 2019; Gowele *et al.,* 2020). Moreover, micronutrients are also very essential in the production of rice (Khan and Iqbal, 2018). However, production becomes costly when fertilizer expenses are factored in (Dinesh *et al.,* 2019). Further, the use of low or excess amount of fertilizers compromises the soil quality and crop yield in addition to high production costs (Raut *et al.,* 2019). Rice fields require slow release of fertilizers (Tarigan *et al.,* 2019) yet large volumes of fertilizers are lost through leaching and fixation following basal fertilizer application (Raut *et al*., 2019). On the contrary, nutrients supplied through foliar spray are rapidly absorbed by plants (Kumar and Nagesh, 2019; Raut *et al.,* 2019). Fageria *et al.* (2009) observed that crop response to foliar fertilizers takes about two days with basal fertilizers taking between five to six days. Foliar fertilizer application is also tolerant to unfavourable weather conditions (Kumar and Nagesh, 2019) while using less fertilizers thereby saving on farmers’ income (Hashem, 2019; Kaleri *et al.,* 2019). Further, foliar fertilizers are reported to have significant impact on the growth and yield of paddy rice (Kumar and Nagesh, 2019; Raut *et al.*, 2019). Hashem (2019) recommended the use of foliar fertilizer application together with the conventional fertilizers at the various growth stages in order to enhance rice productivity. Badawi *et al.* (2013) affirmed that the interaction between foliar fertilizer application and deficit irrigation had significant impact on the yield of rice. Dinesh *et al.* (2019) recommended the integration of organic and inorganic fertilizers so as to increase gross returns.

Deficit irrigation, SRI and foliar fertilizer application have individually proved to be effective in subsidizing rice production costs. However, the economic implications of their combination is limitedly known. Therefore, this study evaluates the economic implications using the benefit cost ratio (BCR) of integrating deficit irrigation and carbonate foliar fertilizer application into SRI under (1) different water applications (2) different fertilizer applications and (3) if any interaction exists between the water and fertilizer applications. The cost benefit analysis is intended to help farmers make informed decisions on the most feasible options.

4.2 Materials and Methods

4.2.1 Description of the study area

The study was conducted at Mkindo farmer managed irrigation scheme in Morogoro, Tanzania. This choice was made given that the scheme is among the few farmer-based schemes which practices SRI. Small scale irrigation schemes are considered essential in improving the livelihoods of majority of small scale farmers in Tanzania (Fundi and Kinemo, 2018). Mkindo irrigation scheme is located in Mkindo village, Mvomero District, Morogoro Region in eastern Tanzania between latitude $6^0$16’ and $6^0$18’ South, and longitude $37^0$32’ and $37^0$36’ East as shown in Fig. 4.1. Its altitude ranges between 345 m and 365 m above mean sea level and is about 85 km from Morogoro Municipality (Kahimba *et al.*, 2014). The major crop grown in the area is rice under surface irrigation supplied by Mkindo Perennial River.

