

**RESPONSE OF HYBRID RICE (*Oryza sativa* L.) VARIETIES TO
FERTILIZER APPLICATION UNDER SYSTEM OF RICE
INTENSIFICATION IN KIRINYAGA AND KISUMU COUNTIES, KENYA**

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of the Degree of Master of Science in Agronomy in the School of Agriculture
and Enterprise Development of Kenyatta University**

June, 2020

DECLARATION

I declare that this thesis is my original work and has not been presented for the award of a degree in any other University or for any award.

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We confirm that the work reported in this thesis was carried out by the candidate under our supervision and has been submitted with our approval as university supervisors.

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DEDICATION

I would like to dedicate this thesis to my family who had an unwavering support and inspiring encouragement through this study.

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LIST OF ABBREVIATIONS AND ACRONYMS

AA	Ancestral Allele
AOAC	Association Officials of Analytical Chemists
AWD	Alternate Wetting and Drying
ANOVA	Analysis of Variance
BC	Before Christ
BW	Bombuwela
DAP	Di-Ammonium Phosphate
DAT	Days after transplanting
EOLSS	Encyclopedia of Life Support System
FAO	Food and Agricultural Organization
GDP	Gross Domestic Product
IRRI	International Rice Research Institute
ITA	Institute for Tropical Agriculture
JICA	Japan International Cooperation Agency
KALRO	Kenya agriculture and livestock research organisation
KEPHIS	Kenya Plant Health Inspectorate Service
LSD	Least Significance Difference
MEFGI	Ministry of Environment and Forests Government of India.
MIAD	Mwea Irrigation Agricultural Development
MOA	Ministry of Agriculture
MOAD	Ministry of Agriculture Development Nepal

MOP	Muriate of Potash
NASEM	National Academics of Sciences, Engineering, and Medicine
NERICA	New Rice for Africa
NIB	National Irrigation Board
NPK	Nitrogen Phosphorus and Potassium
NRDS	National Rice Development Strategy
OECD	Organization for Economic Co-operation and Development
RCBD	Randomized Complete Block Design
SA	Sulphate of Ammonia
SAS	Statistical Analysis Software
SPAD	Soil Plant Analysis Development
SRI	System of Rice Intensification.
TSP	Tri-Super Phosphate
USA	United States of America
WARDA	Women's Agricultural and Rural Development Association

ABSTRACT

Kenyan rice farmers have continuously obtained low yields, this has been credited to poor agronomic practices and use of low quality inbred rice varieties. To alleviate the potential catastrophes and challenges of changing climate and improving rice production, there is need to evaluate productivity of improved rice seeds under alternative production systems such as the system of rice intensification (SRI) using a combination of organic (Evergrow) and inorganic fertilizer (Sulphate of ammonia). To address the challenge, the study had four specific objectives; (a) To determine the growth and tillering ability of the two hybrid rice varieties under System of Rice Intensification (SRI) fertilizer practices, (b) To establish the yield components and grain yield of hybrid rice varieties under (SRI) fertilizer practices. (c) To establish the harvest index of the two hybrid rice varieties under SRI fertilizer practices. (d) To determine the quality of the hybrid rice varieties under SRI fertilizer practices. The field experiment was conducted in Mwea and Ahero study sites. The experimental layout was Randomized Complete Block Design (RCBD) in split plot arrangement with the main plots being organic fertilizer at a rate of 2.5 t/ha Evergrow, 200 kg/ha of Sulphate of ammonia, 2.5 t/ha Evergrow + 200 kg/ha Sulphate of ammonia (SA), 2.5 t/ha Evergrow +100 kg/ha Sulphate of Ammonia and the control where no basal fertilizer was applied while the sub-plots were the two hybrid varieties -Arize Tej Gold, Arize 6444 Gold and a local check (IR2793-80-1). Each of the treatments were then replicated three times. Data collected included plant height, number of tillers, days to 50% and 100% flowering, unproductive tillers, number of grains per plant, harvest index and grained yield per hectare were recorded during the experimental period. Amylose and crude protein content of the grain was determined after final harvest. The collected data was subjected to ANOVA using SAS software version 9.2 and significance differences between means were separated using LSD at 5 % level of probability. The results revealed significance differences ($P \leq 0.05$) on the parameters evaluated as an influence of the fertilizer combinations and used varieties. The control without fertilizer treatment in the variety Arize Tej Gold took the shortest time to 50% flowering recording 78 days and 92 days in Mwea and Ahero respectively. The IR2793-80-1 variety without fertilizer had the least stand count with 16 and 17 counts in Mwea and Ahero respectively. Significance differences were also observed in grain yield in the two study sites with Arize Tej Gold at Evergrow+100kg/ha SA having the yield of 6.37t/ha in Mwea and 4.37 t/ha in Ahero. The grain quality of the rice varieties under the SRI treatments differed significantly on the amylose and protein contents where 2.5 t/ha of organic fertilizer plus 100 kg/ha SA had the highest with 28.77% amylose and 10.58% protein. The application of 100 kg/ha of SA and organic fertilizer leads to higher yields which are not significantly different from that of the doubled rate of the inorganic fertilizer. The 2.5 t/ha Evergrow+100 Kg/ha SA fertilizer SRI practice will lead to the highest growth and tillering of the rice varieties. The study highly recommends the 2.5 t/ha Evergrow+100 Kg/ha SA fertilizer SRI practice under the improved variety which will lead to realization of the potential grain yield.

CHAPTER ONE: INTRODUCTION

1.1 Background information

Rice (*Oryza sativa* L.) is one of the most important food crops in the world, consumed daily by more than half of the human population (Belo, 2002; Gross and Zhao, 2014). It is consumed in variety of forms including boiled rice, noodles, puffed rice, fermented sweet rice and snack foods (Mir, 2017). Rice cultivation was introduced in Kenya in 1907 (Onyango, 2014) from Asia and about 80% of the rice is grown in irrigation schemes including Mwea, Ahero, West Kano, Bunyala and Yala Swamp while the remaining 20% is produced under rainfall conditions by small scale farmers for both food and income (NRDS, 2008).

More than 40,000 varieties of rice have been reported worldwide (MEFGI, 2011). These varieties vary in terms of yields, agro-ecological condition requirements, adaptability to changing climatic conditions, resistance to pest and diseases and maturity time (Chhogyell *et al.*, 2016). Rice together with wheat and maize are the three leading food grains in the world, supplying more than 50% of all calories consumed by entire population (FAO, 2000a; Farina, 2006). Therefore, more emphasis should be put to increase production of these crops in Kenya and globally. Traditionally, local farmers have established and improved suitable cultivated crops and farming systems in a given regional climate, based on their observations of seasonal change over many years (Sakamoto *et al.*, 2009).

Extensive research and adoption of higher yielding varieties will enable Kenyan government to achieve sustained self-sufficiency in food which is paramount to domestic food security (Mburu, 2016). Several studies have shown that rice cultivars perform differently across different agro-ecological zones. Some promising rice genotypes show highly significant yield differences among rice genotypes due to environmental interaction (Sreedhar *et al.*, 2011; Mosavi, 2013). Therefore, local and improved hybrid rice varieties have to be evaluated across different environments to identify superior genotypes that can be adopted by farmers to improve rice production.

Introduction of higher yielding varieties like hybrids with the adoption of new farming systems such as System of Rice Intensification (SRI) will also increase rice production significantly in the country (Berkhout *et al.*, 2015). System of Rice Intensification SRI is an agro-ecological methodology for increasing the productivity of irrigated rice by changing the management of plants, soil, water and nutrients (Thakur *et al.*, 2015). It is based on principles of significantly reducing plant population, improving soil conditions and irrigation methods for root and plant development and improving plant establishment methods (Uphoff, 2007). It involves transplanting single young seedlings with wider spacing, carefully and quickly into fields that are not continuously flooded and whose soil has more organic matter and is actively aerated (Stoop *et al.*, 2002 and Uphoff, 2003). The system is effective in increasing the yield of paddy (kg of unmilled rice harvested per hectare) and the outturn of milled rice (kg of consumable rice per bushel of paddy) (Thakur *et al.*, 2016). System of Rice Intensification (SRI) crops are more resistant to most pests

and diseases and better able to tolerate adverse climatic influences. Time to maturity is also reduced and plants become resistant to biotic and abiotic factors (Uphoff and Thakur, 2019). In System of Rice Intensification, plants develop larger root systems and stronger stalks which make them resistant to lodging caused by wind and/or rain (Uphoff, 2007).

Current research on the response of two hybrid rice to Systems of Rice Intensification (SRI) is aimed at finding solutions to increase rice productivity in Kenya. These solutions could reduce the gap between domestic production and importation in the future. Continued growth in rice production will be possible through intensification and expansion into high potential areas and adopting high yielding genotypes such as hybrids (Meng *et al.*, 2018).

1.2 Problem statement

Rice is one of the staple food crops in Kenya and its demand is generally increasing annually due to increase in population hence requiring more food (Bouis and Saltzman, 2017; Dunkelman *et al.*, 2018). The national rice consumption is estimated at 300,000 metric tonnes compared to annual production of 45,000-80,000 metric tonnes hence implying a deficit in meeting the population demands (Mwongera, 2018). The deficit is met through imports which are valued at Ksh. 7 billion in 2008 (NRDS, 2008; Tani *et al.*, 2017) which increases the cost of living among the population both in urban and rural areas. Despite this increasing demand for rice, the local supply is low even with the introduction of hybrid varieties because farmers in Kenya have not fully adopted SRI methods as compared to other countries (fig 1) (Larson *et al.*, 2016; Macours, 2019). Practical experience has

proven that poor crop management practices are somewhat greater than that contributed by genes alone (NASEM, 2016). Adequate crop management practices could be the key to addressing yield reduction, especially poor management of soil nutrients and soil health management, and high production costs, coupled with low net economic returns (Tsujiimoto *et al.*, 2019).

