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Assessing adoption and water productivity of the system of rice-intensification under farmer-led irrigation system in northern Tanzania

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ASSESSING ADOPTION AND WATER PRODUCTIVITY OF THE SYSTEM OF RICE-INTENSIFICATION UNDER FARMER-LED IRRIGATION SYSTEM IN NORTHERN TANZANIA

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A Dissertation Submitted in Partial Fulfillment of the Requirements for the Degree of Master's in Hydrology and Water Resources Engineering of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

This study was conducted to evaluate farmers' appropriation of the system of rice intensification (SRI) in an informal irrigation scheme in northern Tanzania. Understanding the integration and performance of SRI in the local rice farming will assist in short and long-term planning and allocation of available resources. First, a survey was conducted to explore farmers' adjustments of SRI principles. Second, yield and water productivity of the integrated system was assessed by setting up experimental plots in the farmers' fields. Four treatments representing farmers' adaptations of SRI practices were assessed. One treatment (F1) was continuous flooding while the other three treatments (F2, F3 and F4) were under intermittent irrigation. The yield of 4.8, 8.5, 8.2 and 9.2 tons/ha, and water productivity of 0.15, 0.39, 0.35 and 0.51 Kg/m^3 were obtained for F1, F2, F3 and F4, respectively. Water-saving under SRI was 34.3%, 28.9%, and 45.1% for F2, F3 and F4, respectively. The figures are comparable to those reported under full SRI, which is in the range 20% to 60%. The highest yield (9.2 tons/ha), water productivity (0.51 Kg/m^3) and water-saving (45.1%) was obtained in F4 involving one seedling 15 days old transplanted at 25 x 25 cm. However, this method is not preferred by many farmers due to lack of supporting infrastructure. Hence, F2 involving two seedlings 21 days old planted at 20 x 20 cm with intermittent irrigation is recommended for this area as it ensures a sufficient number of plants, relatively higher yields and a reduced considerable amount of irrigation water.

DECLARATION

I, Rosemary Evarist Kavishe do hereby declare to the Senate of The Nelson Mandela African Institution of Science and Technology that this dissertation is my original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

Rosemary Evarist Kavishe

Name and signature of candidate	**Date**

The above declaration is confirmed

Dr. Hans Charles Komakech

Name and signature of supervisor 1	**Date**

Prof. Frederick Cassian Kahimba

Name and signature of supervisor 2	**Date**

CERTIFICATION

The undersigned certifies that they have read and hereby recommend for acceptance by The Nelson Mandela African Institution of Science and Technology a dissertation entitled; *"Assessing adoption and water productivity of the system of rice-intensification under farmer-led irrigation system in northern Tanzania"* in partial fulfillment of the requirement for the degree of Master's in Hydrology and Water Resources Engineering of the Nelson Mandela African Institution of Science and Technology.

Principal supervisor

Dr. Hans Charles Komakech

________________________________ ____________

Signature Date

Co-supervisor

Prof. Frederick Cassian Kahimba

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Signature Date

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This work is dedicated to my lovely children Precious Nkunya and Perfect Nkunya, my mother Edlitrude Kavishe, and my grandmother Angelista Makawa who always believed in me.

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LIST OF ABBREVIATIONS AND SYMBOLS

AWD	Alternative Wetting and Drying
Cd	Coefficient of Discharge
CF	Continuous Flooding
EC	Electrical Conductivity
ETo	Potential Evapotranspiration
g	Acceleration due to Gravity
ha	Hectare
JICA	Japanese International Co-operation Agency
KATC	Kilimanjaro Agricultural Training Center
Kg	Kilogram
NGO	Non-Governmental Organization
NM-AIST	Nelson Mandela Africn Institution of Science and Technology
PHRD	Japan Policy and Human Resources Development
RCT	Rice Council of Tanzania
PRD	Partial Root Drying
Q	Discharge
RDI	Regulated Deficit Irrigation
SARO	Semi-Aromatic
SRI	System of Rice Intensification
SPSS	Statistical Package for the Social Sciences
UWAMALE	Umoja wa Watumiaji Maji Lekitatu
WESE	Water, Environmental Science and Engineering
WISE–Futures	Water Infractructure and Sustainable Energy Futures
WP	Water Productivity
WUA	Water Users Association
ϴ	Notch angle
V	Volume
T	Time
V_T	Total Volume
Σ	Summation of Individual Events

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Irrigation plays a central role in ensuring food security, providing employment and increasing farmers' income. Irrigation has been identified in Tanzania's national poverty reduction framework as one of the key strategies for economic growth and poverty reduction (Long, 2018). However, irrigation in Tanzania is also considered to be the largest water user albeit very inefficiently (Machibya, 2005). According to the 2002 National Water Policy, the efficiency of irrigation schemes managed by smallholder farmers is very low, often ranging from 15% to 25% (URT, 2002). Rice production in these schemes is low, averaging at 3.5 tonnes/ha (Tusekelege, 2014) compared to the recommended 6-10 tonnes/ha (FAO, 2015). To reduce the gap, rice production is expected to increase (Bouman, 2007).

There have been two commonly known ways of increasing rice production. One is by expanding the area under irrigation, and the other is by using the concepts of green revolution which emphasize on the extensive use of fertilizers and high yield seed varieties. Sometimes a combination of both can be used. Expanding the area under irrigation will mean to increase abstraction from the water sources (Kaya *et al.,* 2015; Greaves & Wang, 2017). To Increase the amount of abstraction may not be feasible as the sector is currently under competition with other sectors such as industries and cities that are claimed to have higher water productivity (WP) than the agriculture sector. On the other hand under the green revolution, more farm inputs are required to raise the production through crop genetic modification, and by increasing external inputs. The green revolution has had success where sufficient amount of capital to be invested was available and its potential benefits have been enjoyed by either commercial/large scale farmers or government schemes (Kabir, 2006). Smallholder farmers, who are poor in resources, have not benefited much from these interventions. Due to the nature of the smallholder farmers, the focus has been on interventions that can easily be implemented by smallholder farmers using locally available resources (Tusekelege, 2014). The current debate has been on finding ways to minimize the amount of water used in the agriculture sector by using adequate agronomic and irrigation practices that conserve water, but do not undermine crop water requirements (Loë *et al.,* 2001; Yihun, 2015). The system of rice intensification (SRI) has been identified as an on-farm water management practice that increases both land and water productivity at a relatively low cost while also conserving the environment (Stoop *et al.,* 2002; Uphoff, 2006). The SRI has also been acknowledged in the Tanzania Irrigation Policy (2010) to ensure food security and alleviate poverty (URT, 2010). The major outweighing benefit of the SRI is laid on the fact that it promotes the use of locally available materials, that can be integrated into the local environment (Stoop *et al.,* 2002). In addition, inputs required for rice production such as water, chemical fertilizers, amount of seeds, herbicides and pesticides are reduced under SRI. In places where SRI has been tested results show significant impacts in reducing both amount of water applied and cost while maintaining the yield and sometimes even improving it (Katambara *et al.*, 2013). Water saved under SRI is reported to range from 25% -50% and yield improvement ranges between 30% to 150% (Stoop *et al.,* 2002; Materu *et al.,* 2018). Yield increase of 0.4 and 3 ton/ha under SRI as compared with conventional flooding (CF) during the wet and dry seasons respectively was reported by Materu *et al.* (2018).

Although much has been reported on the impacts of SRI (Stoop *et al.*, 2002; Kahimba *et al.,* 2013; Katambara *et al.,* 2013; Tusekelege, 2014) most of these studies have been confined to a small area (mainly research plots) and less has been reported on success or failure of this technology under resource-poor farmers' management. Since the system is still new to most people and adjustments have been made by farmers and researchers to suit local conditions, more research is needed to document about the impacts of these modifications to smallholder farming systems. The aim of this study was to evaluate the adaptation and performance of the SRI under farmer-led irrigation schemes. Results from this study will be useful to policy-makers and farmers for decision making and trials of SRI and to research further explorations.

1.2 Statement of the Problem

The SRI principles were developed to assist resource-poor farmers to reduce external inputs while maintaining or improving yields and protecting the environment (Stoop *et al.,* 2002). The SRI consists of principles which when applied properly are believed to improve both land and water productivity. The SRI is reported to have shown significant impact in increasing yield while reducing inputs. However, most of the outstanding impacts of SRI were based on the research plots under controlled conditions where SRI principles were considered as a fixed package (Stoop *et al.,* 2002). It is widely known that under farmer-led irrigation, it may not be feasible to adopt and practice all SRI principles as recommended due to social, economic and technological constraints, as such farmers are encouraged to customize these principles to their local environment and use the available resources to benefit from SRI (Thiyagarajan & Gujja, 2012). Although farmers may use only few principles, the assumption is that they will attain relatively high impacts like the one reported in the literature. Since the information on farmers' management is limited, the concerns to whether farmers are benefiting arise. For better understanding and improvement of SRI in real practice, it is best to study SRI use in a resource-poor farmers' context. Hence, this research aims at understanding how SRI intervention was integrated into the local rice farming system of smallholder farmers in northern Tanzania and assess the performance of SRI under farmer-led irrigation schemes.

1.3 Rationale of the Study

The need to improve both water and land productivity in smallholder irrigation schemes has led to the development of various agronomic and water management strategies. These strategies focus on reducing the amount of water used in agriculture production, increasing the production with the same amount of water or both (Farooq, 2009). Most of these interventions have shown significant results in well-established systems where all resources needed for their implementation are available. The same has not been achieved under resource-poor farmers' management. The reasons behind this low-success have been tied to the nature of the smallholder's irrigation schemes which are characterized by poor water control infrastructures, lack of proper crop and water management, lack of resources and other social-economic factors (Fanadzo, 2010). In addition, farmers are believed to lack knowledge and technology to implement these interventions (Machethe, 2004). Therefore, more knowledge on integration and management of agricultural interventions in farmer-led irrigation management is needed to bridge the gap between theory and real practice.

1.4 Research Objectives

1.4.1 General Objective

To evaluate adoption and performance (yield, WP and water-saving) of the system of rice intensification under farmer-led irrigation management.

1.4.2 Specific Objectives

(i) To assess how SRI was integrated into the conventional rice farming system of smallholder farmers in northern Tanzania.

(ii) To evaluate yield, water productivity and water saving of SRI vs conventional rice farming under farmer-led irrigation and management.

1.5 Research Questions

This study will be guided by the following research questions:

(i) How have smallholder farmers customized SRI principles to suit their specific needs and local conditions?

(ii) To what extent does SRI improve yield and water productivity while saving water as compared to conventional rice farming systems under farmer-led irrigation?

1.6 Significance of the Study

Improving yield and water productivity of farmers is crucial in ensuring sustainable income and food security at the household level in Tanzania. The use of appropriate technologies that minimize the amount of water used in production and maintain or improve yields is deemed necessary for sustainability under water scarcity conditions. Understanding how SRI was integrated into the local rice farming and to what extent smallholder farmers can benefit from this intervention will assist in short- and long-term planning and allocation of available resources. In addition, assessing yield, water productivity and water-saving will give the basis for day to day water management decisions at scheme level and open up more research on how these findings can be integrated to river basin water resource management.

1.7 Delineation of the Study

This study was conducted to evaluate the integration and performance of SRI in the local rice farming system of northern Tanzania. Data were collected through a field survey and field experiment in farmers plots. The survey involved a total of 115 farmers from the study area; in addition, key informants were interviewed to supplement the questionnaire. The experimental work involved four different plots owned by four different farmers. Three farmers are practising SRI and one farmer practising CF.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background

Rice is the third dominant food crop in Tanzania after maize and cassava (Wilson & Lewis, 2015). Rice demand is increasing as a result of both population increase and improved lifestyle. In Tanzania, annual rice demand was expected to triple by 2020 (Wilson & Lewis, 2015). Given the importance of rice two main strategies have been used to meet this demand; namely, expanding the area under cultivation and increasing production per unit area (Balasubramanian *et al.,* 2007). By clearing more land farmers were able to cultivate more area and relatively increase rice production. Along the way, improvement in genetic engineering led to the development of high yield varieties which yielded more than the local varieties. Improved varieties not only increased yield but also enabled farmers to cultivate rice twice a year as most of them were short cultivars instead of one season when using local varieties (long cultivars). The use of fertilizers to supplement soil nutrients needed by plants to produce optimum yield has also played a role in increasing crop production. Combination of high yield varieties and fertilizers to boost agricultural production has been one of the break-through in the history of farming and is what is referred to as green revolution. Under green revolution theory, the emphasis was on the use of improved seeds and intensive use of fertilizers to obtain the highest yield possible. These improvements in the agricultural sector were a great relief to farmers and more people were attracted to rice farming. There were now two phases for rice cultivation namely; rain-fed and irrigated rice cultivation. Overtime farmers realize that higher yields were obtained under irrigation compared to rain-fed farming. Therefore, farmers shifted their efforts to irrigated agriculture. For many decades rice farming has been under the CF method. Under CF the field is kept saturated throughout the growing season by maintaining a ponding depth of up to 5 cm except for the last two weeks before harvesting (Kalinga *et al.,* 2001; Kahimba *et al.,* 2013). This is attributed to the belief that rice is an aquatic plant and therefore, it grows better and produces higher yields in flooding conditions (Sivapalan, 2015). Another reason is to suppress weeds and prevent the rice from cold stress during the night (Farrell *et al.,* 2001). Although the ultimate goal of increasing crop production was met, this achievement came with the expense of abstracting more water from the sources. Water consumption under CF is high with relatively low yield (Humphreys *et al*., 2011) hence results in low water productivity (WP) (Hamdy *et al.,* 2003).

The agricultural sector being the largest water user where it is estimated that 70% of all abstractions made are used with low WP. Increasing abstraction proved to be an unsustainable way of surviving in a water scarcity era, where there are increased demands for water from other sectors. Therefore, improving WP is a stepping-stone towards combating future water shortage by growing more crops per drop.

2.2 Rice Cultivation in Farmer managed Irrigation Schemes

Farmer managed irrigation schemes (FMIS) also known as farmer-led irrigation schemes (FLIS) are the schemes initiated by farmers. Under FMIS farmers organize themselves to take control of land and water governance by taking advantage of the availability of these resources (Woodhouse *et al.,* 2017). Due to limited technology, farmers have been using the conventional method of rice farming in which two to five seeds of 20 to 60 days age are planted in one hole spaced closely (15 x 15 cm or less) or in a random order (Katambara *et al.*, 2013). Under this method, the field is flooded by maintaining a ponding depth of up to 5 cm except for the last two weeks before harvesting where water is removed from the field to allow for drying of rice plants (Kalinga *et al.,* 2001; Katambara *et al.*, 2013). This is attributed to the belief that rice is an aquatic plant and produce higher yields in flooding condition than under non-flooding conditions (Sivapalan, 2015). In addition, flooding the field suppress weeds and prevent the rice from cold stress during the night (Farrell *et al.,* 2001).