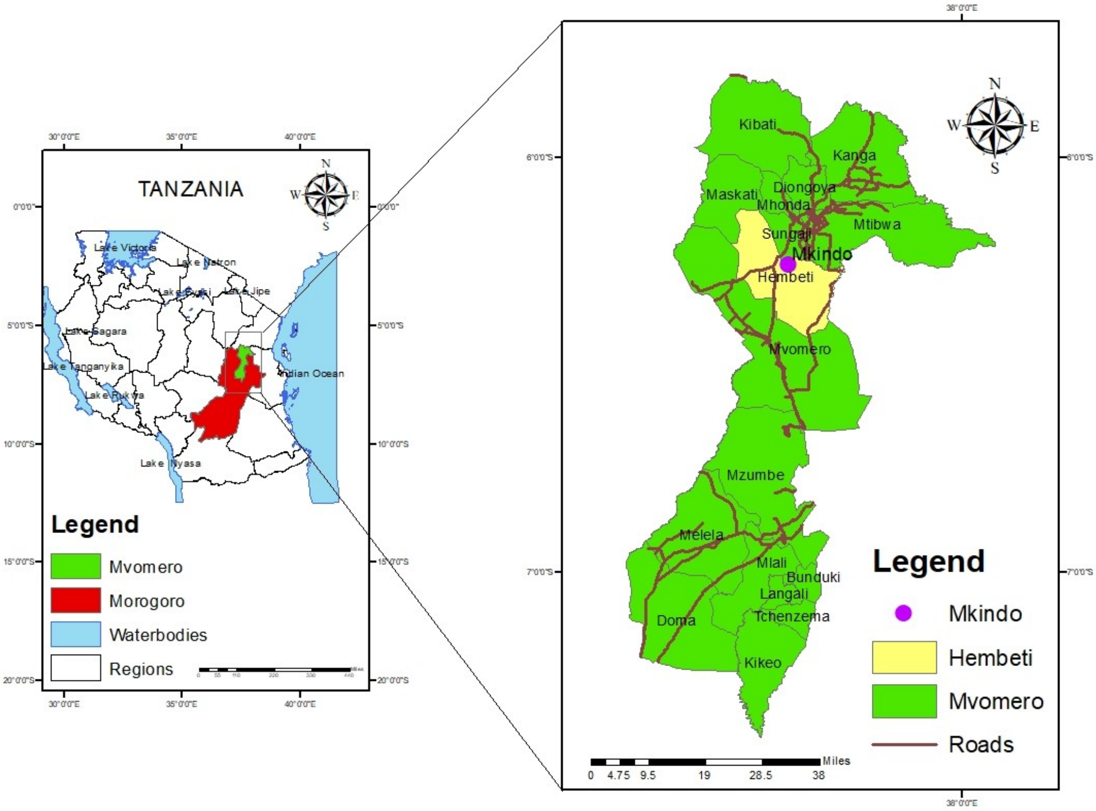


Figure 4.1: Location of the Study area

The study area is characterized by an average annual temperature of 24.95˚C, with a minimum temperature of 15.8˚C in July and a maximum temperature of 33.8˚C in February as shown in Fig. 4.2. The study area has a bimodal rainfall regime which determines the two rice growing seasons - dry season (*vuli*) with short rains starting in October to December and wet season (*masika*) with long rains starting from March to May. Rainfall in Mkindo usually starts in October with an increased trend until May with peak rainfall in April. The trend then decreases from May until July where the least rainfall is attained. The average annual total rainfall ranges between 700 and 1600 mm (Mtibwa Sugar Estate Meteorological Station).