Over decades, small scale farmers have removed large quantities of nutrients from their soils without using sufficient quantities of manure or fertilizer to replenish the soil (Bado and Bationo, 2018, Ntinyari and Gweyi-Onyango 2018a). Several studies have been conducted on System of Rice Intensification water requirements, plant systems and soil but very little has been done on fertilizer regime on hybrid rice (Wu *et al.*, 2015) adopting System of Rice Intensification SRI has been associated with increased productivity of rice since it encourages change of management practices in plant, soil, water and application of nutrients (Ceesay *et al.*, 2006). According to Hosain *et al.* (2018) adopting System of Rice Intensification will help farmers reduce the amount of nutrients they use for crop productivity and get high returns. In addition, in the current context of climate change scarcity of water has increased hence more precision in the usage of available water for irrigation is needed and this can only be solved by adoption of SRI practices (Loucks and Van Beek, 2017). To address this challenge, the performance of two rice hybrid varieties; Arize Tej Gold and Arize 6444 Gold and commonly planted variety (IR2793-80-1) were evaluated under System of Rice Intensification fertilizer regime.

1.3 Objectives

1.3.1 General objective

To evaluate the response of hybrid rice to fertilizer practices under System of Rice Intensification (SRI) practices Mwea and Ahero study sites.

1.3.2 Specific objectives

1. To determine the growth and tillering ability of the hybrid rice varieties under System of Rice Intensification fertilizer practices
2. To establish the yield components and grain yield of hybrid rice varieties under System of Rice Intensification fertilizer practices.
3. To establish the harvest index of the two varieties under System of Rice Intensification fertilizer practices.
4. To determine the quality of the hybrid rice varieties under System of Rice Intensification fertilizer practices

1.4 Hypotheses

1. There is relationship in growth and tillering ability between the hybrid varieties under the different System of Rice Intensification (SRI) fertilizer practices.
2. There is a difference in hybrid rice yield component and yield under System of Rice Intensification (SRI) fertilizer practices.
3. There is a difference in the harvest index among the rice varieties under System of Rice Intensification (SRI) fertilizer practices.

4. There is a difference in rice quality among the rice varieties under System of Rice Intensification (SRI) fertilizer practices.

1.5 Justification

In Kenya rice production is still low attributed to lack of high yielding varieties and minimum application of SRI principles. The performance of irrigated rice greatly depends on management practices, soil, water and nutrients. Farming depletes nutrients in the soil by continuous use of inorganic fertilizers to recover the potential of soil. According to Ohm *et al.* (2017) estimated the annual depletion rate to be as high as 22 kg N, 2.5 kg P and 15 kg K per hectare of cultivated land over the last 30 years in 37 African countries. This is on the greater side since farmers do not use reasonable amounts of manure to replenish the soils. The conventional way to overcome nutrient depletion is the use of inorganic fertilizers. Of all the nutrients, nitrogen is necessary for high yields to be realized. Proper use of organic and inorganic fertilizers in hybrid varieties is necessary to curb food insecurity in Kenya. There is currently lack of adequate and critical information on adoption of System of Rice Intensification fertilizer practices in production of hybrid rice varieties in Mwea and Ahero. Evaluation of the response of hybrid rice to the System of Rice Intensification (SRI) fertilizer practices will provide information on the yield and performance of the two varieties under organic matter and different nitrogen rates. This will also reduce the farmer's dependence on inorganic fertilizers. Therefore, promotion and adoption of System of Rice Intensification fertilizer practices on the hybrid rice varieties that are high yielding will increase rice production and improve food security, increase small holder farmer's income, contribute to employment

creation in rural areas and reduce the huge rice import bill (figure 1). Moreover, high yields will lead to improved livelihoods through increased food and income. This will have positive impact on the economy of the country through food security and revenue generation thus playing a considerable role in national development.

1.6 Conceptual Framework

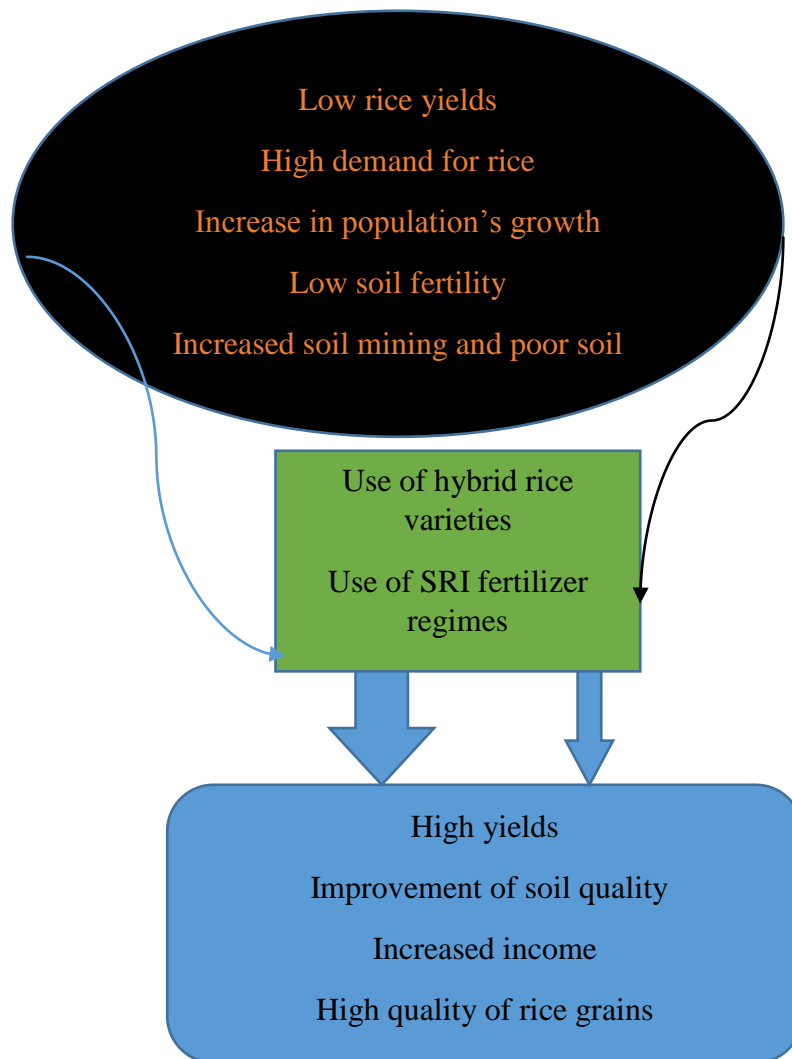


Figure 1: Conceptual Framework

CHAPTER TWO: LITERATURE REVIEW

2.1 Origin and cultivation of rice

Rice is number one food crop of the world. *Oryza sativa* was first cultivated in south-east Asia, India and China between 8000 and 15000 years ago (OECD, 1999; Normile, 2004). The species *Indica* originated from tropical Asia, *japonica* from subtropical Asia where as *Oryza glaberimma* originated from inland delta of the Niger River (Wei and Huang, 2019). *Oryza glaberrima* has been cultivated since approximately 1000 BC (Murray, 2005).

The cultivated species originated from a common ancestor with AA genome perennial and annual ancestors of *O. sativa* are *O. rufipogon* and *O. nivara* and those of *glaberrima* are *O. longistaminata*, *O. breviligulata* and *O. glaberrima* probably domesticated in Niger River delta (Kole, 2006; Dogara and Jumare, 2014). *O. sativa* and *O. glaberrima* are believed to have evolved independently from two different progenitors (*O. nivara* and *O. barthii* respectively) and they are believed to be domesticated in South or South East Asia and tropical Africa respectively. The progenitors of *O. sativa* are considered to be the Asian AA genome diploid species and those of *O. glaberrima* to be African AA genome diploid species *O. barthii* and *O. longistaminata* (Siddiq and Viraktamath, 2001). Current cultivation of *O. sativa* is worldwide, extending from latitude 35 °C (New South Wales and Argentina) to 50 °C (Northern China) (Dos Santos, 2017). Rice is grown from sea level to 3000 m and in both temperate and tropical climates. Cultivars can be divided into three ecological varieties, indica (tropical and sub-tropical distribution), Javanica (grown in Indonesia) and Japonica (temperate distribution) (Ozturk *et al.*, 2019). Generally,

Japonica grains are shorter and wider than Indica grains and are softer and stickier when cooked (OECD, 1999).

2.2 Taxonomy and biology of rice

Rice belongs to the family of Gramineae and the genus *Oryza* (Stein *et al.*, 2018). *Oryzae* contains about 20 different species, of which only two are cultivated: *Oryza sativa* L. and *Oryza glaberrima*. *Oryza sativa* is grown worldwide whereas *Oryza glaberrima* is grown in West and Central Africa (Bashir and Koul, 2018). Species *Oryza sativa* of Asian origin, comprises two main types: *indica* and *japonica sativa* has many cultivars adapted to various environmental conditions (Santos *et al.*, 2019). The morphology, physiology, agronomy, genetics and biochemistry of *sativa* have been intensively studied over a long period (Wang *et al.*, 2019; OECD, 1999). The genus *Oryza* contains 22 species: two are cultivated and 20 are wild (Wu and Ge, 2016). The basic chromosome number of the genus *Oryza* is 12. *Oryza sativa*, *glaberrima* and 14 wild species are diploids with 24 chromosomes, and eight wild species are tetraploids with 48 chromosomes. *Oryza punctate* consists of diploid and tetraploid types (OECD, 1999).

There is confusion in literature concerning the correct nomenclature of the species most closely related to *Oryza sativa*, as they often lack distinguishing morphological characteristics (Vaughan and Morishima, 2003). Vaughan, (2003) proposed new nomenclature for cultivated and wild rice in Asia: *sativa sensu lato* subspecies *indica* and *japonica*, and. *rufipogon sensu lato* subspecies *nivara* (annual) and *rufipogon* (perennial), respectively. In addition, two new wild species,

glumeaepatula and *O malapuzhaensis* have been recognized in the genus (Vaughan *et al.*, 2003).