2.2.1 Water Use, Yield and Water Productivity Under Conventional Flooding for Rice Cultivation in Famer Managed Irrigation Schemes

Water consumption under CF is high, a typical farmer often has to utilize 100–250 mm of water just for the puddling operation (Humphreys *et al.,* 2011) and a total of 1000–2000 mm of water is estimated for the whole growing season (Materu *et al.,* 2018). Amount of yield obtained in CF is considered low as opposed to a large volume of water used. In India for example, Pandian (2010) found that an average yield of 4.5 t/ha requires more than 9204 m^3 of water to produce. In Kenya a comparison of three varieties BW 196, Basmati 370, and IR 2783-80-1 showed the average yield of 3.9, 5.2 and 9.4 t/ha, the amount of water used was 18 475, 14 062 and 17 548 m^3/ha, respectively (Ndiiri *et al.,* 2012). In Tanzania, a study conducted in Mkindo area reported a yield of 3.8 t/ha while using 28 200 m^3/ha (Kahimba *et al.,* 2013). Low yield with a high amount of water used results in low water productivity. The WP in CF is reported to range from 0.4-1.6 Kg/m^3 (Kahimba *et al.,* 2013) with a global average of 1.08 Kg/m^3 (Zwart & Bastiaanssen, 2003; Howitt, 2008). It is for this reason, the irrigation sector is regarded as one of the major water users with low Water Productivity (WP) (Hamdy *et al.*, 2003).

Apart from low yield, high water usage and low water productivity, CF is associated with other disadvantages. One, this technique consumes a lot of energy (for intensive tillage), labour. Second, when practised for a long time CF may enhance deep percolation. Poor drainage facilities in CF causes problems such as waterlogging, salinity, pollution of groundwater and excess recharge of groundwater (Bhuiyan, 1992; Kibret *et al.*, 2014; MoWI, 2016). When proper actions are not taken these negative effects may lead to degradation of physical properties of soil that cause serious effects to the performance of crops, and contributes to methane emissions, as a result, the land that was used for farming may be lost. Farooq *et al.* (2011) argue that due to its intensive water and labour consumption nature, traditional transplanted rice cultivation needs an intervention that will facilitate water and land productivity.

2.3 Shifting from Traditional Rice Farming to Water-Saving Interventions

Interventions capable of maintaining yield while reducing water abstractions or using the same amount of water to produce more yields were needed to ensure the sustainability of agriculture sector against the odds of decreasing freshwater resources and climate change. In responding to the need, agricultural experts introduced deficit irrigation as one of the technologies to minimize water used in irrigation. Under deficit irrigation minimal water stress is allowed, except in critical development stages where crop yield might be damaged (Materu *et al.*, 2018). In addition, deficit irrigation has other benefits such as proper root development and plant growth resulting in higher yields. It has been observed that plants require only sufficient moisture in the soil to allow for aeration, superior root growth and reducing the stress in the plants due to water-logging especially between transplanting and panicle initiation (Materu *et al.*, 2018). Deficit irrigation can be classified into two namely; Regulated Deficit Irrigation (RDI) and Partial Root Drying (PRD) (Capra *et al.*, 2008). Under RDI amount of irrigation water is reduced only on during certain crop cycle phases (English, 1990) while in PRD half of the root zone is kept under dry soil for the whole crop cycle (Dry, 1996). System of rice intensification is an example of regulated deficit irrigation proposed to smallholder farmers in water scarcity area.

2.4 System of Rice Intensification

The system of rice intensification (SRI) is a social-technical innovation developed in Madagascar in the 1980s through on-farm trials. Trials involved a group of smallholder farmers who could not afford expensive external inputs such as fertilizers and improved seeds, but also had limited water supply (Stoop *et al.*, 2002). On struggles to try to boost production with whatever was available in their environment, the system of rice intensification which is believed to produce more rice with the same or reduced inputs was introduced. The experimentation involved younger seedlings (15 days old) transplanted on low fertile soils with no mineral fertilizers and reduced irrigation. As a surprise, the yield increase was tremendous ranging from 7 to 15 t/ha compared to the national average yield of 2 t/ha (Stoop *et al.,* 2002). Since then, there have been additional modifications to incorporate the challenges encountered in the process. To summarize, SRI is considered to have a set of six basic principles, which when used in a combination are believed to produces outstanding results (Sato & Uphoff, 2007). These principles include: a) selection of healthy seeds and nurturing seedlings in a well-managed nursery; b) transplanting a single seedling per hole, and applying square method with wider spacing between plants (mostly recommended 25 x 25 cm); c) transplanting younger plants before fourth phyllochron (8 to 15 days of age); d) application of intermittent irrigation to prevent flooding during the vegetative stage of the crop; e) regular weeding preferably using rotary weeder with minimal or zero use of herbicides; and f) the use of organic fertilizers instead of chemical fertilizers (Stoop *et al.*, 2002; Uphoff, 2006; Kahimba *et al.,* 2013; Katambara *et al.*, 2013; Materu *et al.,* 2018). These principles are further explained below.

2.4.1 Recommended Principles of System Rice Intensification

(i) Nursery and Seed Preparation

The SRI recommends the use of high-quality seeds selected from the previous harvest. The seeds are sorted out by immersing them in a bucket with salty water where the bad grains will float in water and should be removed to leave the best grains at the bottom of the bucket. Where high quality packed seeds are available, they can also be used. The place for nursery establishment should be cleaned and levelled to avoid ponding of water. In addition, the seeds are evenly spread to avoid conjunction of seeds in the nursery to facilitate easy uprooting and separation of young plants during transplanting. In addition, the nursery is monitored for diseases and pests in order to produce healthier plants free from diseases and pastes (Katambara *et al.*, 2013; Tusekelege, 2014).

(ii) Early Transplanting

Early transplanting of seedling preferably at the age of not more than 15 days (before the fourth phyllochron) is recommended in SRI (Uphoff, 2003). Depending on the climatic condition, agronomic practices and soil condition, transplanting age can vary from 8 to 15 days instead of the 20 to 60 days age under traditional rice cultivation (Katambara *et al.*, 2013). The principle requires early uprooting of young plants and transplanting within a short time to prevent dehydration and traumatization of the plant. The major advantage of this principle when used in combination with other practices is that it facilitates quick recovery of plants and produces more tillers per hill.

(iii) Plant Spacing

Provision of optimum space in transplanted rice is very important to ensure proper uptake of the nutrient from the soil and to prevent competition among neighbouring plants. This will facilitate healthier plants that result in healthier grains. In addition, when spaced widely it facilitates the easy circulation of air, optimum use of solar radiation and it facilitates easy weeding. Wider spacing in combination with other SRI practices is reported to increase WP as compared to CF. The spacing of 25 x 25 cm and 30 x 30 cm are preferred under SRI in opposite to 15 x 15 cm used in CF.

(iv) Irrigation Management

The SRI suggests there should be an interval between water applications in the field. Under SRI the soil is not continuously flooded rather sufficient amount of water enough to make the soil moist is applied. Non-flooding condition in SRI allows for air circulation in the root zone that favours easy development and deep penetration of roots into the soil for more nutrients capture at deeper root depth than under CF. Kirk and Solivas (1997) report that only 25% of the roots of plants grown under CF were able to penetrate deeper than 6 cm one month after transplanting. The fields can be flooded with 2 to 3 cm depth standing water and then allowed to drain for sometimes (3 to 6 days) to allow for air circulation in the root zone (Latif *et al.*, 2005; Sato & Uphoff, 2007; Berkhout *et al.*, 2015) and will be irrigated again when the soil has developed hairline cracks (Uphoff, 2006; Kahimba *et al.*, 2013). The interval between irrigations differ from one place to another and depends on the site-specific factors such as soil type, size and shape of the farms, availability and reliability of irrigation water and amount of rainfall available to supplement the irrigation (Sato & Uphoff, 2007). Therefore, in order to optimize water usage under SRI, it is best to determine interval that suits the local environment.

(v) Weeding Management

Under SRI early and regular weeding is more important than in traditional rice because the non-flooded conditions and wider spacing used in SRI favours quick growth and spread of weeds than under CF (Latif *et al.,* 2005; Noltze *et al.*, 2012). Normally four times weeding at regular intervals preferably starting 10 days after transplanting is recommended to reduce competition of nutrients between rice plants and weeds. Also, the use of rotary weeder is recommended to ensure soil aeration (Berkhout *et al.,* 2015).

(vi) Fertilizers/ Nutrients Management

Where manure is abundantly available, SRI recommends the use of manure to the extent possible. The main advantage of using organic fertilizers is to reduce the cost of chemical fertilizers provided manure is locally available or the cost of obtaining is cheaper as compared to that of buying chemical fertilizers. In addition, the use of manure has environmental benefits such as increasing water holding capacity of the soil (Vengadaramana & Jashothan, 2012).

2.4.2 Claimed Benefits of System of Rice Intensification

In areas where the SRI has been accepted and put into practice, it has shown significant results in reducing the amount of inputs such as seeds and fertilizers, improving yields and reducing the amount of water used and hence improving water productivity (Kahimba *et al.,* 2013; Katambara *et al.,* 2013; Tusekelege, 2014).

(i) Input Saving

It is argued that if farmers manage to combine and apply all SRI principles properly they will benefit not only in increasing yields and save water, but also save external inputs such as the amount of seeds, chemical fertilizer, pesticides, time and labour. The SRI requires fewer farm inputs than CF such as the amount of seeds, labour and time since few seeds need to be transplanted and the spacing is wider (Katambara *et al.*, 2013). Although labour input in SRI is higher during the initial learning period researches show that when SRI skills are mastered by farmers, SRI can be labour saving (Uphoff, 2003; Uphoff, 2006). The SRI can reduce chemical fertilizer application by up to 50% (Sato & Uphoff, 2007) due to the use of locally available organic materials as fertilizers (Stoop *et al.,* 2002). Overall production cost reduction of 20% and 25% were reported by Uphoff (2006) and Sato and Uphoff (2007).

(ii) Water-Saving

Water-saving in SRI can be achieved at various stages of rice farming such as during land and nursery preparation and also during the vegetative stage of rice growth (Sato & Uphoff, 2007). This is associated with the fact that standing water is not allowed after puddling and levelling activities in SRI rather only sufficient amount of water enough to make the soil moist is applied in the specified interval (Uphoff, 2006; Sato & Uphoff, 2007; Kahimba *et al.,* 2013). Water-saving in SRI is estimated to range from 24%-70% (Stoop *et al.,* 2002; Uphoff, 2006; Sato & Uphoff, 2007; Chapagain *et al.,* 2011; Kahimba *et al.,* 2013) as compared to CF. Water use reduction of 40% in Indonesia was reported by Sato and Uphoff (2007). Similarly in Tanzania, Materu *et al.* (2018) reported a water-saving of 233 mm and 456 mm in wet and dry seasons, respectively while more than 60% saving in SRI as compared to CF was reported by Kahimba *et al.* (2013) for Mkindo irrigation scheme.

(iii) Yield Improvements

Higher yields of up to 15 t/ha were reported in Madagascar (Stoop *et al.,* 2002) while in Tanzania SRI produced a yield of up to 9.91 t/ha (Katambara *et al.,* 2013). Even with partial adoption, SRI was reported to raise yield by an average of 52% (Uphoff, 2006). While using best conventional practices may also produce higher like SRI, in many parts of the world SRI has been reported to produce more yield using less water as compared to CF. In Tanzania research conducted at Morogoro reported 9.7 t/ha in SRI and 8.7 t/ha in CF for the dry season while the water used was 949 mm/ha and 1 286 mm/ha, respectively (Materu *et al.,* 2018). In Mkindo area 4.8 t/ha in SRI and 3.8 t/ha for CF using 10 300 m^3/ha in SRI and 28 200 m^3/ha in CF (Kahimba *et al.,* 2013).

(iv) Water Productivity

In places where SRI was tested, it has shown significant results in improving WP. Kahimba *et al.* (2013) reported three times increase in WP (0.47 kg/m^3) as compared to 0.136 kg/m^3 in CF in Mkindo irrigation scheme. Kombe (2012) reported a WP of 0.46 Kg/m^3 for the same scheme. In Bumbwisudi irrigation scheme in Zanzibar, Ali (2015) reported a WP of 0.45 kg/m^3.

2.4.3 Adoption of System Rice Intensification by Smallholder Farmers

Adoption of agricultural innovation is considered an innovation-decision process where farmers are expected to go through stages of adoption. The process is stated to involve four stages: (a) awareness stage where an individual becomes aware of the system, (b) acquiring knowledge about an innovation stage, (c) forming positive or negative attitude towards innovation and (d) finally deciding whether or not to adopt the technology (Pandey, 2019). For any new technology, the expectations are that farmers will abandon their current practice and adopt the new technology. However, it has been found that in the real environment some of the components of the technique may not work as in controlled condition where most of the experiments are conducted. For the case of SRI, research has shown that adoption of all six recommended principles of SRI is rarely found (Xiaoyun *et al.,* 2005; McDonald *et al.,* 2006; Moser & Barrett, 2006). There has been a variation on the extent of adoption between farmers and across regions. The rate of adoption depends on farmers characteristics, understanding of the system, farm size and proof evidence of benefits of SRI (Berkhout *et al.,* 2015). Variations on the adoption level may be due to various social, economic and institutional factors. Within the set of principles, there are always easy to adopt principles and vice versa depending on factors such as farmers characteristics, understanding of the system, and evidence of benefits of SRI plays a great role on the adoption of SRI (Berkhout *et al.,* 2015). Easy to adopt principles are those that are within the individual capacity to implement. Principles such as proper management of the nursery or the use of manure for nutrient management can be regarded as easy to adopt principles for individuals. Difficult to adopt principles are the one that needs more than an individual to agree. Some of the principles beyond individual farmer control can be a transplant of young seedlings and apply intermittent irrigation. Since in most smallholder systems resources such as water and labour are collectively owned, the decision on when to transplant or when to apply water may not be individual. In such a situation the collective agreement will make more sense. Therefore, there has to be agreement among farmers on collectively managed resources. With this regard, SRI adoption can be considered as a multi-level decision which is an individual decision and a collective or a society decision. Therefore, an individual decision may not be enough to reach a conclusion on what to adopt and what not to adopt or adopt with modifications. There may be a lot of modifications and changes in social, technical and institutional settings before SRI is successfully put in place. That is why Karki (2011) concluded that for any innovation to be of significance it has to be adopted by a large proportion of farmers despite its environmental and economic benefits.

2.4.4 Critical Views of System Rice Intensification

Critics about SRI innovation comes from various aspects. First is on the definition of SRI itself. Some researchers have raised concerns on what is SRI? Is SRI a standardized package or a customizable package in which farmers are free to choose and modify certain principles? How far can SRI principles be modified? Should farmers use improved or conventional seed variety? Should farmers use chemicals fertilizers or manure? The second critic is on the criteria for assessments of SRI performance. The question arises on what are the criteria for performance evaluation of SRI especially when the SRI principles have been modified? Since there are no specified criteria for assessment, and in some cases, criteria are to be set by the researcher the genuine of the results may be affected.

The SRI critics believe that, for genuine evaluation, SRI knowledge should be transferred and adopted as a standardized package. Any deviation from the recommended principles is regarded as not SRI or simply “dis-adoption”. The reason behind is the belief that there exist synergies between SRI principles such that the benefits of the whole system are greater than those of individual principles (Uphoff, 2002). To SRI critics, farmers’ cultivation system is regarded as inefficient and should be replaced with the SRI package without any alteration.