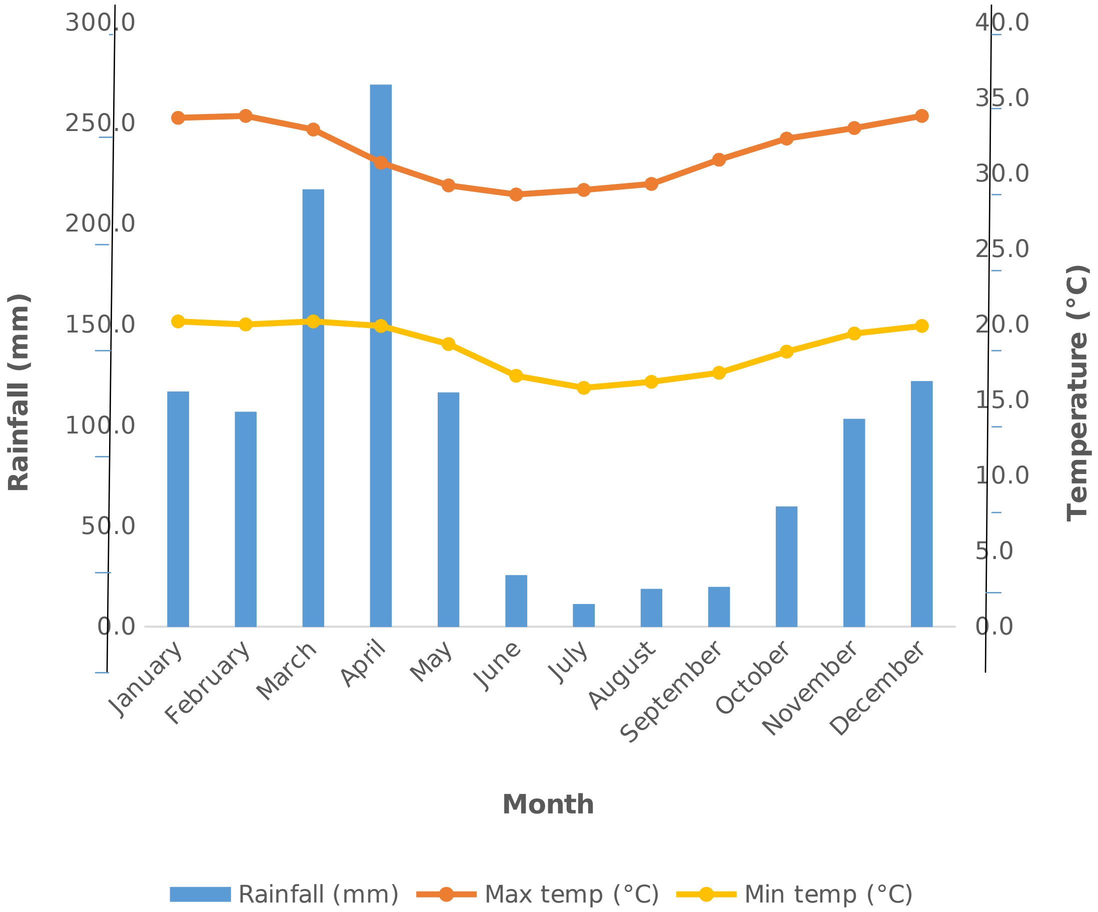


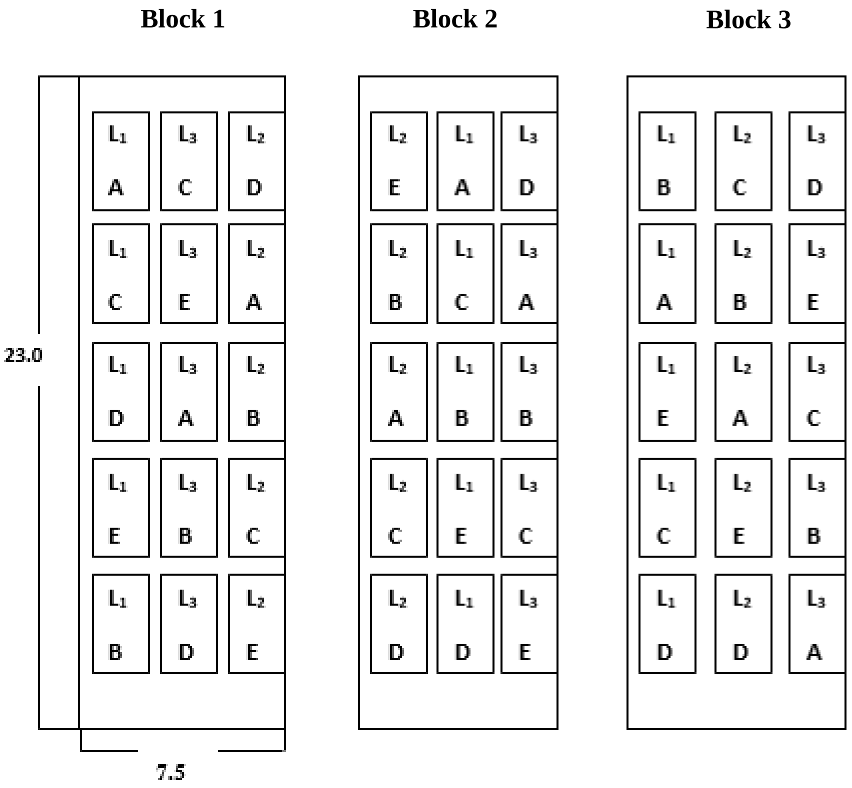
Figure 4.2: Average Monthly Rainfall, Maximum and Minimum temperature from 2000-2020

Source: Mtibwa Sugar Estate Meteorological Station

4.2.2 Experimental design

The experiment was laid out in a split plot design with three levels of irrigation for main plots which were 100% of the irrigation water requirement (40mm) imitating the SRI alternate wetting and drying pattern and induced deficit irrigation applied at 80% and 50% of the irrigation water requirement as IR_{100}, IR_{80} and IR_{50}, respectively. Irrigation was carried out at the appearance of soil cracks in IR_{100}. The sub-plot fertilizer treatments were five in number namely: (A) Diammonium Phosphate (DAP) and Urea (normal practice), (B) DAP, Urea and 100% of recommended foliar fertilizer (Lithovit Standard), (C) DAP, 50% (Lithovit and Urea), (D) Lithovit Standard only and (E) no fertilizer. The combined irrigation and fertilizer treatments tested were $IR_{100}A$, $IR_{100}B$, $IR_{100}C$, $IR_{100}D$, $IR_{100}E$, $IR_{80}A$, $IR_{80}B$, $IR_{80}C$, $IR_{80}D$, $IR_{80}E$, $IR_{50}A$, $IR_{50}B$, $IR_{50}C$, $IR_{50}D$ and $IR_{50}E$.

All the treatments were randomly allocated and replicated three times. An individual plot size was 4 m × 2 m (8 m^2) each separated from the other by 0.5 m buffer zone to prevent lateral movement of water from one plot to another as shown in Fig. 4.3.