Coleoptiles and roots first emerge from the germinating rice seeds. Seedlings differentiate leaves from the growing point of the main culm and tiller buds in the axial of leaves of un-elongated nodes of the main culms (Hodge and Doust, 2017). Panicle primordial differentiates at the top of culms. At heading time, panicles come out of flag-leaf sheaths (Adriani *et al.*, 2016). Flowering takes place in spikelets on a panicle, followed by pollination on stigma and fertilization in ovules. Embryo and endosperm mature in the ovule and become a seed for the next generation (Batygina, 2019). Rice plants are very easily propagated by seeds or tiller buds. The leaf consists of a blade, a sheath, and a ligule and auricle at the junction between blade and sheath. The culm consists of nodes and hollow internodes. The spikelet has six stamens and the ovary has a two-branched stigma (Batygina, 2019). The seed consists of embryo, endosperm, pericarp and testa enclosed by a palea, and a lemma with an apiculus on the top of the lemma (OECD, 1999). A complete seed of rice is called paddy and contains one rice kernel. Outer layer of rice shell is called husk. The next layer is called rice bran and the inner most part is called rice kernel (Hodge and Doust, 2017).

2.3 Global rice production

Rice is grown in 114 countries across the world on an area of about 150 million hectares with annual production of over 503.8 million tonnes, constituting nearly 11 per cent of the world's cultivated land (FAO, 2017). Over 87% of the world rice is produced and consumed in Asian continent (Papademetriou *et al.*, 2000). China is

the largest producer of paddy accounting for 31.8% of total world production followed by India (22.4%) (Ali *et al.*, 2019). Together these countries accounted about half of world paddy area and production. Indonesia (8.5%), Bangladesh (6%), Vietnam (5.4%), Thailand (3.9%) and Myanmar (3.3%) are the other major paddy producing countries (Gyimah-Brempong *et al.*, 2016). In case of productivity, Egypt ranks first with (9,086 kg/ha) followed by USA (7,037 kg/ha), Japan (6,702 kg/ha) and Korea Republic (6,592 kg/ha) (FAO, 2000b). In Africa, production has grown rapidly. West Africa is the main producing sub region, accounting for more than 45% of African production in 2008-2010 (IRRI, 2013).

2.4 Rice ecological requirements

The environmental and socio-economic condition of rice production varies greatly from country to country as well as from location to location (Salmivaara *et al.*, 2016). Rice is produced in a wide range of locations and under a variety of climatic conditions, from the wettest areas in the world to the driest deserts (IRRI, 2013). Environmentally, rice is grown under different climates including temperate, sub-tropical and tropical (Gadal *et al.*, 2019). Within a climate the weather varies from arid and semi-arid to sub-humid and humid. Based on soil-water conditions rice production ecosystems include irrigated lowland, irrigated upland, rainfed lowland, rainfed upland and deepwater/floating ecosystems (Dogara and Jumare, 2014). Irrigated rice is grown on about 79 million hectares, contributing 75% of the world's rice production (Maclean *et al.*, 2002; Bernier, 2008). However, it is estimated that by 2025, 15-20 million ha of irrigated rice will suffer some degree of water scarcity (Tuong and Bouman, 2003), therefore developing and adopting strategies and

practices that will use water efficiently in irrigation schemes will lead to increase rice production.

Rice cultivation is possible only in areas with good rainfall, as the crop requires standing water for growth (Shelley *et al.*, 2016). A monthly rainfall of 100-200 mm is a must and about 125 mm, during vegetative season. There should be no water at ripening stage (Woittiez *et al.*, 2017). Rice being a tropical and sub-tropical plant requires a fairly high temperature, ranging from 20 to 40°C (Shelley *et al.*, 2016). The optimum temperature of 30°C during day time and 20°C during night time is considered favourable for its growth and development (Zhang *et al.*, 2017). During the ripening period of last 35 to 45 days, the yield benefits from sunlight (Woittiez *et al.*, 2017). Bright sunshine with low temperature during ripening period of the crop helps in the synthesis and accumulation of carbohydrates in the grains. The effect of solar radiation is more profound where water, temperature and nitrogenous nutrients are not limiting factors (Shelley *et al.*, 2016).

Rice cultivation is a very water-intensive activity and it consumes more water than the production of any other crop (FAO, 2004). To produce one kilo of rice requires 3,000-5,000 litres of water. It is estimated that irrigated rice receives 34-43% of the world's irrigation water (Bouman *et al.*, 2007). About 95% of the rice grown in Kenya is from irrigation schemes while the remaining 5% is produced under rain-fed conditions (Monteiro *et al.* 2010). Farm size cultivated by a household in Kenya is small which varies from less than one hectare to few hectares which still use enormous amounts of human labour, in spite of strides made in mechanization of rice production (Ouma, 2018). Kenya has potential irrigable land, 3355Km²

accounting for 54.03% is moderately suitable for irrigation, 78km² accounting for 1.26% is marginally suitable for irrigation whereas 175Km² accounting for 2.81% is unsuitable for irrigated agriculture (Muema, 2016). There is 1.0-million-hectare rain fed which could be utilized for rice production (MOA, 2010). Irrigation is key for rice development and there is need to make investments including improvement of the current irrigation system and management in Kenya in order to increase rice yields (Nakawuka *et al.*, 2018).

2.5 Rice production in Kenya

Rice in Kenya is mainly produced by small-scale farmers through four major irrigation schemes (Apind *et al.*, 2015). This includes Mwea in Kirinyaga County, Bunyala in Busia, and Ahero and West Kano in Kisumu. Upland rice is also grown in other parts of the country and this includes; Migori and Kuria in Migori County, and Tana Delta and Msabweni in Coast region. Mwea irrigation Scheme is the largest producer of rice in Kenya (Ndiiri *et al.*, 2013). Demand for rice exceeds country's supply of 40, 000 to 80, 000 tonnes by 200%. The demand stands at 300, 000 tonnes per annum therefore deficit is met through importation ((FAO, 2013; Kihoro *et al.*, 2013a; Mati *et al.*, 2011).

In Kenya the most grown irrigated varieties include BW 196, IR 2793-80-1, Basmati 370, ITA 310 and Basmati 217 (Table 2.1). Variety BW 196 is high yielding with medium long and thick grains (Njeru *et al.*, 2015). This variety requires early harvesting to reduce broken grains during milling, IR 2793-80-1 is an IRRI improved long medium thick grain variety with near translucent grains, which have

lower amylose content than BW 196. Farmers in Western Kenya mainly grow IR 2793-80-1 variety (Njeru *et al.*, 2015). Basmati 217 and Basmati 370 are both indica types with close resemblance to the wild varieties. Their grains are slender medium long and translucent. The varieties have low amylose content and therefore separate after cooking and cooling (Kioko, 2016). Most Basmati characteristics are mimicked by ITA 310 which has a medium yield but not aromatic. Rainfed varieties that were released in 2009 in Kenya include Dourado Precoce, NERICA 1, NERICA 4, NERICA 10, and NERICA 1 (Henga, 2019).

Table 2.1: Varieties grown and their characteristics

Variety	Yield /ha	Characteristics	Growth Duration	Production Culture
IR 2993-80-1	11	Medium tall, non-aromatic, Grain similar to Pishori	120	Irrigated/Rainfed Low Land
ITA 310	8	Dwarf, Non	95	Irrigated
Basmati 217	7	Medium to tall, Aromatic	112	Irrigated
Basmati 370	7	Medium to tall, Aromatic	115	Irrigated
Dourado Precoce		Tall Non-aromatic	90	Rainfed Upland
NERICA 1	4.5	Medium to tall, aromatic	95-100	Rainfed Upland to irrigated
NERICA 4	5	Tall, non-aromatic	95-100	Rainfed Upland to irrigated
NERICA 10	6	Tall, non-aromatic	95-100	Rainfed Upland to irrigated
NERICA 11	7	Tall, non-aromatic	75-85	Rainfed Upland to irrigated
BW-196	9	Medium to tall, non-aromatic	135	Irrigated

Source: Guidelines to rice production in Kenya. JICA-March 2011

2.6 Fertilizer use in production of Rice in Mwea and Ahero

Farmers in Ahero and Mwea irrigation scheme have practiced SRI under the conventional fertilizer programmes which contravenes the principle of SRI fertilizer recommendations (Toungos, 2018). Farmers have used one seedling per hill after 21 days and applied SA at tillering and at heading without using organic fertilizer and young seedling thereby compromising the SRI principles and therefore the need to practice candidly the principles of SRI to maximize the yield (Toungos, 2018).

According to information available at the NIB Website, Mwea Irrigation scheme is located in Mwea division Kirinyaga County, in central Kenya (Ndegwa, 2018). It is located about 100 km South East of Nairobi, the capital city of Kenya and near the foothills of Mount Kenya. Two main rivers Nyamindi and Thiba serve the scheme, with a link canal joining the two rivers which transfers water from Nyamindi to Thiba River which serves about 80% of the scheme while tenancy basis is the form of land tenure operational in this scheme (Ndegwa, 2018). Rice being grown as a single crop per year in Mwea scheme, the yields here are high and almost equal to large scale farms of Japan and USA, with this scheme producing the high quality basmati variety (Kikuchi *et al.*, 2019).

According to the National Irrigation Board, Ahero Irrigation scheme was established in 1969 and is located in the middle of the Kano plain, 25 km southeast of Kisumu town (Mwatet, 2016). The climate of the Kano plain is relatively dry and the average temperatures are high during the day and the soil of the scheme is of the black cotton type and is rather fertile (Nyakach, 2019). When this scheme was being established,

tenants had to shift from subsistence agriculture to a cash cropping economy. Compared to the Mwea irrigation scheme, paddy yields are much lower in this scheme (Uphoff, 2019, Ntinyari and Gweyi-Onyango, 2018b).

Four major inorganic fertilizers are applied in these schemes, that is Di-Ammonium Phosphate (DAP) which is mostly used during planting, Tri-Super Phosphate (TSP) which is used if DAP is not available (Getahun *et al.*, 2019). Sulphate of Ammonia (SA) which is used for top dressing, and Urea which is used for top dressing if SA is not available. Di- Ammonium Phosphate (or TSP) is applied at the transplanting stage, while SA (or Urea) is applied twice for top dressing (Sammy, 2019). Top-dressing is split into two parts: first application is at 14 days after transplanting, while the second application is 43 days after transplanting (Ke *et al.*, 2017).