The emphasis to adopt all SRI principles by every farmer in every agro-ecological environment is good to ensure all farmers benefit relatively equally by SRI. However, this conception may not be achieved in some area due to the complexity and dynamics of smallholder systems both spatially and temporal (Thiyagarajan & Gujja, 2012). The nature of smallholder systems makes it difficult to adopt all SRI principles as recommended. Some principles may not be feasible in a certain environment and therefore farmers may opt not to adopt them. For example in some area where there are no cattle within the scheme, the use of manure may be expensive and farmers may opt to use chemical fertilizers instead. Some of the principles may require some modification to suit the farmers’ specific needs and environment. For example, due to uncertainty in water availability farmers may opt to use 20 days seedlings instead of 15 days or to apply water based on the routine say once per week instead of when cracks appear on the soil. To SRI supporters these deviations from recommended practices are acceptable. They are considered as farmers efforts to benefit from SRI. To SRI promoters, SRI is an evolving technology which requires site-specific experimentation and modification to fit farmer's needs. The emphasis is on whatever works for farmers in their specific environment. Farmers are advised to use whatever is available in their current environment to improve both land and water productivity. In this dissertation, we limit our discussion on adoption of SRI techniques by farmers.

By revolving our discussions around adoption, we limit ourselves to understand what is happening within the smallholder farmers' line. Classifying farmers as adopters and non-adopters leaves out the most important part of the subject which is to explore the changes in practice brought by SRI and the impact of SRI in smallholder farmers' life. As in real life, it is difficult to differentiate adopters from non-adopters (Glover, 2011).

We are aware that challenges and variations on adoption among smallholder farmers have raised concerns on the suitability of SRI in benefiting smallholder farmers, and whether the obtained results are worth the efforts. Although smallholder farmers face a lot of challenges in implementing SRI, researches have shown that these challenges have not denied farmers from appropriating some of the SRI principles to their benefits. In most cases, farmers still use the little resources available to do what they can to get profit from SRI. A research conducted in northern Myanmar by Kabir and Uphoff (2007) concluded that partial adoption by farmers was able to double the production (from 2.04 to 4.18 t/ha). This is proof that even with partial adoption smallholder farmers can still benefit from SRI.

It is therefore, important to understand the mechanism beyond these variations and explore to what extent do farmers benefit from SRI. This study aimed at evaluating the adaptation and performance of the system of rice intensification under farmer-led irrigation schemes and management. First, the study was conducted to understand how smallholder farmers responded to SRI intervention in the Lekitatu smallholder irrigation scheme in Arusha Region, Tanzania. Secondly, field experiments on farmers managed plots were conducted to assess the performance of SRI in the study area.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

3.1.1 Geographic Location, Climatic Condition and Extent of Lekitatu Irrigation Scheme

This study was conducted at Lekitatu irrigation scheme is located in Lekitatu village, Meru district, Arusha region in Tanzania (Fig. 1). The scheme is located between 3°23'03.8" and 3°25'50.9" South, and 36°50’03" and 36°51'50.5" East, with an average altitude of 1110 amsL.

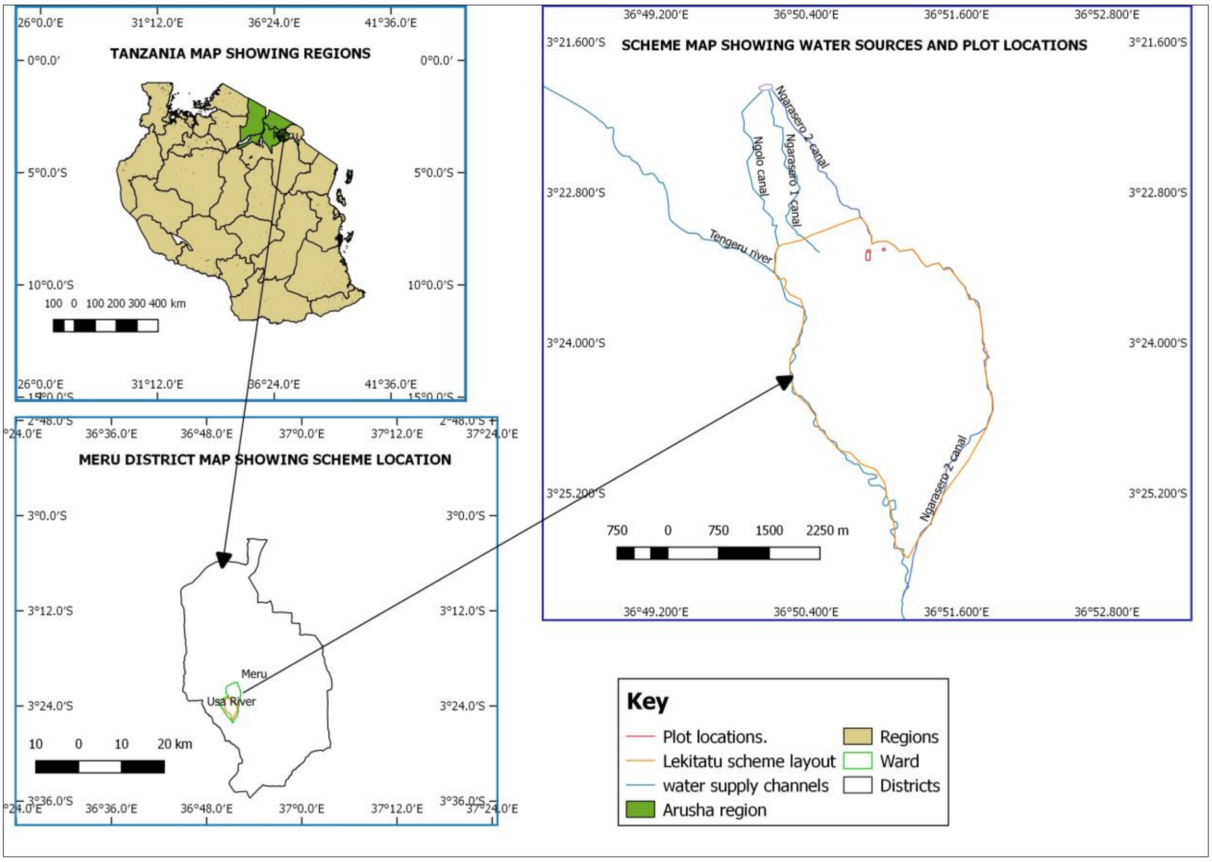


Figure 1: Map showing the location of Lekitatu irrigation scheme

The area lies in the sub-humid region with annual rainfall ranging from 590 mm/year to 1 460 mm/year. Temperature ranges from a minimum of 11.7°C in July to a max of 32.4°C in October, while potential evapotranspiration ranges from a minimum of 151 mm/month in June to a maximum of 218 mm/month in October, average wind speed and relative humidity are 2.4 m/s and 56%, respectively. The area receives a bimodal rainfall regime, with short rains starting from October to December and long rains from March to May, with peak precipitation in April (Fig. 2). Potential evapotranspiration (ETo) is higher than the amount of rainfall in all months except for April. This explains the importance of applying supplemental irrigation even during the long rainy season.

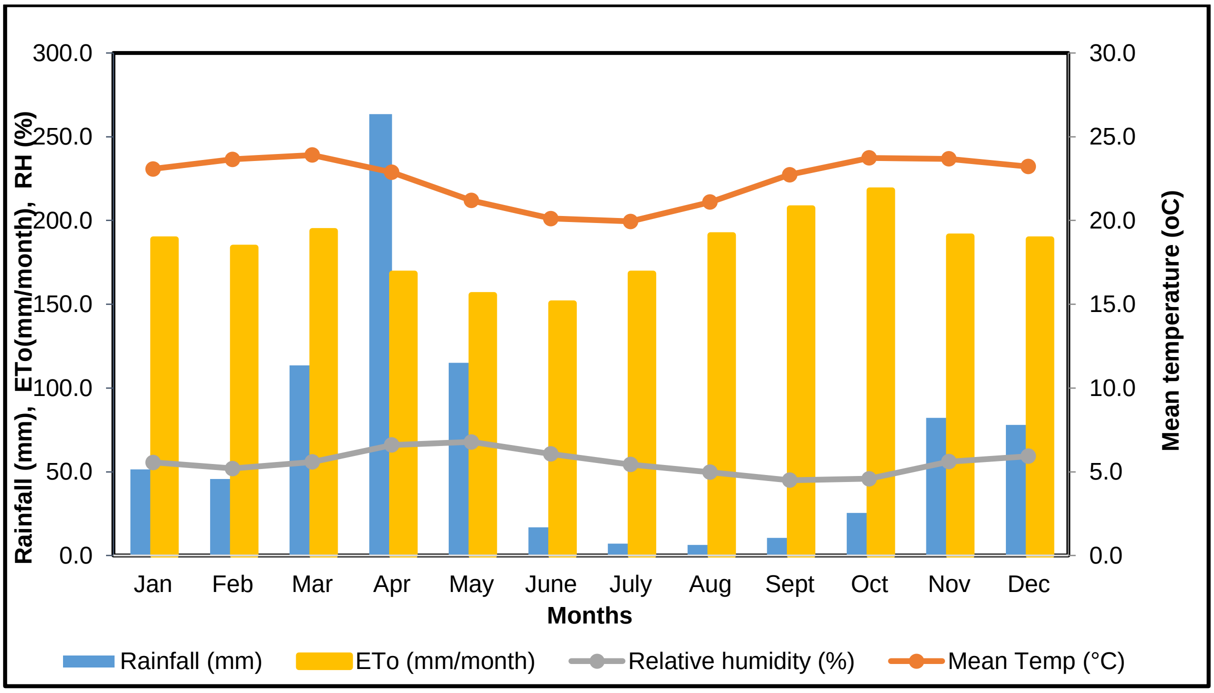


Figure 2: Long-term (1985-2016) monthly average rainfall, relative humidity, mean temperature and ETo for Lekitatu area

The total area of Lekitatu irrigation scheme is 826 ha in which 600 ha are under irrigation. Out of 600 ha, 400 ha are used for paddy farming while the remaining 200 ha are used for other crops (maize 72 ha, beans 100 ha and 28 ha for vegetables). The soils under rice cultivation range from silty loam to loamy sand while those used for other crops are loamy sand to clay. Rice farming is done in two seasons; the first season starts from January to June, which is a wet season (Table 1) and the second season from July to December (dry season) (Table 2). In both seasons irrigation is required although the needs differ between the two seasons due to differences in the amount of rainfall received. During wet season irrigation is required in January and February while in a dry season full irrigation is required and the critical point is in November during the flowering phase of rice crop where the fields are kept flooded for about one month. Although irrigation water requirement is high during the dry season and water competition is high, farmers still prefer dry season over the wet season due to the high yield obtained. The study area was selected based on accessibility, representativeness of small-scale irrigation scheme and availability of information on the adoption of SRI.

Table 1: UWAMALE irrigators' co-operative union rice calendar for the wet season

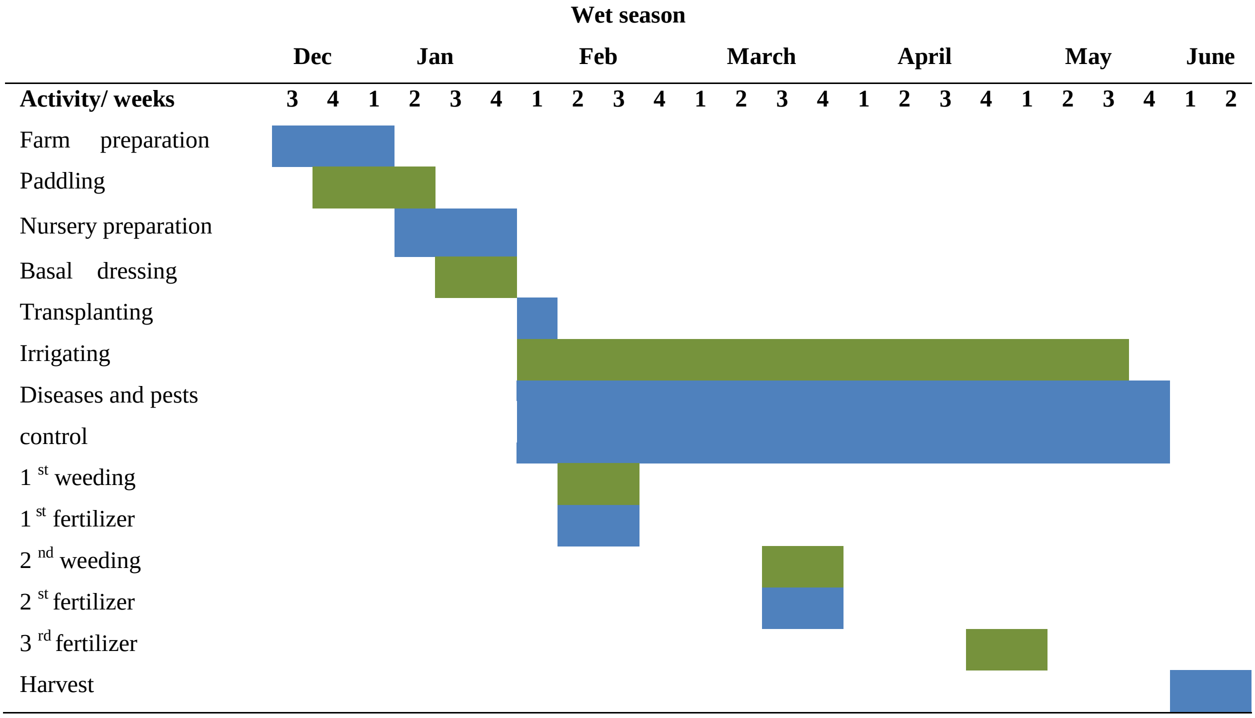
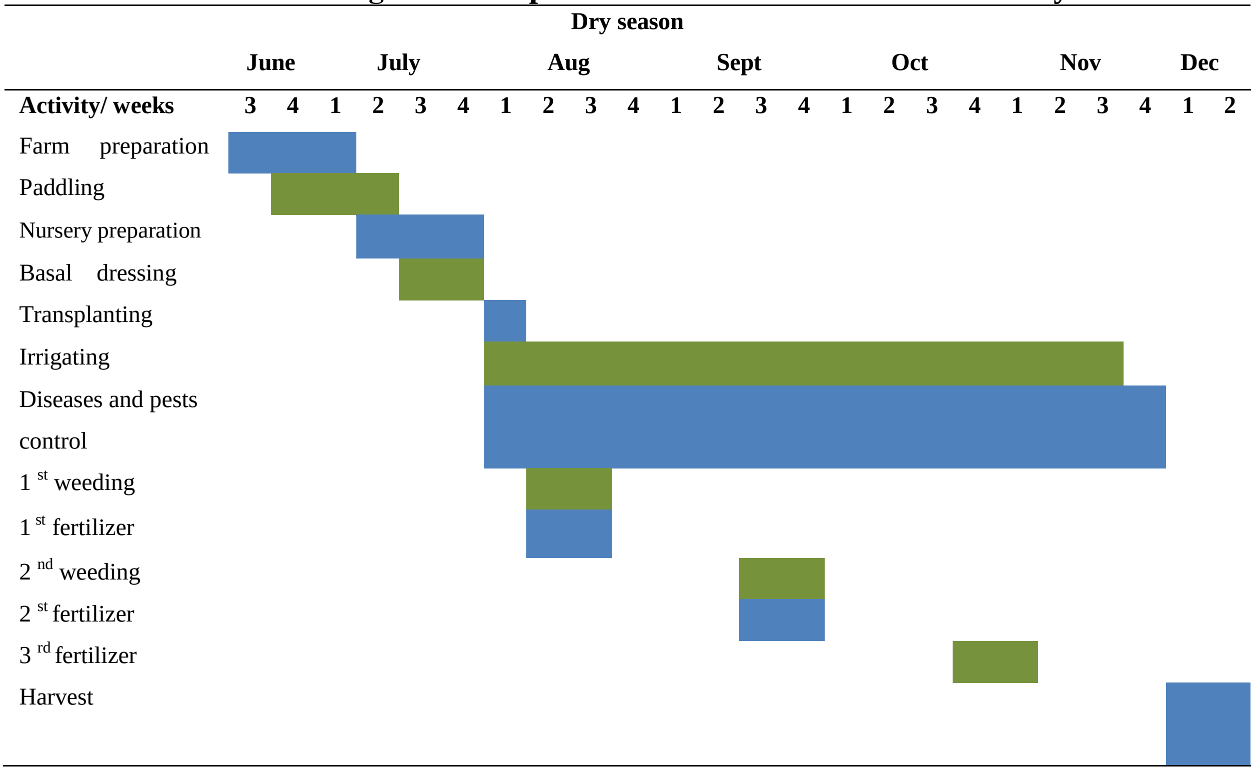