L_1 - IR_{100} (40mm)
L_2 - IR_{80} (32mm)
L_3 - IR_{50} (20mm)
All dimensions in meters

Figure 4.3: Set up of the experiment

4.2.3 Agronomic practices

The agronomic practices that were carried out include nursery and field preparation, transplanting, fertilizer and pesticide application and weeding. During land preparation, the field was properly puddled using a power tiller. Levelling was also carried out to aid uniform wetting of the soil. Proper drainage was maintained to facilitate water discharge especially during the rainy period. The SARO (TXD 306) rice variety was used as it is well suited to the conditions of Mkindo and was recommended by the Ministry of Agriculture, Tanzania (Kahimba *et al.*, 2014). During nursery preparation, only viable seeds were used and were identified by submerging all the seeds in a salty solution in which an egg would float. All the seeds that floated were considered inferior and were discarded. Seed priming was then done by soaking the seeds in clean water to enhance the rate of seedling emergence and germination.

One seedling per hill was transplanted at the age of 10 days using 25 cm × 25 cm spacing (Reuben *et al.*, 2016b). While considering particular sub-plots with their respective treatments, DAP was applied only once on the second day after transplanting (DAT), Urea was applied at two different times (30 and 60) DAT while all foliar fertilizers were applied at 30, 60 and 81 DAT. Urea and DAP were applied at a rate of 125kg/ha while all foliar treatments at 1kg/ha in 100 litres of water. The fertilizer compositions are as shown in Table 4.1.

Table 4.1: Fertilizer composition for the various treatments

S/N	Fertilizers	Composition
1.	DAP	Nitrogen (18%) Phosphate (46%)
2.	Urea	Nitrogen (46%)
3.	Lithovit Standard	Calcium carbonate (60%) Calcium oxide (35%) Silicon dioxide (12%) Magnesia (2%) Iron (1%) Manganese (0.02%)
4.	Lithovit and Urea (50%)	Calcium Carbonate (33%) Nitrogen (21%) Calcium oxide (18.5%) Silicon dioxide (6.5%) Magnesia (1.2%) Iron (0.5%) Manganese (0.01%)

Weeding and spraying of pesticides against white fly infestation was carried out four and two times during the dry and wet seasons respectively. A 14 days dry period was observed before harvesting to allow for maximum transfer of nutrients to the grains. The rice was harvested manually with serrated edged sickles at 112 days when about 90% of the panicles had ripened spikelets and threshed using wooden sticks.

4.2.4 Assessing the benefit cost ratio

From inception to the end of the experiment, costs incurred for each treatment were classified into fixed and variable costs (costs of production) and recorded. The costs of cultivation of rice for the various treatments were calculated by adding all the costs of input parameters and documented. The input parameters included; land preparation, seeds, nursery preparation, fertilizers, pesticides, labour, transportation and irrigation water charges as shown in Table 4.2. The costs of land preparation and labour were calculated based on the prevailing rate at Mkindo. The costs of fertilizers, seeds and pesticides were calculated based on the prevailing market price during the different seasons.

Table 4.2: General costs of field activities

S/N	Activity	Unit cost per acre (Tshs)	Unit cost per hectare (Tshs)
	Labour		
1	Ploughing using power tiller	100 000	247 100
2	Ploughing and puddling	40 000	98 840
3	Nursery bed preparation	10 000	24 710
4	Transplanting	80 000	197 680
5	Weeding	80 000	197 680
6	Spraying pesticides	10 000	24 710
	Inputs		
7	Irrigation water charges	12 000	29 652
8	Pesticides	10 000	24 710
9	Seeds	2 500	6 178
10	Harvesting (combined harvester)	80 000	197 680
	Fertilizers		
11	DAP (1 500 per kg)	75 000	187 500
12	Urea (1 500 per kg)	75 000	187 500
13	Foliar fertilizers	8 100	20 015

(Source: Mkindo Irrigation Scheme)

The price value of all the harvest after sale was also documented (gross return) to assess the benefits. Gross returns were calculated basing on the price announced by the Government of Tanzania for the *masika* and *vuli* seasons of 2020 and 2021 (Tshs. 1000/=). Net returns were calculated using Eq. 4.1 (Ha, 2019).

$$GR = GI_T - TC_T \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (4.1)$$

Where GR is Gross return, GI_T is Gross Income of respective treatment and TC_T is total cost of cultivation of each treatment. The benefit cost ratio (BCR) was then determined using Eq. 4.2 (Ha, 2019). If the BCR is greater than one, the alternative is worth undertaking and if BCR is less than 1, the alternative is not worth undertaking.

$$BCR = \frac{Gross\,returns\left(\frac{Tshs}{ha}\right)}{Cost\ of\ production\left(\frac{Tshs}{ha}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.2)$$

4.2.5 Data analysis

Data was analyzed using IBM SPSS version 20 which is best recommended for split plot nature of experiments. Analysis of Variance (ANOVA) was used ($p<0.05$) to determine the existence of any differences between both the main plot and split plot treatments. Duncan's multiple range test was used to determine if any significant difference existed between the various treatment combinations.