In the schemes, 90.2% of respondents reported to have used DAP during planting and only 6.6% used TSP (Ahmed *et al.*, 2013). For the independent farmers, 75.6% of the respondents applied DAP during planting while 15.6% used TSP. In the same period, 70.5% of the dependent respondents applied SA for top-dressing, while 23% used Urea to top-dress (Ahmed *et al.*, 2013). Etabo *et al.* (2018) showed strong interactions between water levels and phosphorus P on soil chemical properties on yield of two NERICA varieties in Mwea. In the MMRG independent farms, SA was applied to top-dress by 75.6% of the respondents, while Urea was used by 22.2% of the respondents (Ambrose, 2013). Urea is not very popular with the farmers as they argued that it softens the soil, thus causing the lodging of the rice crop (Yakubu, 2016). Besides the inorganic fertilizers, 37.4% of farmers also use Farmyard manure

during the cropping period (Mwangi, 2015), Mean manure cost per cart was reported as Kshs 400 in both groups of farms, though most farmers used manure from their own livestock.

In another study by Mwangi (2015), it was reported that fertilizers were commonly used by the farmers in Mwea and Ahero irrigation schemes. Majority of the farmers used DAP for (87.4%) the basal application and SA for top-dressing (89.9%). On average one bag (50kg) of DAP was used for basal application per acre and in a similar way another bag (50kg) of SA was used for top-dressing in one acre (Kihoro *et al.*, 2013b). This signifies that the farmers spend about Kshs 5,000 on fertilizers alone per acre. Organic fertilizers were greatly used during land preparation. This reduces the need for a lot of synthetic fertilizers during the growing period. Most of the farmers applied dry (47.6%) and fresh (46.6%) animal manure during land preparation (Verma and Singh, 2017). Due to various pests and diseases the farmers used kshs740 on average per acre in one cropping season to buy chemicals and foliar fertilizers.

Irrigation water management is critical in ensuring that the nutrients applied through the fertilisers have a better chance of being taken up by the crop and not lost either by leaching, volatilisation, denitrification or even immobilisation (Parama and Munawery, 2012). Balanced nutrition in rice like all other crops is critical in achieving optimal yields. The application time as well as type and form of the nutrients are essential factors determining the agronomic efficiency of the fertiliser applied (Fixen *et al.*, 2015). Nitrogen, as a nutrient, is particularly prone to many

types of losses, and as such requires careful management to achieve desired yields (Bouraoui and Grizzetti, 2014).

Unlike many other crops, a rice crop will benefit from an ammonium source of nitrogen at the early growth stage, but becomes more efficient on uptake of nitrate nitrogen at the later stage of panicle initiation (Xu *et al.*, 2015). This is so because in the early stage of low nitrogen demand, the ammonium is taken up and some nitrified in time for plant uptake. However, in the peak demand periods – at panicle initiation, application of ammonium N fertiliser is inefficient as there are heavy losses from volatilization more than denitrification and leaching (Jat *et al.*, 2012). For this reason, a nitrate source of N is more efficient as the plant quickly takes up the nitrogen.

A high P fertiliser such as DAP, TSP or an NPK should be applied at 0-5 days after transplanting for early crop establishment (Admas *et al.*, 2015). Some potassium is also required and so, if an NPK is not used, then Muriate of Potash (MOP) should be added to provide the potassium (Sitienei *et al.*, 2013). At tillering stage, about 21-25 days after transplanting, a nitrogen topdressing should be applied, and this could be from a high nitrogen NPK or straight N fertilisers (Das *et al.*, 2012). NPKs with micronutrients and sulphur would be preferred, such as YaraMila fertiliser. Final topdressing should be done at panicle initiation, at 45-50 days with preferably a nitrate N fertiliser, and sulphur and micronutrients applied together with MOP to boost the potash for better grain filling and better protein content in the grain (Joshi, 2018). As already mentioned, all these fertilisation practices must be done under a

sound irrigation management system as well as other agronomic activities to optimise the nutrient uptake for the best quality yields (Wu and Ma, 2015).

2.7 Use of rice crop and rice products

Rice is a nutritious food crop which contains carbohydrates, proteins, lipids and minerals used mainly for human consumption (Chopade *et al.*, 2017). Its straw is an important animal feed in many countries (OECD, 1999). The major part of rice consists of carbohydrate in form of starch, which is about 75% of total grain composition. Rice contains most of the minerals mainly located in the pericarp and germ and about 4% phosphorus (Stein *et al.*, 2015). Rice is the second most cultivated cereal in the world after wheat. It provides 21% of the per capita energy and 15% of protein for human consumption worldwide (Villareal *et al.*, (1994); Gnanamanickam, 2009).

Calories from rice are particularly important for the poor accounting for 50-80% of the daily caloric intake. Rice can also be used as snack food, brewed beverages, flour, oil, syrup and religious ceremonies (Mahatman *et al.*, 2017). Rice bran is a potential source of vegetable oil, fertilizers and feed concentrate for livestock and fish. Rice bran oil is one of the healthiest oil for human consumption and is also used in pharmaceutical products (Helkar *et al.*, 2016). The major use of husk is as boiler fuel (MEFGI, 2011; Ghadge and Prasad, 2012). Long-grain rice is usually dry and non-sticky when cooked and is used in parboiled, quick-cooked or processed rice products. Medium-grain rice is usually moist, sticky and used for dry cereals, soups, baby food and brewing purposes while short grain rice is very sticky. Sake or rice wine and beer are made from non-waxy rice (Ghadge and Prasad, 2012). Low-

amylose rice is used for baby food, cereals and rice bread while intermediate-amylose rice is used in rice fermented cakes. Raw straw is used to make coarse paper, composting and building materials, and as an ultra-pure source of silica (EOLSS, 2006). The large amount of rice straw as a by-product of the rice production is mainly used as a source of feed for ruminant livestock (Vadiveloo, 2003; Sarnklong *et al.*, 2010).

Rice is also believed to have medicinal properties and used in many countries for the same including in India (Umadevi *et al.*, 2012). In Chinese medicine, red yeast rice is used to promote blood circulation, soothe upset stomach and invigorate the function of the spleen. It has also been used traditionally for bruised muscles, hangovers, indigestion and colic in infants (Rahman *et al.*, 2006).

2.8 Economic importance of rice

Agriculture is the backbone in many economies, rice being the staple agricultural product, holds the capacity to pull people out of poverty and ensure sustainable availability of food for the food-insecure population (Lopes, 2019). In Kenya demand for rice is so high (Onyango, 2006) that Kenya had to import about 73% of rice consumed in the country (Kaneda, 2007). Rice imports are used to fill the gap between demand and supply and to stabilize the domestic price of rice (Chung, 2018). As a major part of food spending, rice comprised 16% of the total expenditures of the poorest 30% of the population (World Bank 2007). Therefore, a rise in rice prices could significantly raise cost of living sending more people to poverty. Kenyan government hopes to increase annual production of rice to 178, 570

metric tonnes by 2018 by focusing on ecological areas viz. Nyanza, Central, Western, Coast and Rift valley provinces (MOA, 2009).

Almost a billion households in Asia, Africa and America depend on rice as their main source of livelihood (Ali *et al.*, 2017). Rice is in the frontline in the fight against world hunger and poverty and is also a symbol of cultural identity and global unity. It shapes religious observations, festivals and celebrations (Rahman *et al.*, 2006). It is the cheapest and most effective means available that is likely to eradicate acute under nutrition (Bishwajit *et al.*, 2013). In Bangladesh, Cambodia, Indonesia, Myanmar, Thailand, and Vietnam, rice provides 50–80% of the total calories consumed (Wailes *et al.*, 2018). Africa tops the chart in terms of percentage increase in total consumption, with an increase of 130% from 2010 rice consumption (IRRI, 2013).

Beyond providing sustenance, rice plays an important cultural role in many countries (Wailes *et al.*, 2018). Products of the rice plant such as husk and straw are used for a number of different purposes, such as fuel, thatching, industrial starch and artwork which could earn income to households (Crowther, 2018). Rice earns foreign exchange when exported. Strategies to increase quantity and quality of rice production therefore, has to be put in place to ensure that there are enough amounts of rice for domestic market needs and some may be left for export (Hughes, 2016).

Share of rice in agriculture and Gross Domestic Product (GDP) has been significant for countries like Nepal employing 66% of the population and providing 39% of GDP (MOAD, 2015) and Sri Lanka where rice sector contributes 30% to agricultural GDP (Mendis, 2009). In 2003, India and Bangladesh together

contributed 28% of global rice production and 33% in 2009 (Bishwajit *et al.*, 2013). According to FAO (2003), the future is gloomy because world population is predicted to grow from around 6 billion people today (2015) to 8.3 billion in 2030. Food production will have to increase to provide for this increased population.

2.9 System of Rice Intensification (SRI)

The system of rice intensification(SRI) is a production system that involves the adoption of certain changes in management practices for rice cultivation that create a better growing environment for their growth (Tejendra *et al.*, 2011). It is a set of ideas and principles that emphasize the use of younger seedlings individually planted at a wider spacing together with the adoption of intermittent irrigation, organic fertilization and active soil aeration (Stoop *et al.*, 2002). It has emerged as a set of guiding principles that maintain high yields through stronger and healthier plants and soils while reducing reliance on external inputs (Uphoff, 2007).

Rice growers in general have relied on chemical fertilizers under the belief that they are necessary for high yields. However, achieving high yield based prescriptive use of fertilizers may not be economically warranted (Srivastava and Malhotra, 2017). Therefore, organic System of Rice Intensification practices that rely on on-farm produced organic fertilizers and pesticides have drawn attention of scientists and farming communities (Qiao *et al.*, 2016). On-farm demonstration plots in many tropical and sub-tropical countries have shown the benefits of SRI methods over conventional cultivation methods (Sato and Uphoff, 2007). With System of Rice

Intensification, organic fertilizers could replace some or most of all organic nitrogen in paddy rice production (Shamala *et al.*, 2018).