Table 2: UWAMALE irrigators' co-operative union rice calendar for the dry season



3.1.2 Historical development of Lekitatu irrigation scheme

Lekitatu village was formerly known as Manyata village, which was formed in 1961. In 1975, Manyata village was divided into 2 villages namely Manyata and Lekitatu village. The main activities in this area were livestock keeping and rice farming in small areas. The crop production was mainly for food consumption at the household level. Farmers were scattered, had little knowledge of crop and water management. The yield obtained was very low, an average of 1.3 tonnes/ha below the national average of 1.5 tonnes/ha (Wilson & Lewis, 2015) mostly due to the use of local rice varieties such as *Supa India* (long cultivars) and only cultivating in one season per year.

(i) Transforming Rice Farming in Lekitatu Irrigation Scheme

After the establishment of the scheme, there have been various efforts to assist farmers to benefit more from rice farming. Various actors such as the Japanese International Co-operation Agency (JICA), Kilimanjaro Agricultural Training Center (KATC) and Rice Council of Tanzania (RCT) supported the scheme. Through these actors, farmers have benefited from training, funds and loans and other government incentives. The first training on crop management started in 1997 when the concepts of green revolution were introduced to this scheme by KATC who provided training on the use of high yield varieties and proper use of fertilizers to 15 members of the scheme. The assumption was that later they would transfer the knowledge to other members. With the help of these training, farmers moved from cultivating one season per year using late maturity rice variety to two seasons per year by the use of early maturity varieties such as *Saro* ('saro'= semi-aromatic rice variety), *Saro* 5 (hybrid variety scientifically known as TXD 306) and *Wahiwahi*. Also, farmers were educated on the benefit of using fertilizers to boost productivity. Farmers applied fertilizers at least three times during growing period (an average of 150 kg) at transplanting, one month after transplanting and one month after the second fertilizer. Power tillers which facilitated easy and quick ploughing were also introduced in the scheme. During the green revolution initiatives, farmers were able to improve their rice yield from an average of 1.3 tonnes/ha to 2.5 tonnes/ha. The increased production motivated more farmers to engage in rice cultivation. As a result, the area under cultivation and the need for irrigation increased. As water requirement increased competition and scramble for water began and it is at this point that farmers realized the importance of having a body for water governance.

(ii) Establishment of Water Users Association

In 1998, with the help of a non-governmental organization (NGO) Rikolto (formerly known as VECO), farmers organized themselves and formed water users association (WUA) known as Umoja wa Watumiaji Maji Lekitatu (UWAMALE) for the purpose of managing water allocations. The union began with 15 members and the number had grown to 243 in 2018. The

UWAMALE is also used to govern other activities such as facilitate training, searching for grants and loans to provide credits to members to improve crop production for better income and improved living standards of the members. Even with UWAMALE in place, irrigation water became increasingly scarce as a result of both climate change and competition from other river water users located up and downstream. There was high water shortage especially during peak periods (November and February) where low flows were experienced in the canals. There were little or no flows reaching downstream farms, as a result, farmers always struggled to irrigate their fields and there was always conflict among farmers. To resolve this problem SRI, which was believed to increase yield and minimize the amount of water used for rice production, was introduced in the area.

(iii) Introduction of SRI in Lekitatu Irrigation Schemes

The SRI was first introduced in this scheme in 2014 by JICA through KATC and Japan Policy and Human Resources Development (PHRD). Since SRI was a new way of cultivating rice, farmers did not know to implement SRI and hence knowledge dissemination was the first step in introducing SRI in this scheme. Various methods were used to disseminate the knowledge of SRI to farmers, including demonstration plots within the scheme where few farmers (early adopters) who were willing to give their land for learning purposes were selected for SRI demonstration. The other method used was sending a few representative farmers to learn from other schemes that practice SRI and special arrangement were made to disseminate the lessons learned to the rest of farmers. Until 2019, more than 100 farmers had attended various training in various places. Like any other technology, SRI faced some resistance from farmers as it was a new way of managing their land and water resources. It was not easy to convince farmers to change their long-term rice cultivation practice and adopt the SRI principles. Since the lives of many smallholder farmers depend on agriculture as their main source of food and income, farmers cannot afford the risk of not harvesting even for one season. Very few farmers gave it a try, at first farmers experimented on a small portion of their land or in the selected community experimental plots normally known as farmer field school to avoid the risk of failure (Kabir, 2006). After validating the system these farmers became the ambassadors of SRI. With the spread of knowledge and evidence of yield increase from early adopters, more farmers gave it a try and cultivated some of their portions with SRI and conventional flooding (CF) to validate the method. After impressive results of SRI, farmers have now trusted the SRI and are currently applying SRI principles in their plots.

(iv) Changing Water Management

Introduction of SRI has brought some changes to the water management of the scheme. During experimentation period, experience from the demonstration plots showed that applying irrigation at least once per week (as for the most other crops within the area) was enough to sustain the rice crops and obtain significant yield increase. To ensure equity among all farmers the scheme was divided into zones for easy allocation of water. Each zone is allocated water at least once per week. In addition, to reduce competition for water among rice and other crops especially maize, maize growers are advised to adjust their planting dates to late September so that they can make effective use of the short rains as the agreement is that during November priority will be given to rice growers.

3.2 Data Collection

Both quantitative and qualitative data were collected in this study. Data was collected using semi-structured questionnaires with the help of pilot-testing questionnaires. To supplement the structured questionnaires, first, reconnaissance survey of the whole scheme was done, followed by observation of agronomic practices of the farmers for one season. Second, interviews with key informants and focus group discussion were conducted through meetings where guiding questions on the subject matter were introduced to provoke the discussion. After four experimental plots were set up for SRI practice, water and yield monitoring.

3.2.1 Reconnaissance Survey

To get an overview of the scheme in terms of infrastructure layout, agronomic practices, and general water management a reconnaissance survey of the whole scheme was conducted with the assistance of the extension officer and leaders of the UWAMALE cooperative. During the survey, questionnaires were pre-tested to randomly selected farmers to help capture more information to be included in the interview. In addition, some of the potential farmers to be included in the questionnaire were identified. The respondents were carefully selected to get a good representation of all gender, various age groups, different education levels, farming experience, farm size and both SRI and non-SRI users.

3.2.2 Questionnaires Administration

The survey involved a total of 115 farmers. The sample size was calculated following a previously proposed formula by Gupta (2002) (Equation 1). Questionnaires were carefully designed to explore farmers' appropriation of SRI practices (Appendix 1). Filling of the questionnaire was done by the respondent with the researcher to ensure complete filling and clarifying any ambiguous questions (Rundblad, 2006). A list of all farmers was obtained from Lekitatu extension office, each farmer was assigned a unique code and excel was used to generate a random list (Omair, 2014).

$$\mathbf{n} = \frac{\mathbf{N}}{\mathbf{1+N(e)^2}} \qquad \text{Equation 1}$$

Where; n = sample size

N = population size (total number of farmers)

e = the level of precision, (0.05)

(i) Data Cleaning and Processing

Data cleaning was done after transferring data into the excel sheet. The overall samples of the survey results were 115 smallholder farmers. The samples were processed according to the following criteria; for the sample to be included it must contain data on nursery management, transplanting age, spacing and amount of seeds/hill, weed management, irrigation management and nutrient management; comparisons for data from different correspondents in the same data cluster were made (Adèr, 2008). Where the data seems inconsistent or invalid, the arrangement was made to follow up on these farmers to get more valid data (Cochran, 1977). Where it was not possible to correct the data the sample was removed from the analysis. After data cleaning three samples were removed and remained with 112 samples.

3.2.3 Experimental Field Data

(i) Site Selection and Experimental Setup

Data collection for assessment of water productivity (WP) was done for the dry season 2019/2020 from July to December 2019. Data were collected from four farms with four different practices commonly found in the area (Table 3). In all farms, *Saro* 5 which is the dominant rice variety in the area was grown. Nurseries were prepared one week before the end of the wet season in a selected portion outside the field. After the harvest, the herbicide (round up) was sprayed to the field to kill the grasses. Three weeks later, the fields were ploughed and saturated for up to five days before puddling. Power tillers were used for ploughing and levelling followed with manual levelling. Transplanting was done soon after puddling followed by application of the herbicide (Rilo) to kill weeds seeds from the previous season two days after transplanting. After 21 days, another herbicide (basagram) was applied to kill the emerging grasses. In the F1 treatment, the field was puddled and ponding layer was maintained throughout the growing season except for the last two weeks. Initially, the water depth was kept at 2 cm and gradually increased to 10 cm at maturity stage. In other treatments F2, F3 and F4 plots, the soil saturation was done for 1 day before transplanting and the fields were kept flooded for one week to ensure good crop establishment. Afterwards, intermittent irrigation was applied once per week following water scheduling of the scheme. The same amount of fertilizers was applied three times to all fields (25 Kg/ha DAP for basal dressing, 50 Kg/ha YaraVera Amidus for first and second fertilizer application and 25 Kg/ha Yara Mira for third fertilizer). All farm activities such as dates for nursery establishment and transplanting, fertilizers application amount and dates, weeding methods and dates were recorded and tabulated as shown in (Table 3). Amount of irrigation water and drainage, standing water levels, and crop yield were documented.

Table 3: Treatment details and farming activities of the selected farms

Treatment	Unit	F1	F2	F3	F4
Cultivation method		CF	SRI	SRI	SRI
Irrigation method		Flooding	AWD	AWD	AWD
Transplanting age (days)		21	21	21	15
Seedling/hill (no.)		2	2	1	1
Spacing (cm)		15 X15	20X20	20X20	25X25
Nursery establishment	Date	6^{th} July	4^{th} July	4^{th} July	9^{th} July
Basal dressing	Date	24^{th} July	22^{nd} July	22^{nd} July	25^{th} July
Transplanting	Date	27^{th} July	25^{th} July	25^{th} July	25^{th} July
Weed control (herbicides application)	DAT*	1	2	2	1
1^{st} weeding (manual pulling)	DAT	28	29	30	28
1^{st} Fertilizer application	DAT	31	32	32	32
2^{nd} weeding (manual pulling)	DAT	54	53	53	52
2^{nd} Fertilizer application	DAT	58	57	57	56
3^{rd} fertilizer application	DAT	70	68	68	70

*DAT =days after transplanting

(ii) Determination of Physio-Chemical Properties of the Experimental Plots

Soil sampling was done to determine the physio-chemical properties of the experimental plots. Bulky density was determined using the core method following procedures explained in (Blake & Hartge, 1986). The location was selected and the top 10 cm layer was removed to avoid the disturbed soil by agricultural activities. The pit of 1.2 m^3 was created and the total of

9 undisturbed samples was collected, three replicates at each layer for three layers (0-30 cm, 30-60 cm and 60-90 cm) at each sampling location. Sampling was done carefully using a complete stainless steel Kopecky's Rings with a castle and a hammer. The rings have a diameter of 5 cm, a height of 5 cm and a volume of 98.125 cm^3. The samples were taken to the laboratory, weighted and kept for oven drying 24 hrs at 105°C. After drying the samples was weighed and the ration of the dry mass to the volume was determined as bulky density (Equation 2) (Folegatti, 2001).

Soil profiler was used to obtain soil samples for the determination of soil pH and conductivity. On each field, 10 subsoil samples were collected from a depth of 0-15 cm. The soil samples were mixed to obtain one homogenous sample (weight about 500 g) for analysis of pH and conductivity. The samples were air-dried and ground to obtain fine particles. In each sample, a solution containing 10 g of air-dry soil and 10 mL of deionized water was prepared in a 50 mL beaker. The samples were taken to a reciprocating shaker for 30 minutes in the low speed of the reciprocate shaker and centrifuge it for 5 minutes in 2000 rpm in Vance's lab. The samples were left for 15 minutes and EC was measured first followed by pH. Before measurements, EC and pH meters were standardized using standard solutions. For EC the solution used were EC 1.12 and EC 1.0 and for pH solution of pH 7 and pH 4 were used.

$$\boldsymbol{\rho_b} = \frac{\mathrm{Wd}}{\boldsymbol{V_t}}$$ Equation 2

Where

ρ_b=Bulky density (g/cm^3)

Wd = Dry mass (g) and Vt = Total volume (cm^3)

(iii) Irrigation Water Measurements

Amount of irrigation water applied to the field was measured by using 90˚ V-notch which was fabricated and calibrated by allowing water to pass the V-notch and record the time taken for water to fill a container of known volume for consecutive measurements then it was installed at the inlet of the farm (Fig. 3). The V-notch was applied because it is a simple and accurate method for measuring low flows (Ibrahim, 2015). The head over the V-notch crest and time took to complete each irrigation event was recorded and the discharge was calculated using (Equation 3) (Herschy, 1995; Chanson, 2013). Irrigation volume (V) in each plot was calculated by multiplying discharge (Q) with time (Equation 4), total irrigation amount used for the entire growing period was obtained by summation of all individual volumes (Equation 5).

$$Q = \frac{8}{15} * C_d * \tan\frac{\emptyset}{2} * \sqrt{2gh^5}$$ Equation 3

$$V = \text{Discharge } (m^3/s) * \text{time (seconds)}$$
Equation 4

$$V_T = \sum_{i,j=1}^{n} Q_{i*}\, T_j$$ Equation 5

Where,

Q = Discharge (m^3/s)

C_d= coefficient of discharge, which depends on notch angle and for θ = 90°,Cd= 0.58

h = Measured head of water over the V-notch (cm)

g = acceleration due to gravity (m/s^2)

ϴ = Notch angle, V = Volume (m^3), T = Time (seconds)

V_T = Total volume for the entire growing period (m^3)

i and j are individual irrigation events.