4.3 Results and Discussion

4.3.1 Response of water applications on BCR

The integration of deficit irrigation into SRI on benefit cost ratio was significant ($p<0.05$). Fig. 4.4 shows the dry and wet season BCR for water treatments IR_{100}, IR_{80} and IR_{50}.

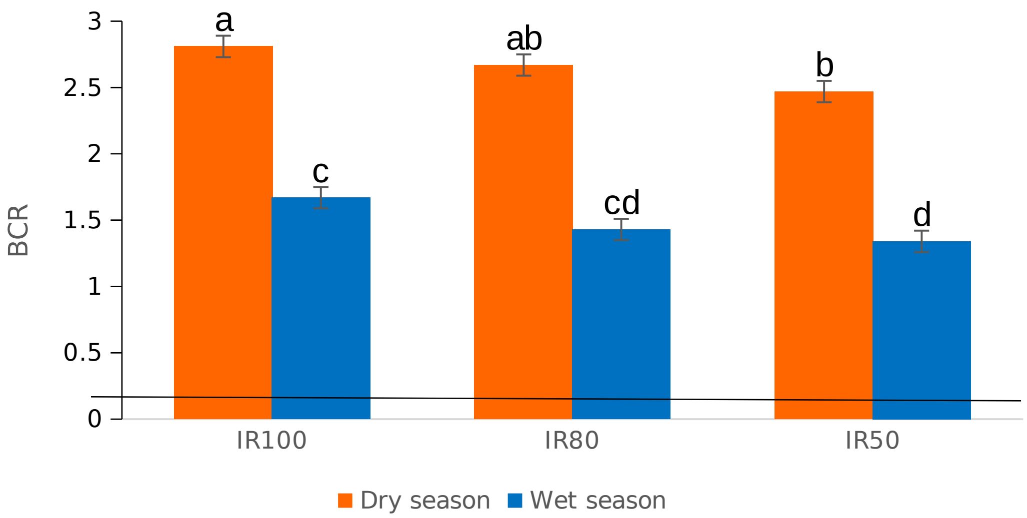


Figure 4.4: Dry and wet season benefit-cost ratio for IR100, IR80 and IR50

For the dry season, IR_{100} had the highest BCR of 2.81 followed by IR_{80} and IR_{50} with 2.67 and 2.47 respectively. A similar trend was followed by the wet season with BCR of 1.67, 1.43 and 1.34 for IR_{100}, IR_{80} and IR_{50} respectively. In both seasons, BCR>1. In each season, IR_{100} and IR_{50} were statistically significantly different while IR_{80} and IR_{100} were not. The dry season had higher BCR than the wet season by 68%, 87% and 84% for IR_{100}, IR_{80} and IR_{50} respectively.

The BCR falls in the range of Nayak *et al.* (2016) and Rathika and Ramesh (2018) who reported BCR of 2.18 and 2.44 respectively under SRI in India. However, Kashyap *et al.* (2015) attained higher BCR than in this study of 3.2 while Ndiiri *et al.* (2013) reported BCR of 1.82 which was lower and higher than the dry and wet season BCR respectively. The variation in BCR is attributed to the differences in ponding depth that led to differential yield. However, heavy rainfall during the second (November 2020) and first (March 2021) months of the vegetative phase for both the dry and wet seasons respectively disrupted water regimes thereby leading to no significant difference between yield. This was also reported by Materu *et al.* (2018).

4.3.2 Response of fertilizer applications

The integration of various fertilizer applications into SRI on BCR was statistically significant (p<0.01). The dry and wet season BCR for the various fertilizer application treatments A, B, C, D, and E are shown in Fig. 4.5.