2.10 Principles of System of Rice Intensification

System of Rice Intensification principles are based on number of components including young seedling that need to be transplanted between 8-12 days old with 2-3 leaves, but should not be older than 15 days (Lampayan *et al.*, 2015), When the seedling is transplanted carefully it grows healthily and generates more number of tillers thus achieving a potential of giving higher yield. (Lampayan *et al.*, 2015).

In System of Rice Intensification, single seedlings should be very carefully and gently planted, rather than plugging clumps into the soil together, which can invert the root tips and impair the rice plant's subsequent performance. This will set back their resumption of growth (Soyk *et al.*, 2017). Careful handling of seedlings avoids trauma to the roots, with little or no interruption of plant growth. Wider spacing is another principle of System of Rice Intensification where the seedlings are spaced widely with gaps of at least 25x 25cm, that is, 16 plants/ m² (Wani, and Sharma, 2016). Plants should be spaced in a square pattern rather than in rows to enable rice plants to achieve maximum exposure to sunlight and air on all sides. Wider spacing helps to achieve the edge effect throughout the field because all the leaves get enough solar radiation for photosynthesis and no leaf need to be subsidized by other leave's photosynthesis because of shading (Soyk *et al.*, 2017).

In System of Rice Intensification practices, fields are not continuously flooded which triggers more weed problems, thus needs more weeding (Stoop *et al*, 2002). Mechanical weeders agitates up the soil and buries weeds which allow more oxygen and nitrogen into the soil resulting in soil aeration and increased yields (Wani, and Sharma, 2016). Soil should be kept moist but not continuously flooded, during the plants vegetative growth phase up to the stage of flowering and grain production (Stoop *et al*, 2002). This is because, rice is not an aquatic plant, nor does it perform best under submerged, hypoxic soil conditions. This avoids the suffocation and degeneration of rice plant roots and supports more abundant and diverse populations of aerobic soil organisms that provide multiple benefits to the plants. This can be done by alternate wetting and drying (AWD) with cycles ranging from 6 to 14 days (Thakur *et al.*, 2014). The operative principle is to provide both roots and soil biota with optimizing amounts of both water and oxygen. The result is larger and deeper root growth which gives rice plants more resilience to adverse climatic conditions, such as drought, storms or extreme temperatures (Andrea, 2018).

Use of (preferably) organic manure or compost to improve soil quality in SRI is requirement. The effect of organic fertilizer is slower as compared to the chemical fertilizers but they stimulate biotic growth and activity in the soil (Jiaguo *et al*, 2004). Adequate organic fertilization improves soil structure and biological diversity. Synthetic fertilizers can also be used with SRI but addition of compost, mulch and manure gives best results (Uphoff, 2007). Organic matter when added to the soil, multiplies microorganisms in the soil many times and bring nutrients into available form when they are needed (JICA, 2011).

2.11 Importance of System of Rice Intensification

System of Rice Intensification practice helps farmers improve their livelihood. It has raised hope among farmers, development activists and policy makers to solve food deficit problem (Brown, 2018). It is so because System of Rice Intensification increases yields as well as it reduces the cost of production (Kumar and Shivay, 2004). System of Rice Intensification helps small scale farmers to attain higher yields even when they produce in infertile soil with no or minimum mineral fertilizer input, reduced irrigation and fewer seeds (Stoop *et al*, 2002). Grain yields are increased on average by 20-50%, but often more. This not only generates more food, but releases some land and labor for other productive activities (Rajaram and van Ginkel, 2019). Higher productivity per unit of land reduces pressure to expand cultivated area at the expense of other ecosystems (Friedrich *et al.*, 2017).

System of Rice Intensification crops have more resistance to pests and diseases as compared to conventionally grown rice (Uphoff, 2007). They have less insect and disease attacks (Jianguo *et al*, 2004). Climate change is expected to increase the prevalence and distribution of pest species as temperatures and rainfall patterns change. With System of Rice Intensification management, farmers observe less loss to pests and diseases even though they use fewer agrochemicals (Reddy, 2018). With System of Rice Intensification fewer seedlings are used. Since farmers need 80-90% fewer seeds for transplanting, they need much less space to sow the seed nurseries (Reddy, 2018). Conventional nurseries are planted with a seed rate of 50-75 kg/ha whereas System of Rice Intensification nurseries are planted with a seed

rate of 5-7 kg/ha, leaving farmers more rice to use for food rather than planting. Smaller nurseries are easier to manage and require a lot less land (Singh, 2017). Uphoff (2007) states that System of Rice Intensification crops have more nutritional value. That there is 30-65% chalkiness in System of Rice Intensification grains because the roots are large and grow deeper into the soil hence taking up a lot of micronutrients from the soil. The System of Rice Intensification crops are tolerant to adverse biotic and abiotic stress since they have large and strong root systems which enable them to tolerate adverse climatic conditions, storm, water stress, large and heavier panicles etc. (Thakur and Uphoff, 2017). System of Rice Intensification gives a higher turn-out of milled rice (kg of consumable rice per bushel of paddy) since they have fewer unfilled grains and less shattering as compared to conventionally grown rice (Uphoff, 2007). SRI require less labour compared to conventional methods (Thakur and Uphoff, 2017). Some farmers in Sri Lanka have calculated that once they have mastered SRI techniques and can do them confidently and quickly, their total labor invested per hectare with System of Rice Intensification is actually less than with conventional modern practices (Uphoff, 2007).

2.12 Challenges facing System of Rice Intensification

Most farmers are taking long to adopt System of Rice Intensification practices. Uphoff (2007) argues that resistance to recognize and disseminate System of Rice Intensification success is often based on its counter-intuitive nature. Farmers find it hard to consent that they can essentially produce more by using less – more output with less input (Doss, 2018). This is due to disadvantages to the application of System of Rice Intensification such as the many requirements for careful water

management. Controlling water and keeping the field regularly wet and drained are crucial elements for SRI to work (Veldwisch *et al.*, 2019). Thus, System of Rice Intensification needs some sort of irrigation structure to be in place, which may rely on government commitment as it may be beyond farmers' control (Veldwisch *et al.*, 2019). Therefore, System of Rice Intensification's combination of practices is often difficult to apply in agricultural settings that lack a reliable system of water control. In addition, as System of Rice Intensification requires fields to not be kept flooded, weeds tend to grow much faster than they would when using traditional methods (Moser and Barrett, 2003). This results in increased workload creates concerns that the System of Rice Intensification method is extortionately labor-intensive. It also increases the time spent in the rice fields, and often requires the help of additional labourers (Moser and Barrett, 2003). However, once farmers acquire skill with and confidence in the methods, more and more evaluations show SRI to be labour-neutral or even become labour-saving (Uphoff, 2007).

2.13 Constraints in rice production

2.13.1 Biotic factors

Climate change shifts towards increasing aridity and desertification; and increasing incidence and impacts of crop pests and disease which poses serious threats to agricultural production systems (Tubiello *et al.*, 2007). Diseases are amongst important limiting factors that affect rice production, causing 5% annual yield loss. More than 70 diseases caused by fungi, bacteria, viruses or nematodes have been recorded in rice, among which rice blast (*Magnaporthe grisea*), bacterial leaf blight

(*Xanthomonas oryzae*) and sheath blight (*Rhizobacter solani*) are the most serious constraints on high productivity (Kihoro *et al.*, 2013a). *Magnaporthe grisea* the causal agent of rice blast disease displays remarkable morphogenetic and biochemical specialization to its pathogenic lifestyle and is an efficient and devastating agent of disease. Each year rice blast causes losses of between 10 and 30% of the rice harvest (Talbot, 2003). Resistant cultivars and application of pesticides have been used for disease control (Song and Goodman, 2001) and thus identification of resistant hybrid varieties will be a breakthrough in Kenyan rice production.

The high humidity and temperature of the rice growing environments during the cropping periods increases the incidence of pests and diseases (Zibae, 2013). Several insects attack rice including rice water weevil, rice stink bug, fall armyworm, chinch bug, Mexican rice borer, sugarcane borer, grasshoppers, blister beetles and leafhoppers. Major insect pests include Stem borer, Gall midge, leaf roller and rice bug and minor pests include thrips, case worm, blue beetle and whorl maggot (Zibae, 2013).

Apart from nutritional and socio-economic benefits associated with irrigated rice cultivation there also comes along with the creation of large and more permanent larval habitats that support higher densities of malaria vectors (Mwangangi *et al.*, 2010). However, a study conducted in Mwea irrigation scheme by Muturi *et al.* (2008) found that irrigated rice cultivation may reduce the risk of malaria transmission by *Anopheles funestus* but has no effect on malaria transmission by *Anopheles arabiensis*. Efficient and safe control of rice pests and diseases prevents

any exotic yield loss (Pretty, 2018). Because of rising concerns on environmental pollution, resurgence, resistance and emerging of secondary pests caused by synthetic chemicals, researchers and farmers are seeking for safer and more efficient tactics such as by using insect growth regulators, bio-control agents and sanitation (Zibae *et al.*, 2009).

2.13.2 Abiotic factors

Drought stress is the most important constraint to rice production in rainfed systems, affecting 10 million ha of upland rice and over 13 million ha of rainfed lowland rice in Asia alone (Pandey and Bandhari, 2007). Water stress in rice production arises from reductions in the number of rainy days (Tao *et al.*, 2004). By 2025, 15–20 million ha of irrigated rice will experience some degree of water scarcity (Bouman *et al.*, 2007). Availability of water is a prerequisite for increased rice production. Most of the rice production in the country depends on rainfall water for irrigation. Annual variation in the amount and distribution makes rain-fed rice production susceptible to flooding and/or drought, often within the same season (Ndiiri *et al.*, 2013). Drought risk impedes investment, causing production to stagnate at subsistence level. The deterioration of the drainage and irrigation facilities is posing a considerable constraint to the increased production of rice (Bouman *et al.*, 2007). The funding is necessary for rehabilitation of the irrigation infrastructure since it is beyond the capacity of small producers. A study by Ndiiri *et al.* (2013) showed that System of Rice Intensification (SRI) gave the highest yields and water savings for both field trials and farmer survey and could be adopted to minimize water

requirement for irrigation. Similar study by Omwenga *et al.* (2014) found SRI to be efficient and it improved yields with reduction in water use by about 32%.