Figure 3: Field measurement of irrigation water using V-notch

(iv) Crop Performance and Yield Measurements

To assess the effect of each treatment on crop growth and performance, the height of the plant was taken at a regular interval, Average tiller number was determined at harvesting stage from each plot from an area of a square meter. The number of tillers per hill was determined by sampling 10 plants/hill from each plot. Yield measurement followed the procedure described in Sato and Uphoff. (2007) whereby sampling was done in 2.5 x 2.5 m^2 spot. Sampling spots were selected at about one-fourth distance from the plot perimeter to avoid edge effects with care to select representative yield conditions as much as possible. Three locations were selected from each plot and plants were cut manually and collected on a large vinyl sheet. After sampling the following was done: (a) carefully separating grains from the panicles on a large vinyl sheet; (b) separate filled and unfilled grains and discard unfilled grains; (c) measure the total weight of the remaining grains; (d) measure the moisture content of the grain using portable grain moisture meter; and (e) calculate total paddy yield by converting the moisture content of paddy to be 14%.

(v) Water Productivity

In wider meaning productivity compares the output to the input. Input and output vary from one field to another and within field depending on the context it is being used. In an agricultural context, water productivity (WP) defined as the physical or economic benefit derived from the use of water (Molden & Sakthivadivel, 1999) is usually used. In this study, input was regarded as the water used in production (m^3) and the grain/harvestable yield (kg) as output. Therefore, WP was regarded as the ratio of yield produced to the amount of irrigation water applied and its unit is given in kg/m^3 (Equation 6) (Mdemu *et al.,* 2013). Percentage of water-saving was calculated using (Equation 7) (Kahimba *et al.,* 2013).

$$\mathbf{WP} = \frac{\textbf{Yield produced (Kg/ha)}}{\textbf{Amount of water used}(\mathbf{m^3/ha})} \qquad \text{Equation 6}$$

$$\textbf{Water saving} = \frac{\textbf{Water used in the Conventional Flooded plot} - \textbf{Water used in AWD plot}}{\textbf{Water used in the Flooded plot}} \qquad \text{Equation 7}$$

3.3 Data Analysis

The interview data were analysed using Statistical Package for the Social Sciences (SPSS) 16. For general information, frequency tables were generated, t-tests were used to compare the mean differences between farmers practising SRI and CF. Categorical data were analysed using chi-square tests and correlations were used to identify the interdependence. Yield components and irrigation water use in all the treatments were analysed using Microsoft Excel 2010 following data analysis procedures for agricultural research recommended by Gomez (1984). To determine if there exists a significant difference among treatments based on the p-value of 0.05, Duncan's Multiple Range Test was done.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Integration of System of Rice Intensification into the Local Rice Farming System of Smallholder Farmers

4.1.1 Demographic Information

The questionnaires involved a total of 112 respondents. The ratio of males to females was almost equal (51% females, 49% males) and their ages ranged from 20-30 up to above 60 years. Most of the respondents (82%) had primary school level education and only 6% had a diploma and above (Table 4). Farmers of different experiences were interviewed ranging from those with less than 5 years to those who had more than 20 years of farming experience. A majority of the respondents (62%) had plots of 0.5 to 1 acre and 80% of them were using the alternate wetting and drying (AWD) method of cultivation (Table 5).

Table 4: Demographic information of respondents (gender, age and education level of farmers) (n=112)

Variable	Characteristics	Frequency	Per cent
Gender	Male	55	49
	Female	57	51
Age (Years)	20-30	6	5
	31-40	23	21
	41-50	44	39
	51-60	20	18
	Age >60	39	35
Education level	Primary	92	82
	Secondary	14	13
	Diploma	2	2
	Degree	1	1
	Higher	3	3
	CF	23	21

Table 5: Summary of education level, farming experience, farm size and cultivation method of farmers in Lekitatu irrigation scheme (n=112)

Variable	Characteristics	Frequency	Per cent
Farming experience (Years)	Less than 5	28	25
	6-10 years	38	34
	11-20	28	25
	more than 20 years	18	16
Farm size (acres)	Less than 0.5	4	4
	0.5-1.0	69	62
	1.1-1.5	27	24
	More than 1.5	12	11
Cultivation method	AWD	89	80
	CF	23	21

4.1.2 Farmers Adoption of SRI Principles in Lekitatu Irrigation Scheme

In this study, it was found that during the experimentation period farmers realized that some of the SRI principles such as transplanting of young (8-15 days), single plants at a wider spacing of 25 x 25 cm or more, applying water after the development of hairline cracks on the soil, the use of organic fertilizers instead of chemical fertilizers, and the use of rotary mechanical weeder to aerate the soil could not be adopted in their environment without modifications (Table 6). Since farmers saw the potential of SRI to increase their production and somehow minimize water usage, they were not willing to let go of this “wonders maker” technology rather they decided to modify these principles to suit their local specific needs as discussed below.

Table 6: Adoption rate of recommended SRI principles by farmers in Lekitatu scheme

SRI Principles	Description	No of farmers	Percent
Careful Nursery management	Preparing well-managed nurseries (garden-like managed)	112	100
Early transplanting	Use seedling of 8- 15 days old	15	13
Early and regular weeding	Weeding starting at least 10 days after transplanting	4	4
Alternative wetting and drying	Fields kept moist but not continuously flooded	89	79
Single widely spaced	Use of 25 x 25 cm and above	16	14
Application of manure	The use of organic fertilizer to the extent possible	19	17

(i) Nursery Management

Careful nursery management has been integrated into the rice farming system of smallholder farmers. All farmers interviewed (112/112) reported that they raise their seedbeds in a garden-like manner irrespective of their irrigation method or seed variety (Table 6). It was found that farmers have set aside a portion of their farm to be used for nursery establishment only. This portion is prepared such that it allows for easy drainage. Seeds in the nursery are spread widely, to allow for air and sunshine in the plants. Since more than 80% of farmers in this scheme use improved seeds (which is relatively expensive), careful nursery management reduces the amount of seeds required, which is a benefit to farmers. Reduction in the amount of seeds required in SRI was also reported in the study conducted in Bangladesh by latif *et al*. (2005) where SRI requires an average of 13% (8 Kg/ha) of the seeds required in CF (60 Kg/ha). In addition, careful nursery management increases the rate of germination (Uphoff, 2007), reduces diseases and pests at an early stage, resulting in plants that are healthier and resistant to diseases and also facilitate easy uprooting and separation of young plants during transplanting.

(ii) Transplanting Age of Seedling

Transplanting of young seedling at the age below 15 days as recommended in SRI is not a preferred option by most smallholder farmers. Only 13% (15/112) were able to follow this practice. Other farmers, however, had made changes on the transplanting age. Most farmers preferred to use 16- 20 days (31%), 21-25 days (47%) and 9% use > 25 days (Fig. 4) to avoid the risks associated with transplanting of young seedlings. There are several reasons why most smallholder farmers fail to transplant seedling younger than 15 days old. One is difficulties in handling young seedlings, from farmer's experience, at the age below 15 days the seedlings are so small and need careful handling during uprooting to prevent root damage. Two, Since water is not reliable, most farmers prefer to flood their fields also known as puddling before transplanting to ensure moist condition for the plants, experience shows that young plants at the age below 15 days can easily be stacked in the muddy since the leaves are so small the rate of failure is high. As explained by Uphoff (2011), it is best to consider physiological age (i.e. transplanting at 2-3 leaf stage) instead of calendar age. Three is lack of enough power tillers within the scheme, whereby some farmers are made to wait for more than three weeks before their fields are ploughed. These delays in getting power tillers make the whole process delay. To solve this problem farmer may opt to use the non-tillage technique which preserves the soil structure and save time and cost.

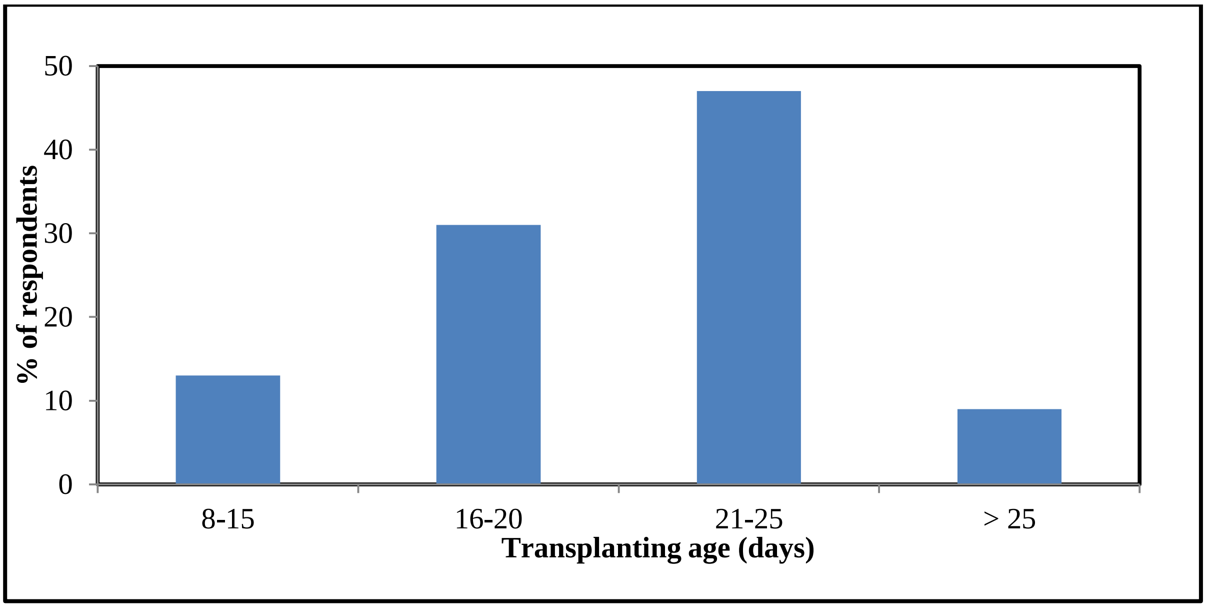


Figure 4: Farmer's preference for transplanting age of 8-15 days, 16-20 days, 21-24 days and above 25 days based on their local condition (n=112)

(iii) Spacing and Amount of Seedling

The SRI recommends the use of a single plant at a wider space of at least 25 x 25 cm. Only 14% (16/112) were able to follow this principle. Most farmers preferred the use of 20 x 20 cm with one (33%) or two seedlings (31%), 14% preferred to use two seedlings at 15 x 15 cm (Fig. 5). Farmers' preference to use a closer spacing of 20 x 20 cm is a mitigation measure against pests (worms) and diseases. During the reconnaissance survey, it was observed that most of the last row of edge/border of the basins had dry plants which were cut by worms. Transplanting two plants at closer spacing was found to help maintain sufficient plant population (Das *et al.*, 2018). Another reason is farm labourer's capacity to carefully separate attached plants during transplanting. Singly transplanting can be labour intensive especially at early years of adoption (Latif *et al.*, 2005; Lee & Kobayashi, 2018) where farmers are still learning the process, but may reduce with time as farmers master the system.

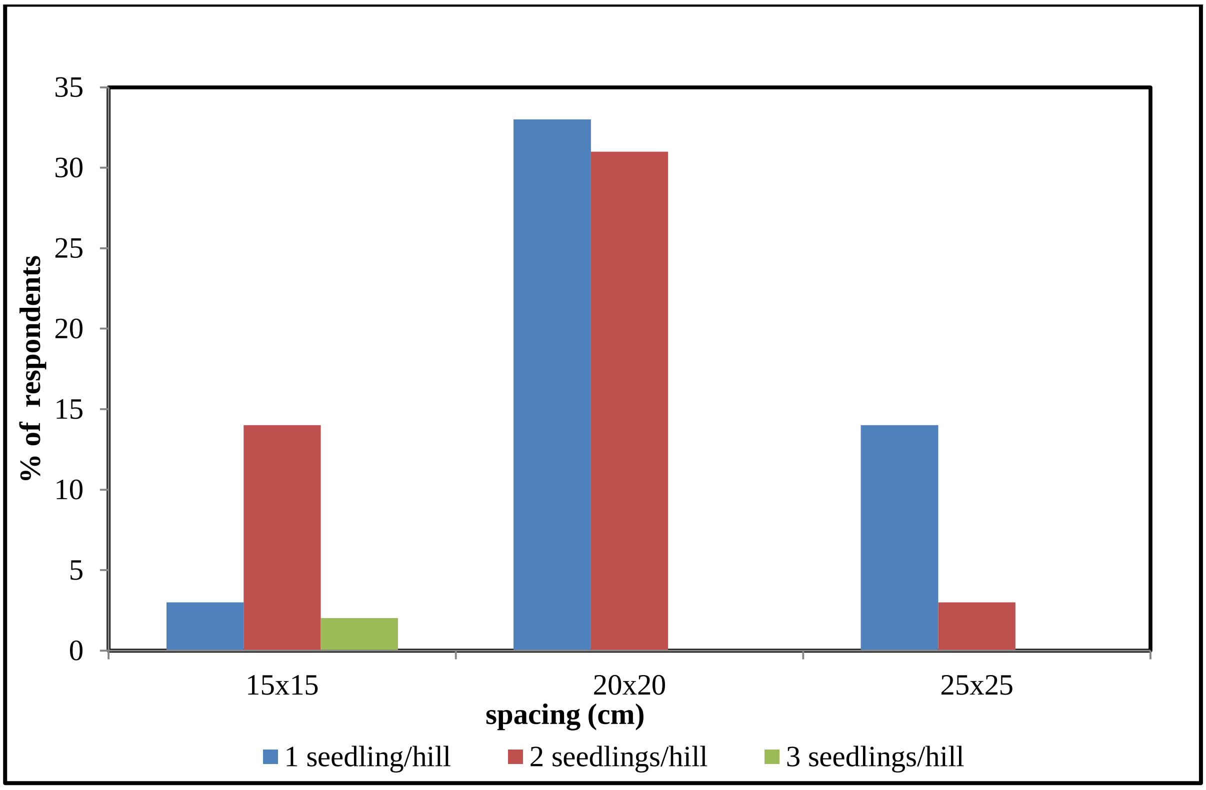


Figure 5: Number of seedlings vs. spacing (15 x 15 cm, 20 x 20 cm and 25 x 25 cm) as used by farmers in Lekitatu irrigation scheme based on the prevailing local environment (n=112)

(iv) Irrigation Water Management

In this study, 79% reported using intermittent irrigation, especially at the panicle initiation stage. Though under SRI it is advised to apply water after the development of hair-like cracks in the soil, farmers in this area apply irrigation between 4-7 days depending on weather and water availability (Fig. 6). Farmers cannot use hair-like cracks as an indicator for irrigation because there is water allocation schedule of the scheme in which each zone is allocated water at least once per week. Farmers are supposed to irrigate when water is allocated to them for there is little or no possibility to have water before the next schedule. Lack of adequate water supply and no- flexibility in water allocation was also reported as one of the major constraints for adopting SRI in Cambodia (Lee & Kobayashi, 2018). It was also proved difficult to apply intermittent irrigation at the Mwea Irrigation Scheme in Kenya (Ndiiri *et al.*, 2013).