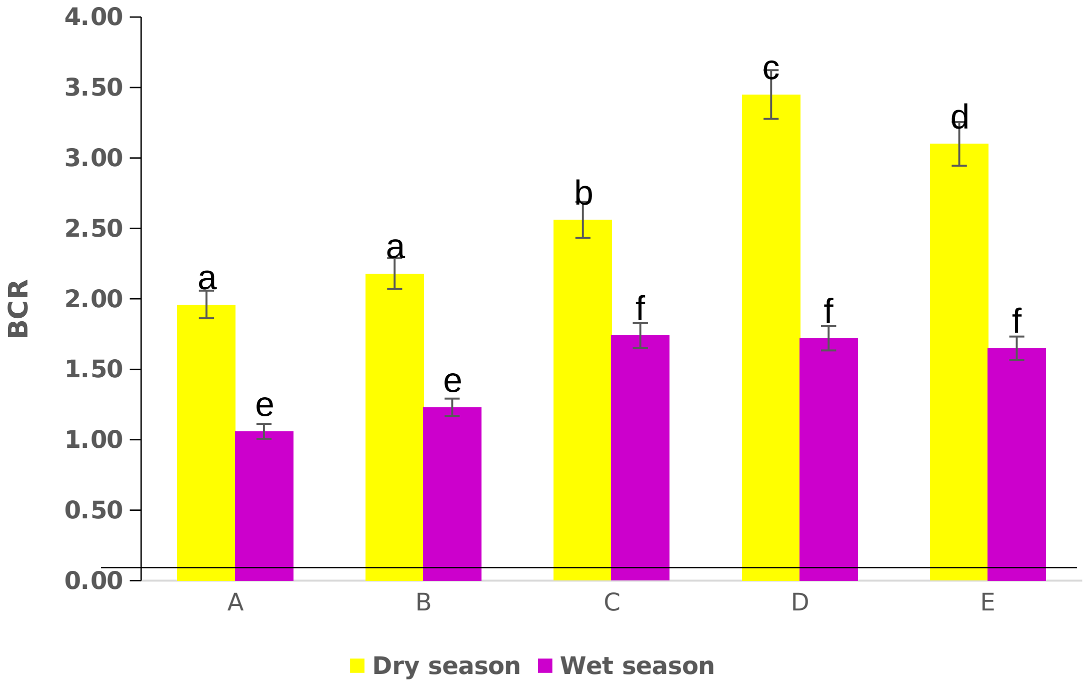


Figure 4.5: Dry and wet season benefit cost ratio for fertilizer treatments A, B, C, D and E

For the dry season, D had the highest BCR of 3.45 followed by E, C, B and A with 3.10, 2.56, 2.18 and 1.96 respectively. For the wet season, C had the highest BCR followed by D, E, B and A with 1.74, 1.72, 1.65, 1.23 and 1.06 respectively.

In both seasons, BCR>1. This is due to the considerably good yield which was attained following good management practices such as SRI, basal and foliar fertilizer application that led to large returns compared to the overall production costs and inputs. Foliar treatments D and C had the highest BCR for the dry and wet season respectively while the conventional fertilizer application A had the least BCR in both seasons. Lithovit contains calcium carbonate which supplies higher concentrations of carbon dioxide than in the atmosphere thereby aiding photosynthesis hence increasing crop growth and therefore yield. Further, photorespiration which consumes a lot of water and energy thereby reducing photosynthesis by about 20-30% is reduced following higher CO_2 concentrations (Kumara *et al.,* 2019). In addition, Calcium together with Magnesium and Sulphur form the three secondary elements most essential for healthy plant growth (Kumara *et al.,* 2019). Calcium is an imminent constituent of cell walls, aids nutrient transportation and offers more resistance to plant attacks (Zoz *et al.,* 2016; Kumara *et al.,* 2019). This justifies the better performance of the foliar fertilizer treatments.

The no fertilizer treatment E had 88% and 85% higher BCR than the conventional basal fertilizer application A for both the dry and wet season respectively. This is attributed to the low costs incurred and considerably the high yields attained following application of SRI. The alternate wetting and drying process under SRI enhances microbial organism activities that readily supply nutrients to the soil thereby facilitating the considerably good yields. This is in agreement with Dinesh *et al.* (2019). Other principles of SRI such as using less seeds, transplanting young plants, wider spacing and regular weeding contributed to the good performance of E amidst no fertilizers.

The dry season had higher BCR than the wet season by 85%, 77%, 47%, 100% and 88% for A, B, C, D and E respectively. Dry season BCR is greater than Tusekelege *et al.* (2014) who obtained values in the range of 2.3-2.51. However, wet season BCR was lower than Tusekelege *et al.* (2014).

4.3.3 Interaction between water treatments and foliar fertilizer applications

The interaction between water and fertilizer applications for the dry and wet seasons is as shown in Table 4.3. The interaction between water and fertilizer treatments was not significant ($p>0.05$). However, considering the dry season for each water regime, D had the highest BCR followed by E, C, B and A. The BCR ranged from (1.94-3.82), (1.98-3.40) and (1.89-3.12) for IR_{100}, IR_{80}, IR_{50} respectively.