Yet globally, water is anticipated to become scarce and there is increasing competition for land, putting added pressure on agricultural production. Floods are a significant problem for rice farming (Steduto *et al.*, 2017). Complete submergence causes plant mortality after a few days, partial submergence over longer timespan triggers substantial yield losses, waterlogging in direct-seeded rice creates anaerobic conditions that impair germination (IRRI 2013). Temperatures beyond critical thresholds not only reduce the growth duration of the rice crop but also increase spikelet sterility, reduce grain-filling duration, and enhance respiratory losses, resulting in lower yield and lower quality rice grain (Fitzgerald and Resurreccion, 2009; Kim *et al.*, 2011). Rice is relatively more tolerant of high temperatures during the vegetative phase but is highly susceptible during the reproductive phase, particularly at the flowering stage (Jagadish *et al.*, 2010).

Although Sodium ion is important micronutrient, excess levels are toxic for plant growth. Salinity adversely affects quantity and quality of crop produce (Blumwald and Grover 2006). Salt affected soils in arid and semi-arid areas regions of Asia, Africa and South America causing considerable agronomic problems. Salt-tolerant transgenic rice plants have been produced through genetic, molecular biology and comparative genomic methods (Sahi *et al.*, 2006). Most of the rice soils of the world are deficient in nitrogen, so nitrogen is usually supplied to rice crop as commercially available fertilizer urea (Choudhury and Kennedy, 2004).

2.13.3 Availability of quality certified seed

Seed is a living product that carries genetic information of a variety. Certified seed production, certification and utilization is important in ensuring increased productivity with yield increase of 5-6 %, control in dissemination of weeds and diseases (Pathak *et al.*, 2018). Good quality certified seed enables farmers to attain crops, which have: the most economic seed rate, a higher percentage of seed germination, lower gap filling, a vigorous seedling, a more uniform plant stand faster growth rate, and greater resistance to stress and diseases, and uniformity in ripening (Chauhan *et al.*, 2016).

The government through the National Rice Development Strategy (2008-2018) recommended that seed producers should produce seed under supervision of Kenya Plant Health Inspectorate Service (KEPHIS) (Makihara *et al.*, 2018). All stages of seed rice production which include; breeders seed which is seed with highest purity, Pre-basic and basic seed which are progeny of breeder seed, produced by trained officers and certified seed will undergo thorough inspection to reduce cases of varietal impurity which results to admixtures and poor quality crop (Chauhan *et al.*, 2016).

CHAPTER THREE: MATERIALS AND METHODS

3.1 Site description

The study was carried out at two sites Mwea and Ahero research centres. Mwea Irrigation Agricultural Development (MIAD) research centre is located at Mwea Irrigation Scheme in Wamumu sub-location, Kirinyaga County, Kenya (fig 3.1) managed by KALRO. It lies at an altitude of 1175 meters above the sea level, latitude of 00°42'S and longitude of 37°22'E. The soils are predominantly montmorillonite clay.

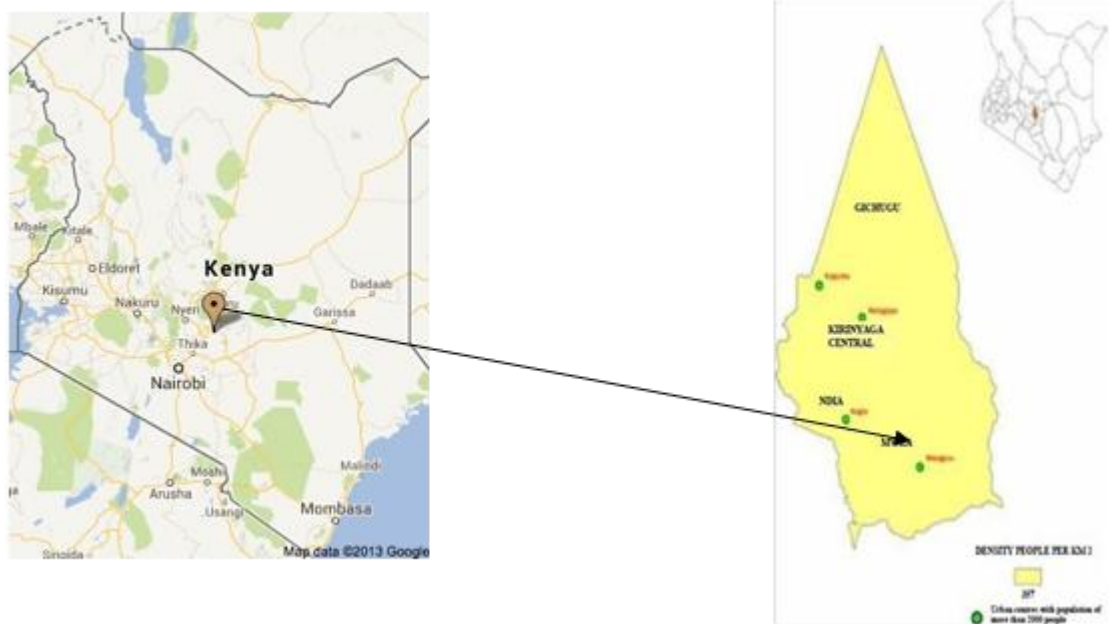


Figure 3.1: Showing Mwea experimental site in Kirinyaga County (google maps)

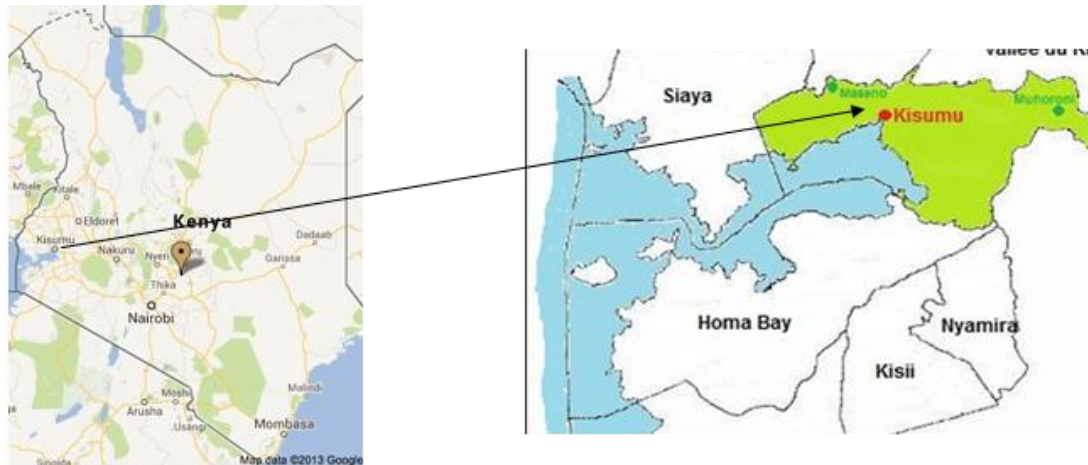


Figure 3.2: Showing Ahero study site in Kisumu County (google maps)

The second site was Ahero Irrigation Scheme in Nyando sub-county of Kisumu County, Kenya (fig 3.2). The scheme is located in the Kano plains, at altitude of about 1131m above sea level, Latitude: 0° 10' 60.00" N and Longitude: 34° 54' 59.99" E. The climate of the area is relatively dry with high temperatures. The scheme is managed by the National Irrigation Board in partnership with the farmers who pay a fee for scheme operation and maintenance. Irrigation water comes from river Nyando. The soils are predominantly montmorillonite clay.

3.2 Experimental design, layout and treatments

The field study was laid out in a split plot arrangement in a Randomized Complete Block Design (RCBD) with the main plots (5) being organic fertilizer, Evergrow (Nitrogen (N) >1.0% Phosphorus (P) >0.4% Potassium (K) >0.5% Calcium (Ca) >1.3%) at a rate of 2.5 t/ha Evergrow, 200 kg/ha of Sulphate of ammonia (21% Nitrogen), 2.5 t/ha Evergrow + 200 kg/ha Sulphate of ammonia (SA), 2.5 t/ha Evergrow +100 kg/ha Sulphate of Ammonia and the control (zero fertilizer) while

the sub-plots (3) were the two hybrid varieties -Arize Tej Gold, Arize 6444 Gold and a local check IR2793-80-1 replicated three times. The plot size was measuring 2 m x 4m with 1m path between each main plots and 0.5m between each sub-plots to avoid treatment contamination effects across the plots. A spacing of 25 cm by 15 cm was used with five rows planted and data collected on the inner three rows.

3.3 Planting and agronomic field management

The research plot sizes were 2m x 4m and an 800m² piece of land ploughed, harrowed and levelled to ensure even growth and to maintain a uniform water depth. Seedlings of each variety was raised in a non-flooded nursery beds measuring 1.5m x 10m and raised to 5 cm above ground level. Seeds were broadcasted evenly on the bed at rate of 5 kg/ha (0.5kg/100m² nursery) and applied 1 kg of N and 1kg P per 100m². The seedlings were transplanted after 8 days when 2 leaves had developed to hills in the field at single seedling per hill, at a spacing of 25 by 15 cm. Five lines of each variety were planted in each sub-plot. Top dressing was done using sulphate of ammonia in two splits, at active tillering stage and at panicle initiation stage except in control. Water control and weeding was done according to SRI management recommendation. The field was intermittently flooded and dried, that is, three days of wetting and seven days of drying. The overall outlook of the plots and stages of rice growth in Mwea and Ahero is as shown in Appendix 1.

3.4 Data collection.

Random sampling was done for every parameter measured.

i. Plant height (cm).

Height of 20 sample hills per plot was measured by the use of a tape measure starting from the base of the plant to the tip of the panicle at an interval 21 days after transplanting.

ii. Chlorophyll content

Chlorophyll content measurements were taken using SPAD-502 meter whereby five hills were sampled and measurement performed on the uppermost expanded leaf blade and average calculated at tillering and panicle initiation.

iii. Days to 50% and 100% flowering

This was counted from the date of sowing to the date when 50% and 100% of the plants had flowered.

iv. Days to 50% heading

This was counted from date of sowing to the date of start of when 50% of the plants per plot had flowered.

v. Stand count

Stand count was taken 21 days after transplanting by counting the number of established hills

vi. Number of tillers (productive tillers)

This was counted using 20 sample hills at random. Only the rice plants, with productive panicles were counted.

vii. Number of unproductive tillers.