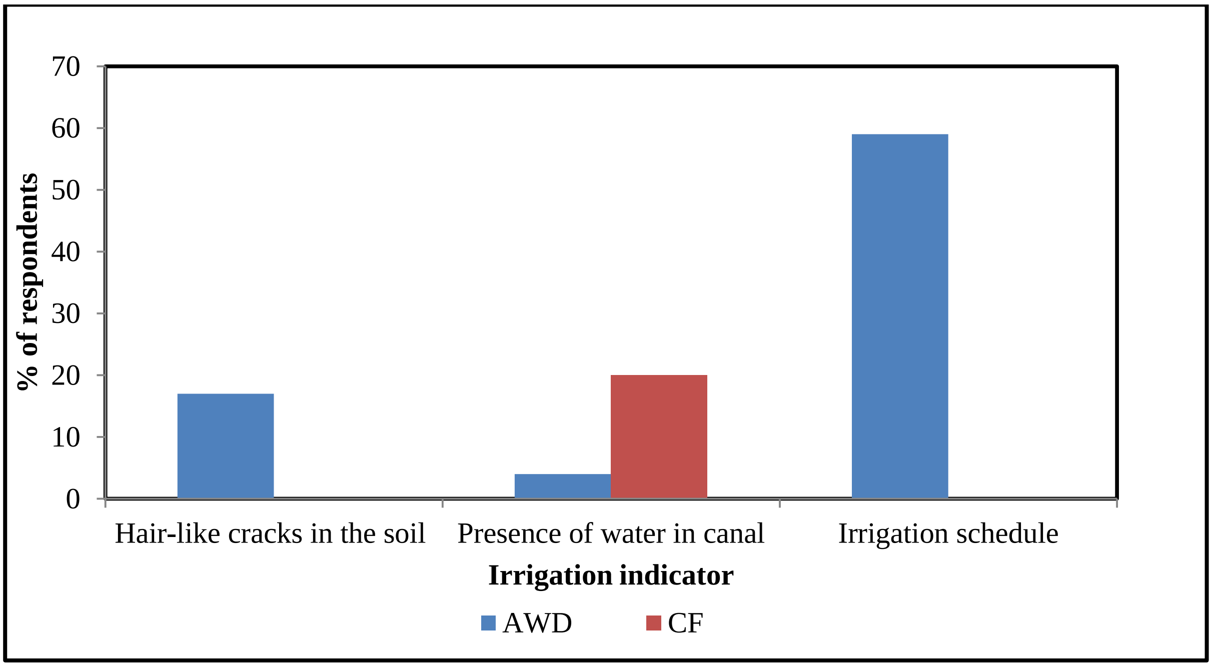


Figure 6: Irrigation indicators (hair-like cracks in the soil, presence of water in the canal or irrigation schedule) as used by farmers practising AWD and CF (n=112)

(v) Weed Management

The commonly used method for weed management is herbicides applied within three days after transplanting to kill weed seeds and prevent their germination followed by two manual weeding 80% (Fig. 7). First-hand weeding starting one month after transplanting contrary to 10-15 days as recommended in SRI and the second weeding is done one month later during the reproductive stage. The use of herbicides is attributed by two factors; one manual labour is expensive and two rotary weeders are not available. The use of herbicides reduces the number of weeding from four to five times into two. In addition, farmers find the use of herbicides cheaper and require less labour as compared to manual weeding. According to Latif *et al.* (2005) use of herbicides can be justified when the labour cost involved is less than that required in manual or mechanical weeding, also when there is an improvement in yield. For the case of rotary weeders, as explained by Ndiiri *et al*. (2013) farmers have to manufacture their mechanical weeders that will suit their specific needs.

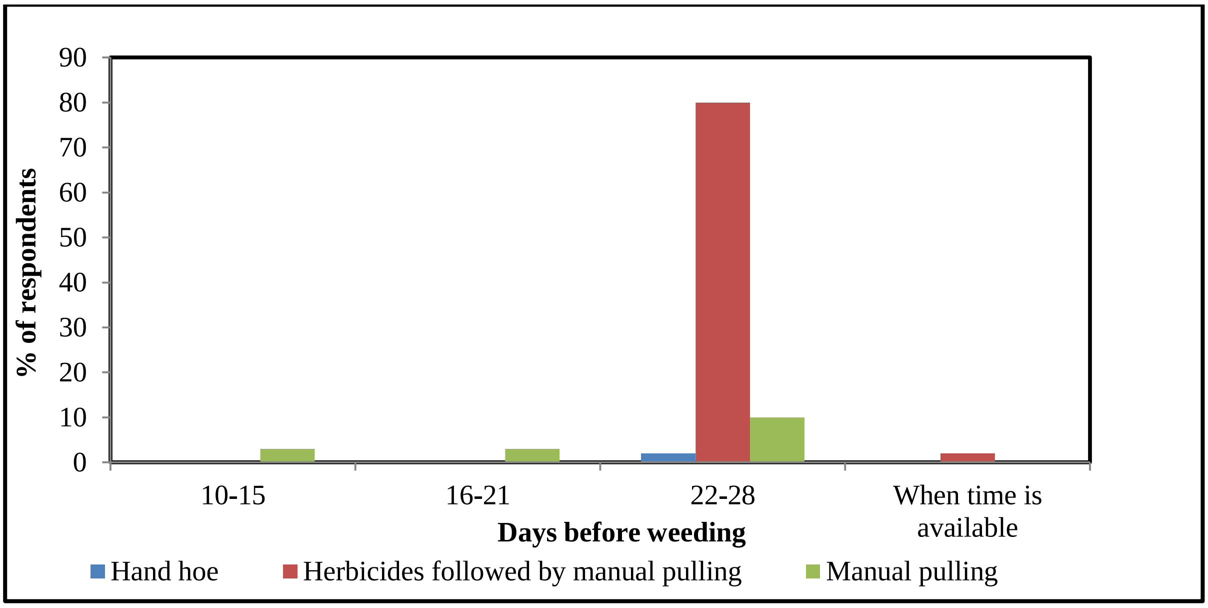


Figure 7: Time taken before first weeding for farmers using hand hoe, herbicides followed by manual pulling, and manual pulling (n=112)

(vi) Nutrients Management

Concerning nutrient management, farmers use either only chemical fertilizers as the main supply of nutrients to plants (81% of respondents) or a mixture of chemical fertilizer with manure (18%). Only 1% use manure only (Fig. 8). High use of inorganic fertilizers is caused by lack of enough manure within the vicinity. As explained by Uphoff (2007), the use of organic fertilizers is not mandatory in SRI if chemical fertilizer alone or a combination of manure and chemical fertilizer will provide better results (Sato & Uphoff, 2007). In Madagascar, for example, manure was used because farmers were not able to afford chemical fertilizers. Later it was found that the use of organic fertilizers was beneficial in improving soil fertility (Uphoff, 2011). In a study conducted in Bangladesh, Latif *et al.* (2005) reported higher yield when chemical fertilizers were used alone or when supplemented by organic manure, but not as a substitute. Therefore, if organic manure is not available it should not prevent the use of other SRI components. The other option can be mixed farming where farmers will also keep cattle/chicken to obtain more organic fertilizers.

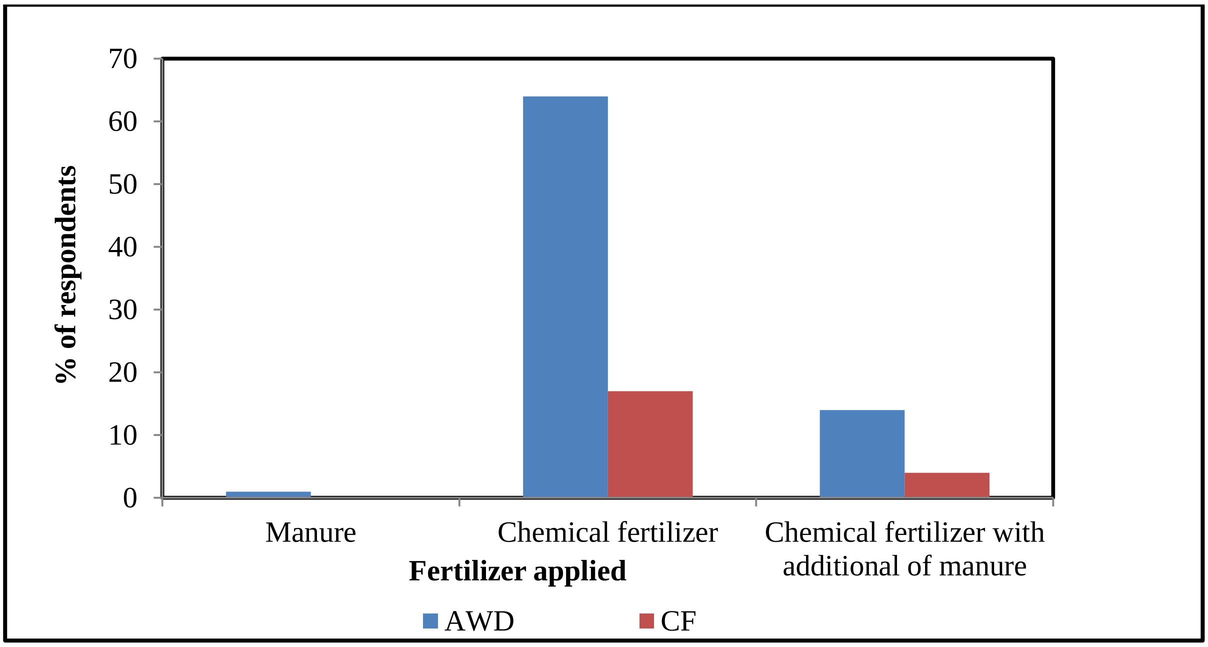


Figure 8: Difference in nutrient management between farmers practising AWD and CF in their local farms using (manure, chemical Fertilizer and chemical fertilizer with additional of manure) (n=112)

4.2 Physio-Chemical Properties of the Experimental Plots

Soils at the experimental site are classified as sandy loam with an average bulk density of 1.4 g/cm^3. The pH values of the experimental sites range from 6.4 -7.2, which makes the soils suitable for rice cultivation (Samanta *et al.*, 2011). The EC values range from 0.2-0.3 ds/m which are suitable for rice cultivation (Raza *et al.*, 2018) (Table 7).

Table 7: Soil physio-chemical properties of the experimental sites

Soil properties	**F1**	**F2**	**F3**	**F4**
Physical properties				
Sand (%)	66.40	68.10	68.10	69.4
Silt (%)	33.30	31.50	31.60	30.1
Textural class	Sandy loam	Sandy loam	Sandy loam	Sandy loam
Bulk density (g/cm^3)	1.48	1.42	1.4	1.46
Chemical properties				
pH (water)	6.4	7.2	7.1	7.1
EC (ds/ m	0.2	0.2	0.2	0.3

4.3 Performance of SRI Under Farmers' Management

4.3.1 Plant Morphology and Soil Environment

The number of tillers per m^2 was higher (544.2) in F2 using two older seedlings at 20 x 20 cm with intermittent irrigation, followed by F1, two seedlings at a closer spacing of 15 x 15 cm under continuous flooding (Table 9). Results for F1, F2 and F3 were not significantly different at $p<0.05$. The lower number of tillers per m^2 (384.1) were obtained in F4 which was statistically different from all other treatments (F1, F2 and F3) based on LSD post hoc test at $p< 0.05$. The lower number may be attributed to wider spacing (25 x 25 cm) resulted in a fewer number of plants per unit area. Maximum tillers number per hill was recorded in F4. Wider spacing (25 x 25 cm) with single transplanting in F4 reduces plant competition for nutrients, allow for better utilization of light and water hence resulted in more tillers than in all other treatment. In addition, it was observed that plants under intermittent irrigation had better root development compared to those under continuous flooding because the soils are well aerated. It was also observed that crop and water management greatly affected plant growth, as seen in (Table 8), the average plant height was higher in F3 and F4 where single plants were transplanted at a wider spacing of (20 x 20 cm) and (25 x 25 cm) respectively compared to closer spacing in F1 and F2. Statistically, F1 and F2 were not significantly different from each other but from F3 and F4. The same is true for F3 and F4. The influence of SRI in improving plant morphology has also been reported by other researchers (Thakur *et al.*, 2011; Kahimba *et al.*, 2013; Thakur *et al.*, 2014).

Table 8: Morphological characteristics of rice plants under different treatments in Lekitatu scheme

Treatment	Number of Tillers /m^{2*}	Max Tillers number/hill*	Average tillers number /hill*	Average Height (cm)*
F1	521.0^a	26.2^a	20.4^a	79.6^a
F2	544.2^a	43.3^c	30.4^b	82.2^a
F3	489.1^a	37.9^b	37.5^c	84.0^b
F4	384.1^b	59.6^d	52.2^d	85.5^b

***** Means with the same letter are not significantly different at $p < 0.05$.

4.3.2 Grain Yield

The average grain yield obtained from experimental fields were 4.8, 8.5, 8.2 and 9.2 tons/ha for F1, F2, F3 and F4, respectively. The highest grain yield was obtained from F4 followed by F2 and F3 while the lowest was obtained from F1 (Fig. 9). It was noted that transplanting of young single seedling (15 days old) at a wider spacing of 25 x 25 cm combined with AWD in F4, gives the optimal yields (9.2 tons/ha) (Fig. 9). These results support the results found by other researchers, for instance, Vijayakumar *et al.* (2006), Kahimba *et al*. (2013) and Reuben *et al.* (2016) who recommended that younger seedlings (8-14 days old) singly transplanted at wider spacing (25 x 25 cm to 30 x 30 cm) with AWD irrigation regime produce optimum yields. However, this method is not preferred by many farmers due to lack of supporting infrastructure. For farmers to apply this treatment water should be reliable. In F2, where two 21 days plants were used at a spacing of 20 x 20 cm with AWD, the results were significantly higher (8.5 tons/ha) compared to F3, where single plant of 21 days at 20 x 20 cm spacing with AWD was used (8.2 tons/ha). Therefore, in places where water is not reliable and farmers lack enough capacity to handle young plants, two 21 days seedlings at a spacing of 20 x 20 combined with AWD may be the best option. The statistical analysis of different treatment showed a significant difference in grain yield (Table 9).

The use of single young seedling at wider spacing (25 x 25) in F4 resulted in the higher weight of 1000 grains (28 g) as compared to other treatments (Table 9). Lower weight was obtained under F1, where two older seedlings were transplanted at a closer spacing (15 x 15) with continuous flooding. Statistically, F1 and F4 were different from other treatments, whereas F2 and F3 were not significantly different from each other at $p<0.05$.