The highest BCR was attained by IR_{100}D while the least by IR_{50}E with 3.82 and 1.89 respectively. This study had higher BCR than Kashyap *et al.* (2015) and Nayak *et al.* (2016) who attained BCR of 3.2 and 2.18 respectively under SRI in India while Ndiiri *et al.* (2013) reported BCR of 1.82 in Kenya.

Table 4.3: Dry and wet season BCR between water levels IR100, IR80, IR50 and fertilizer treatments A, B, C, D and E

Main plot	Subplot	Dry season (BCR)	Wet season (BCR)
IR100	A	1.94	1.19
	B	2.29	1.21
	C	2.77	2.03
	D	3.82	2.08
	E	3.24	1.82
IR80	A	1.98	0.97
	B	2.35	1.30
	C	2.54	1.55
	D	3.40	1.68
	E	3.08	1.67
IR50	A	1.89	0.97
	B	1.96	1.21
	C	2.38	1.64
	D	3.12	1.42
	E	2.99	1.45

For the wet season, IR_{100}D, IR_{80}D, IR_{50}C had the highest BCR of 2.08, 1.68 and 1.64 respectively in each water regime. The least BCR in each water regime was attained by A with a BCR of 1.19, 0.97and 0.97 for IR_{100}, IR_{80} and IR_{50} respectively. Kashyap *et al.* (2015) and Nayak *et al.* (2016) had higher BCR than the wet season. However, Ndiiri *et al.* (2013) reported BCR of 1.82 in Kenya which falls within the range in this season. All BCR >1 except IR_{80}A and IR_{50}A each with a BCR of 0.97. The conventional treatment A had the least BCR due to having higher input costs compared to the gross returns. The high input costs were as a result of the expensive basal fertilizers compared to the foliar fertilizers.

The dry season had greater BCR than the wet season. This is due to the variation in yield given that more yield was attained in the dry season than the wet season. The differential yield was as a result of the low temperatures below 16°C in the wet season as average minimum temperatures in this study were 14.8 °C and 13.5 °C for the months of May and June respectively -the reproductive and ripening stages which are most prone to sterility hence justifying the low performance. Further, frequent rainfall in the month of April 2021 resulted in prolonged saturation which hinders root and tiller growth following restriction in root zone aeration. This was also observed by Materu *et al.* (2018).

4.4 Conclusion

The integration of deficit irrigation and carbonate foliar fertilizers into SRI led to high BCR. Water regime IR_{100} and IR_{50} had the highest and lowest BCR respectively. Foliar fertilizer treatments D and C had the highest BCR while the conventional treatment A had the least. This is attributed to the fact that considerably good yield was attained with less inputs. All BCR >1 except IR_{80}A and IR_{50}A each with a BCR of 0.97. The principles of SRI such as using less seeds, transplanting young seedlings, AWD practice, wider spacing and regular weeding contributed to the good performance of the no fertilizer treatment E compared to the conventional treatment A. The dry season had higher BCR than the wet season due to variation in yield performance. Generally, the use of carbonate foliar fertilizers is considered cost effective in enhancing rice production.

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CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Generally, integrating deficit irrigation and carbonate foliar fertilizers into SRI greatly influenced growth, yield and water productivity performance in addition to BCR. Water application IR_{80} performed best while IR_{50} had the least performance in terms of growth, yield and water productivity. Treatment B had the best performance in terms of growth and yield attributes in addition to water productivity. Therefore, combining foliar treatments with conventional fertilizers played a key role in the performance enhancement of treatment B.

Foliar treatments C and D performed considerably as good as the conventional fertilizer treatment A. The good performance of the foliar treatments is attributed to the influence of Lithovit foliar fertilizers in enhancing yield by accelerating physiological and biological processes, availing micronutrients and reducing on the impact of water stress.

Treatment E had the least performance in terms of all growth and yield attributes as no fertilizers were applied throughout the entire growing period. However, its overall performance was still better than the conventional continuous flooding due to the impact of SRI. The practice of AWD facilitates about 80% of free living bacteria and other microbes in and around rice roots which have nitrogen fixing ability thereby supplying nutrients to the crops hence the better performance. Other principles of SRI such as using less seeds, transplanting young plants, wider spacing and regular weeding contributed to the good performance of the no fertilizer treatment E. Further, the residual sandy clay loam soils of medium acidity also contributed towards performance enhancement of rice production despite the absence of fertilizers.