This was counted using 20 sample hills at random. Number of empty grains was counted in the panicle and average calculated.

vii. Weight of 1,000 grains (g).

One thousand seeds were selected at random after open drying at about 10-13% moisture content and weighing with a digital weighing balance.

viii. Number of grains per plant.

This was determined using 20 sample panicles taken at random per treatment from 20 sampled hills, number of grains counted per panicle and mean calculated.

ix. Grains yield per hectare.

This was taken by winnowing the grains after drying to 10-13% moisture content harvested from the plot and later converted to Yield per ha.

x. Harvest index

Harvested rice was threshed and weighed and then harvest index calculated according to the following formula: Harvest index % = Grain yield / Biological yield * 100

xi. Determination of Crude protein (AOAC, 1995)

Rice grain samples were ground to fine powder for use in analysis of crude protein and amylose content. Micro-Kjeldahl method was used where 0.2g of the dried sample was accurately weighed and placed into micro-Kjeldahl digestion tubes. Into the sample, 10 ml of concentrated nitrogen free sulphuric acid was added to each tube and one selenium tablet was added as a catalyst. The rice grain samples were

digested in a digester (2012 digester Foss Tecator) at 445 °C for 3 hours. The digested samples were then cooled to room temperature and distilled using Kjeldahl distillation unit (2200 kjeltec auto distillation Foss tecator). The distillate was collected in a 15 ml 0.1M HCl in which a mixed indicator of methyl red and methylene blue was added. The excess HCl was titrated against 0.1M NaOH. The involved calculations were as follows:

$$\% \text{ crude protein} = (V1 - V2) \times (M \times 1.4 \times 6.25) / W.$$

Where **V2** is volume of HCl used in test portion,

V1 is volume of HCl used in blank test

M is molarity of acid

W is weight of test portion.

xii. Determination of amylose content

To determine total amylose in rice grain iodine reagent was made by dissolving 1 g iodine and 10 g KI in water to make up to 500 ml. The standard amylose solution was prepared by dissolving 100 mg amylose in 10 ml 1 N NaOH; and volume made up to 100 ml with water.

Powdered rice grain samples were weighed (100 mg) then 1 ml of distilled ethanol was added. Ten (10) ml of 1 N NaOH was added and solution left overnight. The sample solution was heated in a boiling water bath instead of overnight dissolution. The volume was made to 100ml and 2.5 ml of the extract was taken and added 20 ml of distilled water followed by addition of three drops of phenolphthalein then 0.1 N of HCL was added drop by drop until pink colour disappeared then 1 ml of iodine reagent was added and the volume made to 50 ml then colour read at 590nm.

To prepare standard graph, 0.2, 0.4, 0.6, 0.8 and 1 ml of the standard amylose solution was taken and colour developed as in the case of sample. The amount of amylose present in the sample was calculated using the standard graph and 1 ml of iodine reagent was diluted to 50 ml with distilled water and used as blank.

The absorbance corresponds to 2.5 ml of test solution which is equal to x mg of amylose. Percent amylose = $x / 2.5 * 100$ mg amylose.

3.5 Data analysis

Agronomic data and yield was subjected to analysis of variance (ANOVA) using SAS statistical software version 9.2. Significance differences between means were separated using Least Significance Difference at a significance level of $P \leq 0.05$.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 System of Rice Intensification (SRI) fertilizer practices effect on growth and tillering ability of hybrid rice varieties

4.1.1 Plant height at maturity

Significant differences ($P \leq 0.05$) were observed due to treatments on the plant height of rice where the control showed the shortest plants in all the varieties. In Mwea, the tallest plants were of Arize 6444 Gold variety treated with Evergrow+200 Kg/ha SA and Evergrow+100 Kg/ha SA fertilizer recording 26.7 cm and 26.3 cm respectively at 21 after transplanting (DAT) (Table 4.1). At 42 (DAT), Evergrow+100 Kg/ha SA treatment surpassed the Evergrow+200 Kg/ha SA treatment on the growth rate in terms of plant height up to 84th day from transplanting were not significantly different from Variety Arize Tej Gold on the Evergrow+100 Kg/ha SA and Evergrow+200 Kg/ha SA fertilizer treatments (Table 4.1). All through this period the local check IR2793-80-1 had the shortest plants with the tallest in the variety shown in the Evergrow+100 Kg/ha SA fertilizer. A similar trend was observed in Ahero with the application of the organic fertilizer and SA at both rates showing the tallest plants in the new varieties while the shortest were under the control at the different stages of all the varieties with the local check showing the least as showed in table 4.2.

Table 4.1: Influence of variety and System of Rice Intensification fertilizer treatments on the plant height of rice at Mwea

Variety	SRI Treatments	21 DAT	42 DAT	63 DAT	84 DAT	HARVEST
Arize 6444 Gold	Control	20.0d	33.6d	45.3d	53.3d	59.3c
	200 Kg/ha SA	21.3cd	36.6c	48.0c	57.0c	82.3ab
	Evergrow 2.5t/ha+100 Kg/ha	26.3a	41.0a	57.3a	67.0a	92.3a
	Evergrow2.5t/ha+200 Kg/ha	26.7a	39.7ab	56.0ab	65.3a	92.0a
	Evergrow 2.5 t/ha	22.3bc	37.0c	49.3c	61.0b	66.6c
Arize Tej Gold	Control	16.7g	32.3d	44.3d	51.3ef	64.6c
	200 Kg/ha SA	20.3d	36.3c	48.0c	57.3c	83.0ab
	Evergrow+100 Kg/ha	23.7b	39.0b	55.7ab	66.0a	91.0a
	Evergrow+200 Kg/ha	23.3b	39.7ab	55.3b	66.0a	91.6a
	Evergrow 2.5 t/ha	18.7f	36.7c	49.0c	61.0b	73.0bc
IR2793- 80-1	Control	11.3i	26.0h	36.6f	43.3h	57.0c
	200 Kg/ha SA	13.3h	29.6g	38.6e	46.0g	72.3bc
	Evergrow+100 Kg/ha	17.7f	31.0f	45.3d	53.6d	71.6bc
	Evergrow+200 Kg/ha	17.0fg	31.6f	44.3d	53.0de	70.7bc
	Evergrow 2.5 t/ha	14.3h	30.7fg	39.0e	49.7f	63.7c
	LSD	1.506	1.373	1.769	1.87	18.794
	P-Value	<.001	0.027	<.001	0.002	<.001

Values with the same letters within the column are not significantly different, DAT- Days After Transplanting, SRI- System of Rice Intensification

Table 4.2: Influence of variety and SRI fertilizer treatments on the plant height of rice at Ahero

Variety	SRI Treatments	21 DAT	42 DAT	63 DAT	84 DAT	HARVEST
Arize 6444 Gold	Control	23.7b	34.3c	44.7b	54.0b	63.7d
	200 Kg/ha SA	26.33a	41.0a	55.7a	68.7a	94.7a
	Evergrow+100 Kg/ha SA	27.0a	39.0a	52.3a	63.3a	84.3b
	Evergrow+200 Kg/ha SA	26.0ab	40.7a	57.3a	67.7a	93.0a
	Evergrow 2.5 t/ha	26.3ab	36.7b	43.6b	57.3b	67.0d
	Arize Tej Gold	Control	23.3b	34.3c	44.7b	54.0b
200 Kg/ha SA		26.2a	42.8a	56.7a	67.0a	90.0a
Evergrow+100 Kg/ha SA		28.9a	40.1a	50.0ab	60.7a	85.7b
Evergrow+200 Kg/ha SA		23.7b	38.6b	56.7a	65.7a	90.3a
Evergrow 2.5 t/ha		25.8ab	37.7b	45.0b	53.7b	67.3d
IR2793-80- 1		Control	13.3e	23.3f	34.7c	43.3c
	200 Kg/ha SA	21.2c	31.9d	50.6ab	59.0ab	81.3b
	Evergrow+100 Kg/ha SA	23.1b	31.0d	46.0b	55.0b	75.3c
	Evergrow+200 Kg/ha SA	17.7d	30.6d	46.3b	54.3b	73.7c
	Evergrow 2.5 t/ha	17.6d	27.2e	39.0c	50.0b	58.7e
	LSD	2.686	2.971	6.425	8.56	5.979
P-Value	0.028	<.001	<.001	<.001	0.055	

Values with the same letters within the column are not significantly different, DAT- Days After Transplanting, SRI- System of Rice Intensification

The findings of this study agree with those of Pratiwi *et al.* (2009) who found that plant height differences between System of Rice Intensification and conventional methods were as a result of plant root competition for nutrient and water.

These findings agree with those of Doni *et al.* (2015) who reported an increased in plant height and other growth varieties in paddy rice under SRI cultivation methods.

One of the important principles for System of Rice Intensification (SRI) practice is

the early establishment of roots reported by Yuan *et al.* (2007) which can be derived from this study. In addition, improved root characteristics leading to greater access to nutrients in the soil have been recorded with the use of cyanobacterial inoculants under SRI management Prasanna *et al.*, (2015) which can be attributed to the change in plant height in this study. In another study done by Pascual and Wang, (2017) it was reported that plant height was positively influenced by organic fertilizers under the SRI practices which also agrees with the results of this study.

4.1.2 Chlorophyll Content

There were significant differences ($P \leq 0.05$) between treatments on the chlorophyll content in Ahero at 30 and 60 days after transplanting. The highest SPAD reading (42.0) was recorded under Arize Tej Gold variety in the full organic plus inorganic SRI treatment in Ahero (Table 4.3). There were no significant differences between the SRI treatments on the chlorophyll content in all the varieties at the other sampling periods. In Mwea, the SRI treatments did not show significant differences on the chlorophyll content in the three varieties during the sampling stages. However, the highest chlorophyll contents were recorded on the organic treatment under variety Arize Tej Gold (Table 4.3), which at the same time showed the highest grain weight per hectare. The higher chlorophyll content makes leaves remain green during grain filling, this enables photosynthesis to remain high, which is favourable for higher yield because this increases the supply of photosynthates to seeds (Fu and Lee, 2008). The higher photosynthesis rate may be caused by having higher chlorophyll content as shown in Arize Tej Gold in both amendments (Evergrow + SA 100 kg/ha and Evergrow + SA 200 kg/ha) in Table 4.3.