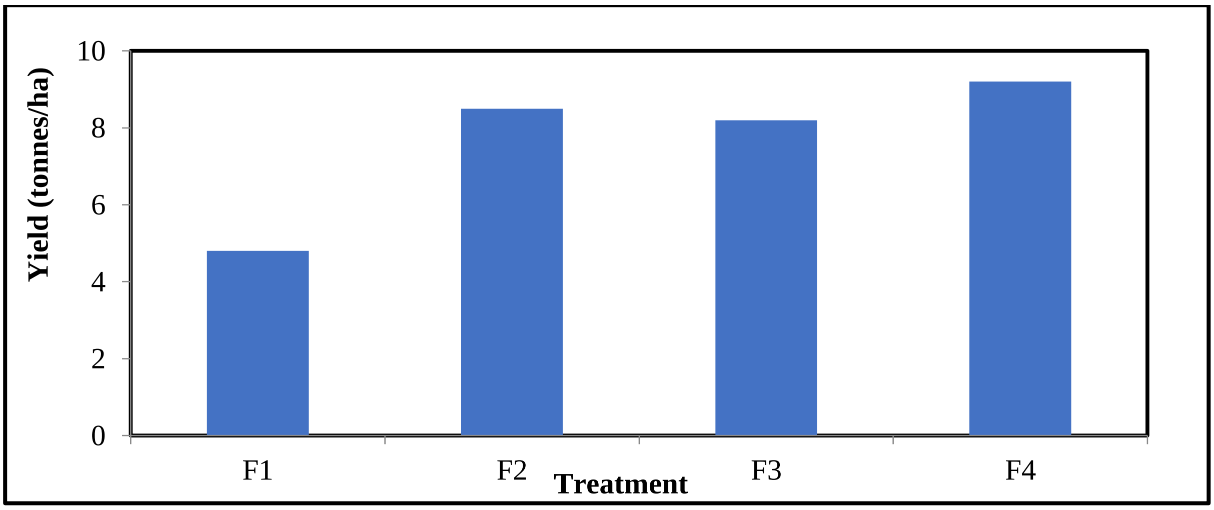


Figure 9: Grain yield (Tons/ha) for different treatments during the dry season at Lekitatu

Table 9: Performance of different treatments under farmers' management in Lekitatu irrigation scheme

Treatment	Yield * (tonnes/ha)	Yield increase (%)	Irrigation water use* (m3/ha)	Irrigation water saving (%)	Water Productivity* (Kg/m3)	1000 grains weight* (g)
F1	4.8[a]	0	32936[a]	0	0.15[a]	24.7[a]
F2	8.5[b]	77	21628[b]	34.3	0.39[b]	26.6[ab]
F3	8.2[c]	71	23414[b]	29	0.35[c]	27.8[ab]
F4	9.2[d]	91.7	18080[c]	45.1	0.51[d]	28[b]

* Means with the same letter are not significantly different at p = 0.05.

4.3.3 Irrigation Water Use and Water-Saving

Highest irrigation water uses of 32 936 m^3/ha was recorded in F1 (control treatment) in which continuous flooding was practised throughout the crop growing season (Table 9). In other treatments F2, F3 and F4, in which intermittent irrigation was applied, the average irrigation water uses of 21 628; 23 414; and 18 080 m^3/ha respectively, were recorded (Table 9, Fig. 10). The mean ranking based on LSD post hoc test at $p< 0.05$ showed that irrigation water use of the control treatment F1 and F4 were statistically different from that of F2 and F3 (Table 9). Water-saving under SRI practice was 34.3%, 28.9%, and 45.1% for F2, F3 and F4; respectively. These results agree with the results reported by Keisuke (2007) that AWD can save water used in rice production by 20-50% compared to CF. Similarly, Sato and Uphoff (2007) reported water saving ranges of 24% - 60% under SRI management compared to CF in eastern Indonesia. If proper management of water is done such that farmers have assurance on water availability more water will be available to downstream farmers in the scheme who always suffer water scarcity during high demand period (November).

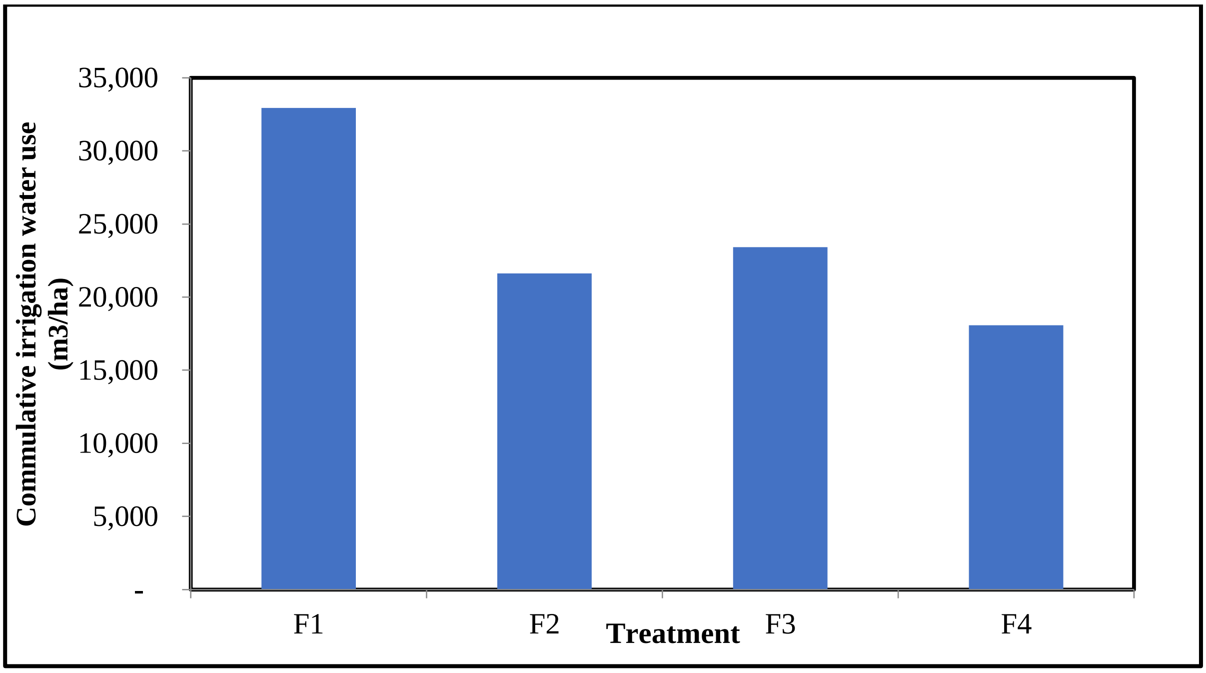


Figure 10: Cumulative irrigation water use under different treatment in Lekitatu area

4.3.4 Water Productivity

Water Productivity was highest (0.51 kg/m^3) in F4 where SRI practice was applied with young (8-15 days), single widely spaced at 25 x 25 cm followed by 0.39 kg/m^3 in F2 with two seedlings, 21 days old spaced at 20 x 20 cm. The WP was lowest (0.15 kg/m^3) in F1 where continuously flooding is applied with 2 seedlings closely spaced at 15 x 15 cm (Fig. 11). The lowest WP in CF (0.15 Kg/m^3) agree with the finding of Kahimba *et al.* (2013) in Mkindo irrigation scheme where WP was 0.14 Kg/m^3 in CF. Statistically, at $p<0.05$, water productivity in all treatments was significantly different (Table 9).

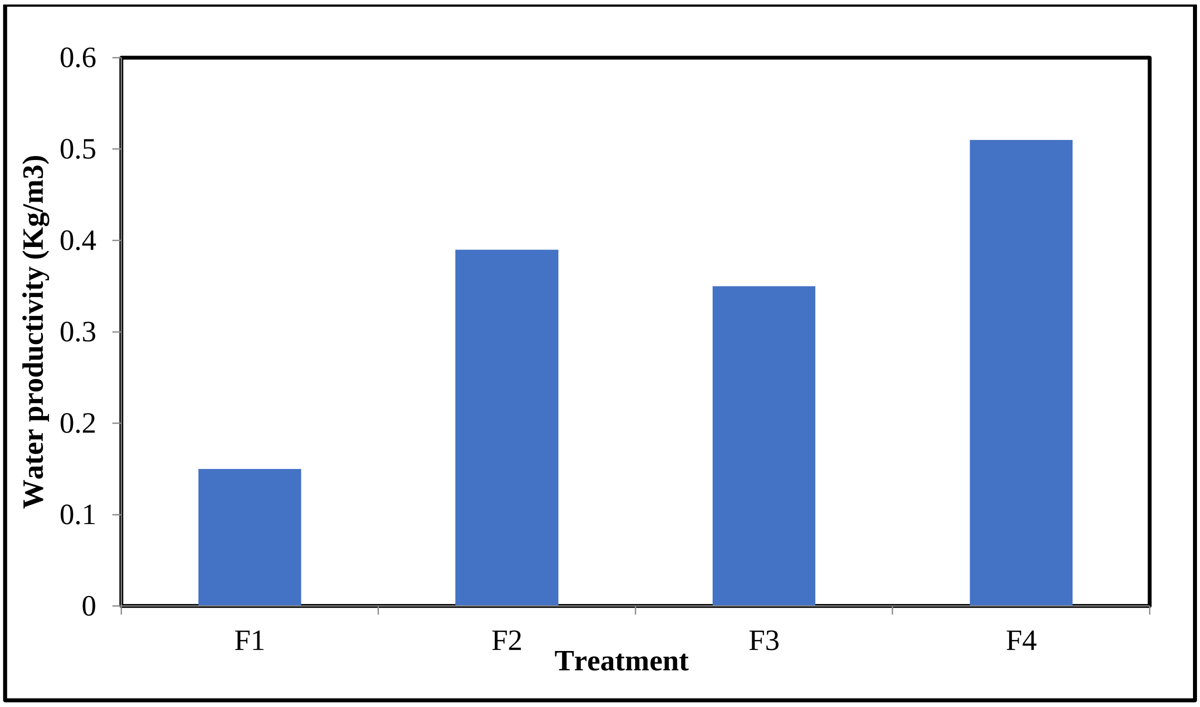


Figure 11: Water productivity obtained by farmers' under different treatments in Lekitatu area

4.4 Challenges in Implementing System of Rice Intensification

4.4.1 Water Reliability and Allocation Flexibility

For effective implementation of SRI a reliable source of water is required. Since the seedlings are transplanted at a very young age (8-15 days) and permanent flooding is avoided in the vegetative stage, reliability of water is very critical in implementing SRI to avoid crop stress. In addition, when hair-like cracks appear in the soil as an indicator of irrigation trigger, the fields need to be irrigated immediately to prevent stress to plants which if critical can damage the final yield. In this scheme water is reliable but there is no flexibility in allocation (Fig. 12). Although in this scheme the irrigation schedule was strictly followed during high demand (November for the dry season and February for wet season) farmers in the down-stream area were still struggling to irrigate their fields. Although there is an arrangement that farmers who could not get water will be considered first in the next cycle. This is still a big challenge as it will mean that the soils will stay two weeks without water. This lack of assurance on availability of water has created fear for farmers to apply intermittent irrigation as lack of water in the vegetative and reproductive stage can damage the crops and hence affect the final yield. It was also observed that irrigation canals are very long up to 5 km, given characteristics of earthen canals a lot of water is lost during conveyance due to seepage and percolation and little or sometimes no water reaches downstream. In this scheme as in many other smallholder irrigation schemes, water distribution is guided by informal management and water allocation depends on mutual agreement among irrigators. Under this scenario, farmers are advised to make proper arrangement to make sure each farmer gets water when needed (Wallace, 2000; Sokile & Van Koppen, 2004).

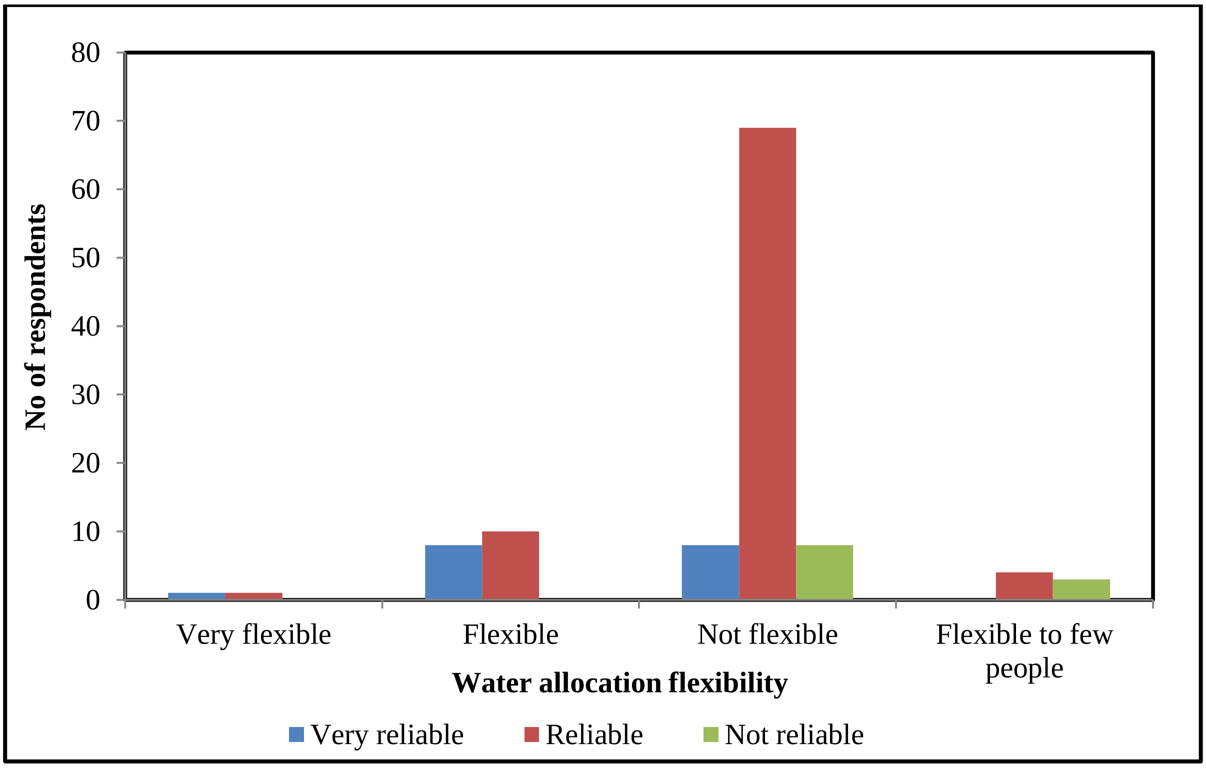


Figure 12: Farmer's opinion on Water reliability vs. water allocation flexibility (n=112)

4.4.2 Production Cost

Farmers reported that the total production cost under SRI was higher than CF. The cost involved in SRI was estimated to be Tshs. The 1 500 000 (50% higher) compared with Tshs. 1 000 000 for CF. The cost involves labour cost for transplanting, weeding and irrigating. In a study conducted in Bangladesh, the results showed that transplanting and weeding costs in SRI were 19% and 27% higher than in CF while irrigation cost increased by 33% (Latif *et al.*, 2005). Although generally total production cost of rice is in smallholder scale is high due to high labour requirement and little mechanization, the cost is expected to increase under SRI especially where farmers have not mastered the system (Wilson & Lewis, 2015). The research has shown that the labour cost involved in SRI can reduce with time if farmers are willing to learn and improve their practice (Sato & Uphoff, 2007). Alternatively, farmers may give try on direct seeding which is estimated to reduce labour cost by up to 40% (Ramasamy *et al.*, 2006).