Treatment B had the highest WP followed by A, C and D while E had the least performance in both seasons. Foliar fertilizer treatments D and C had the highest BCR while the conventional treatment A had the least implying that foliar fertilizers are cost effective. All BCR >1 except IR_{80}A and IR_{50}A each with a BCR of 0.97. The use of foliar fertilizers gave literally the same yield as conventional fertilizers, however when costs are factors in, foliar fertilizers performed better. This is attributed to the fact that foliar fertilizers are cheaper than conventional fertilizers.

Further, the dry season performed better than the wet season for all attributes. This is due to the low temperatures below 16°C as average minimum temperatures in this study for the wet season were 14.8 °C and 13.5 °C for the months of May and June respectively - the reproductive and ripening stages which are most prone to sterility hence justifying the low performance.

From this study, it can be deduced that high growth, yield and WP was attained following the use of SRI that cut down on unproductive water losses and calcium carbonate foliar fertilizers which act as a long term reservoir for carbon dioxide especially during water stress periods. Increasing WP will imply more yield per drop of irrigation water used to the farmer and while for the country, it will imply more value for every unit of water used. Therefore adopting yield enhancement and water saving practices such as carbonate foliar fertilizer application is indispensable.

5.2 Recommendations

1. Further reduction in water input can be realized by reducing unproductive evaporation, seepage and deep percolation. This can be achieved by increasing resistance to water flow in the soil and minimizing on idle periods during land preparation such as puddling and soaking.
2. A comparative study can be carried out to assess the impact of SRI and continuous flooding on the deep percolation and seepage rates.
3. More field trials can be carried out on carbonate foliar fertilizer application under SRI to affirm or verify yield enhancement.
4. Given that carbonate foliar fertilizers are cheap, they can be afforded by majority of farmers who find conventional fertilizers expensive and therefore can easily be adopted in their farming activities.
5. A study can be carried out to assess the impact of deficit irrigation and foliar fertilizer application into SRI on growth and yield attributes with the three water applications namely 100% (40mm), 80% (32mm) and 50% (20mm) maintained from vegetative to ripening stage.

6. A study could also be carried out to assess the impact of carbonate foliar fertilizers applied at exactly two weeks after transplanting and thereafter every two weeks until maturity stage under SRI.
7. A study to assess the impact of different foliar fertilizer treatments on the market could be carried out to assess the competitive advantage of the various fertilizers under SRI.
8. The impact of carbonate foliar fertilizers applied at different rates under SRI could be carried out to assess the effect on the growth and yield parameters.
9. The impact of foliar fertilizers applied at different times within the various crop stages under SRI could also be carried out.

APPENDICES

Appendix 1: Monthly dry and wet season deep percolation and seepage

Season	Month	Days	Average ET + Dp (mm/day)	Average ET (mm/day)	Dp (mm/day)	Growing period	Total Dp per season (mm)
Dry	November	30	-2.2	-3.40	1.20	98	117.6
Wet	April	31	-3.13	-4.23	1.10	98	107.8
Average		30.5	-2.67	-3.82	1.15	98	112.7

Appendix 2: Dry and wet season general costs for fertilizer treatments A, B, C, D and E (Tshs)

	Activity	**Dry season**					**Wet season**				
	Labour	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**
1	Ploughing using power tiller	247100	247100	247100	247100	247100	247100	247100	247100	247100	247100
2	Land preparation	98840	98840	98840	98840	98840	98840	98840	98840	98840	98840
3	Nursery bed preparation	24710	24710	24710	24710	24710	24710	24710	24710	24710	24710
4	Transplanting	197680	197680	197680	197680	197680	197680	197680	197680	197680	197680
5	Weeding	790720	790720	790720	790720	790720	593040	593040	593040	593040	593040
6	Spraying pesticides	49420	49420	49420	49420	49420	49420	49420	49420	49420	49420
	Inputs										
7	Irrigation water charges	29652	29652	29652	29652	29652	29652	29652	29652	29652	29652
8	Pesticides	49420	49420	49420	49420	49420	49420	49420	49420	49420	49420
9	Seeds	18533	18532.5	18532.5	18532.5	18532.5	18533	18532.5	18532.5	18532.5	18532.5
10	Harvesting	197680	197680	197680	197680	197680	197680	197680	197680	197680	197680
	Fertilizers										
11	DAP	463313	463312.5	463312.5	0	0	463313	463312.5	463312.5	0	0
12	Urea	926625	926625	0	0	0	926625	926625	0	0	0
13	Foliar fertilizers	0	60045.3	60045.3	60045.3	0	0	60045.3	60045.3	60045.3	0
		3093692	**3153737**	**2227112**	**1763800**	**1703755**	**2896012**	**2956057**	**2029432**	**1566120**	**1506075**