4.4.3 Diseases Affecting Rice Plants

It was found that diseases such as rice yellow mottle virus are common in this area, especially in the wet season. These diseases affect the growth of rice plants and hence reduce the yield. Farmers are required to transplant more than one seedling and also to reduce the planting space to cover for losses. In addition, a lot of chemicals are needed to control diseases. In a few cases, farmers have attempted re-transplanting more than three times without success. This challenge has made some farmers quit cultivating in the wet season. During focus group discussion, some farmers reported under SRI when farmers follow the cropping calendar, there is a possibility of reducing diseases. Although this was known by most farmers, they argued that their failure to follow the proposed crop calendar was because of the unreliability of water during transplanting.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study was conducted to evaluate the performance of the system of rice intensification (SRI) under traditional farmers' management. By first understanding how smallholder farmers appropriate SRI practices and use it in their fields, the study shows that farmers have a positive response towards SRI practices. Second, by assessing yield, water productivity and water saving, we find that adopting all recommended practices may not be practical to some farmers; there are always initiatives to try finding out what is or isn't working based on local conditions. It is through these trial and error experiments that smallholder farmers were able to integrate SRI into their farming systems.

Application of SRI principles is hindered by various social, economic and institutional constraints. The SRI needs a reliable source of water, proper water distribution facilities to ensure water gets to the field at the required time and amount, proper land preparation to facilitate easy movement of water within the field, to store moisture, and proper water control structures to avoid entering of overflow from the neighbouring fields. In addition, SRI is labour and knowledge-intensive; it requires farmers and labourers to invest time in understanding the processes behind each stage, test and adjust these principles to suit their environments. The SRI may involve decisions that are beyond an individual capacity; it requires changes in social and institution arrangement which needs to be made before and during the implementation of SRI. Therefore, co-operation and coordination among farmers and between farmers and their leaders within a given common irrigation block are important.

It was found that replacing traditional rice farming system with SRI may not be a one-time event. It will require a lot of investments in terms of money and time to prepare the environment for proper implementation of SRI. To make SRI application successful, SRI training should involve more than just training the landowners (farmers), rather field labourers, water allocation and distribution officers and extension officers' should be part of the training. In addition, support from government or external agent is required in supporting SRI implementation.

Regardless of the challenges in integrating SRI into local farming system, the results obtained by farmers were worth the trouble. By singly transplanting 15 days old seedlings at 25 x 25 cm with intermittent irrigation, the yield of 9.2 t/ha was obtained, which is 92 % increase; WP of 0.51 Kg/m^3 and water saving of 41.5% was obtained compared to yield of 4.8 t/ha and WP of 0.15 Kg/m^3 for conventional rice farming. Though the results are very promising and higher compared to all other treatments, most farmers fail to use this method for it requires a reliable water supply, knowledge on handling young seedlings and proper weeds, diseases and pests management. Instead of backing up most farmers decide on making SRI their own by customizing the principles to suit their environment. This involves using older seedlings, reducing the planting space and sometimes even using two seedlings to ensure adequate plant population. When 21 days single seedling at 20 x 20 cm with intermittent irrigation was used the yield was 8.2 t/ha which is 71% increase, WP of 0.35 Kg/m^3 and water saving of 29% was obtained compared to conventional rice farming. Using two seedlings 21 days old at 20 x 20 cm with intermittent irrigation yielded of 8.5 t/ha which is 77% increase, WP of 0.39 Kg/m^3 and water saving of 34% was obtained compared to conventional rice farming. The latter is recommended as it reduces the risk of ending up with the insufficient number of plants, but also farmers are assured of higher yields and reduced amount of irrigation water.

5.2 Recommendations

This study recommends the following:

(i) More studies should be conducted to gather more information on the site-specific adaptation of SRI principles.

(ii) In order for SRI to be successful, there should be strong co-operation and mutual agreement between farmers on how collective resources such as water will be shared.

(iii) There should be continuing education on SRI principles to farmers and extension officers.

(iv) To ensure farmers sustainability, the use of two seedlings of the age 21 days at a space of 20 x 20 cm with intermittent irrigation is recommended for this area.

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APPENDICES

Appendix 1: Questionnaires for assessing the adaptation of SRI principles in Lekitatu Irrigation sheme

General Information

NELSON MANDELA AFRICAN INSTITUTE FOR SCIENCE AND TECHNOLOGY

Questionnaire for Respondents

Dear Respondent,

I am **Rosemary E Kavishe**, a bona fide student of NM-AIST. Currently, I am conducting a research on "**Assessing adoption and water productivity of the System of rice-intensification under farmer-led irrigation area, Tanzania"** in partial fulfilment of the requirements of MSc in Hydrology and Water Resources Engineering Degree.

I would like to request your assistance in responding to the given questions. Your cooperation will be highly appreciated. I would like to assure you that this study is purely for academic purpose and not otherwise.

**Please tick one only except where instructed otherwise"*

Section 1: Demographic Information

1. **What is your Gender?**
    a. Male ( )
    b. Female ( )
2. **How old are you?**
    a. 20-30 ( )
    b. 31-40 ( )
    c. 41-50 ( )
    d. 51-60 ( )
    e. >60 ( )
3. **What is the level of your education?**
    a. Primary level ( )
    b. Secondary ( )
    c. Diploma ( )
    d. Degree ( )
    e. Higher degree ( )
    f. Not attended formal education ( )
4. **For how long have you been farming in this area?**

a. 0-5 years ( )

b. 6-10 years ( )

c. 11-20 years ( )

d. More than 20 years ( )

5. What is the size of your farm?

a. Less than 0.5 acre ( )

b. 0.5- 1 acre ( )

c. 1- 1.5 acres ( )

d. More than 1.5 acres ( )

Section 2: Water and Crop Management

» Water Management

6. Which method do you use to cultivate your Rice?

a. Continuous flooding (CF) ( )

b. Alternative wetting and drying (AWD) ( )

c. Rain-fed cultivation without managing the water ( )

d. Others (Specify) ( )

7. Why have you chosen to practice the method mentioned above?

a. Availability of water ( )

b. It is cheaper ( )

c. It is a traditional practice ( )

d. I was advised to do so by extension officer ( )

8. How often do you irrigate your crops?

a. Everyday ( )

b. After every three days ( )

c. After every five days ( )

d. Once in every two weeks ( )

e. Whenever water is available ( )

9. How reliable is the water source?

a. Very reliable ( )

b. Reliable ( )

c. Not reliable ( )

10. Is there a water allocation/ distribution schedule?

a. Yes ( )

b. No ( )

11. If Yes, How flexible is water allocation/distribution in your canal?

a. Very flexible ( )

b. Flexible ( )

c. Not Flexible ( )

d. Flexible only to few people ( )

12. How do you know it's time to irrigate?

a. By measuring soil moisture content ( )

b. By feeling of the soil ( )

c. When I see cracks in the soil ( )

d. Whenever water is available in the canal ( )

e. By following irrigation schedule ( )

» Seed management

13. What type of seed do you use?

a. Hybrid ( )

b. Local breed ( )

14. Please specify the name of the seeds used

____

15. Do you raise your own nursery or buy young seedlings from other farmers?

a. Yes I raise ( )

b. No ( )

Section 3: System of rice intensification management

16. Do you know about the concept of SRI (Kilimo Shadidi cha Mpunga ?)

a. Yes I know ( )

b. No ( )

17. Do you personally practice SRI?

a. Yes I practice ( )

b. No ( )

18. What procedures of SRI are being practiced in your area? (tick all appropriate)

a. Raising seedlings in a carefully managed garden-like nursery ( )

b. Early transplanting of old seedlings (8 to 15 days old) ( )

c. Single, widely spaced transplants (at least 20X20 cm) ( )

d. Early and regular weeding ( )

e. Carefully controlled water management ( )

f. Application of manure to the extent possible ( )

19. What SRI procedures are not being practiced in your area and why? (tick all appropriate)

a. Raising seedlings in a carefully managed garden-like nursery ( )

b. Early transplanting of old seedlings (8 to 15 days old) ( )

c. Single, widely spaced transplants (at least 25X25 cm) ( )

d. Early and regular weeding ( )

e. Carefully controlled water management ( )

f. Application of manure to the extent possible ( )

20. How many days do the seeds stay in the nursery before transplanting?

a. 8-15 days ( )

b. 16-20 days ( )

c. 21-25 days ( )

d. More than 25 days ( )

21. How many seeds do you plant per hole?

a. One ( )

b. two ( )

c. three ( )

d. four ( )

22. What spacing do you use in transplanting?

a. 15X15 cm ( )

b. 20X20 cm ( )

c. 25X25 cm ( )

d. 30X30 cm ( )

e. Irregular spacing double row planting ( )

23. How do you manage weed on your farm?

a. Using a hand hoe ( )

b. Using a rotary weeder ( )

c. Using herbicides ( )

d. Manual hand pulling (*kung'olea*) ( )

e. Others explain ( )

24. When do you start weeding after transplanting /planting?

a. 10-15 days ( )
b. 16-21 days ( )
c. 22-28 days ( )
d. Whenever time is available ( )
e. Others explain ( )

25. What kind of fertilizer do you use on your farm?

a. Manure ( )
b. Chemical fertilizer ( )
c. Both manure and chemical fertilizer ( )
d. None ( )

Thank you very much for your co-operation

RESEARCH OUTPUTS

(i) Research paper accepted in Paddy and Water Environment Journal.

(ii) Poster Presentation

Reaserch Outputs: Poster Presentation

Assessing adoption and performance of the system of rice-intensification under farmer-led irrigation system in northern Tanzania

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Abstract

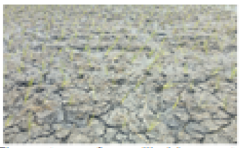
This study was conducted to evaluate farmers' appropriation of the system of rice intensification (SRI) in an informal irrigation scheme in northern Tanzania. Field survey and experiment were conducted. One treatment (F1) was continuous flooding while the other three treatments (F2, F3 and F4) were under intermittent irrigation. The yield of 4.8, 8.5, 8.2 and 9.2 tons/ha, and water productivity of 0.15, 0.39, 0.35 and 0.51 Kg/m³ were obtained for F1, F2, F3 and F4, respectively Water-saving under SRI was 34.3%, 28.9%, and 45.1% for F2, F3 and F4, respectively. The figures are comparable to those reported under full SRI, which is in the range 20% to 60%. The highest yield (9.2 tons/ha), water productivity (0.51 Kg/m³) and water-saving (45.1%) was obtained in F4 involving one seedling 15 days old transplanted at 25 x 25 cm. However, this method is not preferred by many farmers due to lack of supporting infrastructure. Hence, F2 involving two seedlings 21 days old planted at 20x20 cm with intermittent irrigation is recommended for this area as it ensures a sufficient number of plants, relatively higher yields and a reduced considerable amount of irrigation water.

Introduction

- The need to improve productivity in irrigation schemes has led to the development of various agronomic and water management strategies.
- SRI has been identified as an on-farm water management practice that increases both land and water productivity at a relatively low cost while also conserving the environment. Hence, it is considered the best suit for smallholder farmers context.

SRI consist of six basic principles

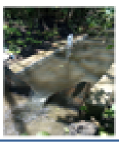
i. Careful Nursery management
ii. Early transplanting (8- 15 days old)
iii. Early and regular weeding (starting 10 days after transplanting)
i. Alternative wetting and drying (AWD)
ii. Single widely spaced (Use of 25X25 cm)
iii. Application of manure.

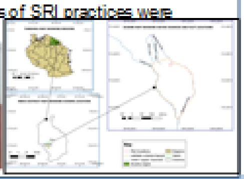


- The nature of smallholder systems makes it difficult to adopt all SRI principles as recommended. Instead farmers are adopting what is possible in their environment.
- Although farmers may use only few principles, the assumption is that they will attain relatively higher productivity as in full SRI.
- This research aims at understanding how SRI intervention was integrated into the local rice farming system of smallholder farmers in northern Tanzania and assess the perfomance of SRI under farmer-led irrigation schemes.

Methods and Materials

- Survey involving 112 farmers was conducted to explore farmers' adjustments of SRI principles.
- Yield and water productivity was assessed by setting up experimental plots of four treatments representing farmers' adaptations of SRI practices were assessed.





Results

(a) Adoption of SRI by smallholder farmers

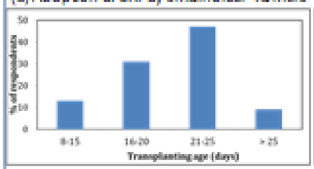


Figure1 : Farmer's preference for transplanting age

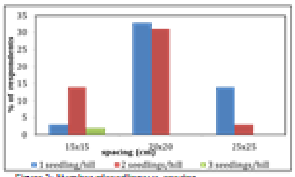


Figure 2: Number of seedlings vs. spacing

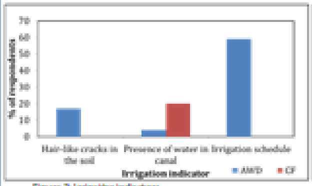


Figure 3: Irrigation indicators

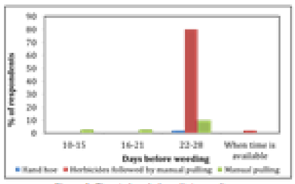


Figure 4: Time taken before first weeding

(b) Performance of SRI under farmers' management

Table 1 : Performance of different treatments under farmers' management

Treatment	Yield * (tonnes /ha)	Yield increase (%)	Irrigation water use* (m3/ ha)	Irrigation water saving (%)	Water Productivity* (Kg/m3)	1000 grains weight* (g)
F1	4.8^{a}	0	32536^{a}	0	0.15^{a}	24.7^{a}
F2	8.5^{b}	77	21629^{b}	34.3	0.39^{b}	26.4^{ab}
F3	8.2^{c}	71	23414^{b}	29	0.35^{c}	27.3^{ab}
F4	9.2^{d}	91.7	18008^{c}	45.1	0.51^{d}	29^{b}

* Means with the same letter are not significantly different at p = 0.05.

Discussion

- It was found that during the experimentation period farmers realized that some of the SRI principles such as transplanting of young, single plants at a spacing of 25x25 cm, applying water following hairline cracks on the soil and the use of manure could not be adopted in their environment without modifications
- Farmers were not willing to let go of this "wonders maker" technology rather they decided to modify these principles to suit their local specific needs.
- Transplanting of young single seedling (15 days old) at a wider spacing of 25x25 cm combined with AWD in F4, gives the optimal yields (9.2 tons/ha), higher water saving of 45.1 % and WP of 0.51. This treatment is recommended in places where all the infrastructure supporting SRI are available.
- Due to lack of supporting infrastructure modification of using two 21 days plants at a spacing of 20x20 cm with AWD, produced significantly higher the results of (8.5 tons/ha)

Conclusions

- Regardless of the challenges in integrating SRI into local farming system, the results obtained by farmers were worth the trouble.
- By using 2 seedlings 21 days old at 20x20 cm with intermittent irrigation yielded of 8.5 t/ha which is 77% increase, WP of 0.39 Kg/m³ and water saving of 34% was obtained compared to conventional rice farming.
- The latter is recommended as it reduces the risk of ending up with the insufficient number of plants, but also farmers are assured of higher yields and reduced amount of irrigation water

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