Table 4.3: Influence of System of Rice Intensification treatments under different varieties on the chlorophyll content at Ahero and Mwea

VARIETY	SRI TREATMENT	Ahero		Mwea	
		30 DAT	60 DAT	30 DAT	60 DAT
Arize 6444 Gold	Control	34.7ab	35.1ab	33.3a	33.9a
	200 Kg/ha SA	34.5ab	35.2ab	29.1a	30.5a
	Evergrow+100 Kg/ha SA	41.4a	39.4a	36.5a	36.6a
	Evergrow+200 Kg/ha SA	28.2b	35.5ab	35.2a	35.4a
	Evergrow 2.5 t/ha	27.8c	28.5b	37.9a	34.4a
Arize Tej Gold	Control	31.1ab	32.0ab	36.5a	33.9a
	200 Kg/ha SA	33.7ab	34.7ab	34.1a	33.7a
	Evergrow+100 Kg/ha SA	42.0a	39.1a	39.7a	41.4a
	Evergrow+200 Kg/ha SA	41.0a	40.9a	37.6a	39.4a
	Evergrow 2.5 t/ha	34.6ab	32.0ab	38.3a	42.9a
IR2793-80-1	Control	32.8ab	36.5ab	38.7a	38.3a
	200 Kg/ha SA	36.0ab	32.7ab	35.7a	39.1a
	Evergrow+100 Kg/ha SA	30.8ab	38.9a	39.5a	39.5a
	Evergrow+200 Kg/ha SA	34.2ab	33.3ab	33.0a	39.3a
	Evergrow 2.5 t/ha	38.3a	27.7b	34.9a	32.9a
	P Value	0.011	0.022	0.354	0.55
	SE	4.76	5.006	4.818	5.387

Values with the same letters within the column are not significantly different,

SRI- System of Rice Intensification

The rate of photosynthesis increases with increasing nitrogen content in the leaves, the results of this study contradict with the finding of (Sheehy *et al.* 2014) who reported that SRI didn't have a major role in increasing rice production. Edwards *et al.* (2015) have shown through their studies on the root microbiome in rice that the microbial communities in rice roots are influenced by SRI cultivation practices that influence chlorophyll formation which can be derived from the findings of this study.

4.1.3 Days to 50% flowering

The days to 50% flowering were significantly different ($P \leq 0.05$) between the varieties with marginal differences observed between the SRI fertilizer treatments in the two study sites. The control in all the varieties showed the shortest period in attaining 50% flowering where the Arize Tej Gold variety had the least period to 50% flowering while the local variety had the longest recording 83 days in both Mwea and Ahero study sites (Table 4.4). Variety Arize Tej Gold had the least period to 50% to flowering at Ahero under the control treatment (92 days) with the local check taking the longest of up to 115 days under the Evergrow+200 Kg/ha SA treatment.

Table 4.4: Days to 50% flowering, 100% flowering and heading of 3 rice varieties as influenced by the SRI fertilizer practices at Mwea and Ahero Irrigation Schemes

Variety	SRI Trt	Days to 50% Flowering		Days to 100% Flowering		Days to 50% Heading	
		Mwea	Ahero	Mwea	Ahero	Mwea	Ahero
Arize 6444 Gold	Control	86c	105b	92c	111b	78bc	94ab
	200 Kg/ha SA	100a	107ab	108ab	114ab	92a	98a
	Evergrow+100 Kg/ha SA	95b	106ab	101bc	116a	85b	97a
	Evergrow+200 Kg/ha SA	98b	104b	107b	116a	88b	93ab
	Evergrow 2.5 t/ha	91b	106ab	98c	111b	83b	98a
Arize Tej Gold	Control	78d	92c	86d	101c	70c	86b
	200 Kg/ha SA	93b	95c	101b	105b	84b	85b
	Evergrow+100 Kg/ha SA	87c	95c	96c	103c	78b	83b
	Evergrow+200 Kg/ha SA	90bc	96c	98c	109b	82b	87b
	Evergrow 2.5 t/ha	83c	83d	92c	101c	77b	85b
IR2793-80-1	Control	92b	108ab	104b	116a	89b	100a
	200 Kg/ha SA	105a	113a	118a	123a	103a	102a
	Evergrow+100 Kg/ha SA	97b	114a	111ab	121a	99a	103a
	Evergrow+200 Kg/ha SA	102a	115a	115a	122a	102a	102a
	Evergrow 2.5 t/ha	95b	112a	109ab	120a	95a	92ab
	LSD	6.12	9.02	7.15	5.91	8.72	6.11
	P Value	0.01	<.001	0.002	0.009	0.014	0.033

Values with the same letters within the column are not significantly different, SRI- System of Rice Intensification

These results agrees with those other researchers (Thakur *et al.*, 2016; Gweyi-Onyango 2018b; Wathome *et al.*, 2019) who reported that creating more favorable above-ground and below-ground environments for rice to grow in, SRI enhances several morphological and physiological characteristics in rice plants that represent more productive phenotypes from a given genotype as shown with the flowering periods observed at Mwea and Ahero. These findings also agrees with those of Sønsteby *et al.* (2017) who reported that plants without fertilization takes a shorter to flowering to enable them complete lifecycle due to nutrient stress which was also observed from the current results. Also in another study by Roussos *et al.* (2017) they found out plants with organic fertilizer treatments took relatively longer time to

flower compared to those without fertilization which can be confirmed from this study.

4.1.4 Days to 100% flowering

The days to 100% flowering were significantly influenced ($P \leq 0.05$) by the rice varieties under the different SRI fertilizer practices as illustrated in table 4.4. The control under the Arize 6444 Gold variety had the least period to 50% flowering (92 days) while the longest (118 days) was observed on the local variety, IR2793-80-1 as shown in table 4.4. At Ahero, the days to 100% flowering were significantly lower in the Evergrow+100 Kg/ha SA treatment of Arize Tej Gold variety (101 days) with the longest recording 123 days under the 200 Kg/ha SA fertilizer treatment of the local variety IR2793-80-1.

Wei *et al.* (2016) reported that applying organic soil amendments increased rice yield components support rice productivity; thus the plants need to be treated carefully since early cultivation to get better yield which agrees with the current findings. The data of this study agrees with the findings of Berkelaar, (2001) who reported that earlier seedling would have longer phyllochrons generation period before panicle initiation as observed in this study. Chang *et al.*, (2016) also reported that rice productivity using SRI cultivation was higher than conventional rice cultivation method, supported by higher yield components in SRI which agrees with the current findings.

4.1.5 Days to 50% heading

The rice varieties differed significantly at $P \leq 0.05$ on the number of days to heading and marginal on the SRI fertilizer treatments in both Mwea and Ahero study sites. In Mwea, Arize 6444 Gold variety showed the least days to heading (78 days) under the control SRI treatment with the longest (103 days) recorded on variety IR2793-80-1 in the inorganic fertilizer treatment (Table 4.4). The same trend was observed on the days to 50% and 100% flowering was observed on the days to heading at Ahero where there were significantly lower in the Evergrow+100 Kg/ha SA treatment of Arize Tej Gold variety.

According to Bierke *et al.* (2008) the reduction in days to heading under the organic treatment compared to the inorganic treatment might be due to increased enzymatic activity and lower fixation of nutrients like P and K due to addition of organic matters, crop residues during the crop growth period which can be derived from the current findings. In another study by Dzomeku *et al.* (2016) the delay in flowering in the SRI plants was probably due to longer and higher accessibility of nitrogen by the SRI plants which concurs with results of this study. Additionally, the finding of WARDA (2004) agrees that higher levels of nitrogen in rice plant prolonged vegetative growth phase of the plant which in turn increased days to flowering.

4.1.6 Stand count

The stand count of the rice was significantly influenced ($P \leq 0.05$) by the SRI fertilizer practices and variety in both study sites Mwea and Ahero respectively. In Mwea, the stand count was lowest in the control of all the 3 varieties in study with

the least under the local variety while the highest number of plants realized in the Evergrow+100 Kg/ha SA fertilizer treatment (38.27) under variety Arize 6444 Gold (Table 4.5). The highest stand count at Ahero was recorded under Evergrow plus 200 kg/ha SA and sole 200 kg/ha of variety Arize Tej Gold with the lowest on the control of Arize 6444 Gold (15) (Table 4.5).

Table 4.5: The stand count of 3 varieties under the 4 SRI fertilizer practices at Mwea and Ahero

Variety	SRI Treatments	Mwea	Ahero
Arize 6444 Gold	Control	18e	15f
	200 Kg/ha	31b	32c
	Evergrow+100 Kg/ha	38a	43a
	Evergrow+200 Kg/ha	37a	41a
	Evergrow 2.5 t/ha	31b	22e
Arize Tej Gold	Control	19e	16f
	200 Kg/ha	30b	33c
	Evergrow+100 Kg/ha	35a	44a
	Evergrow+200 Kg/ha	36a	43a
	Evergrow 2.5 t/ha	30b	21e
IR2793-80-1	Control	16f	17f
	200 Kg/ha	24d	27d
	Evergrow+100 Kg/ha	30b	39b
	Evergrow+200 Kg/ha	27c	36b
	Evergrow 2.5 t/ha	26c	18f
	LSD	2.001	2.62
	P-Value	<0.001	0.004
	CV%	4.3	6.1

Values with the same letters within the column are not significantly different, SRI- System of Rice Intensification

The differences in the stand count could be probably due to the fact that organic manures improve physical, chemical as well as biological properties of the soil resulting into more survival of the seedlings that agrees with the findings of Ananda

et al. (2006). In another study done by Kumar and Yadav (2008) it was reported that better initial vigorous growth under the treatment accrued to better nourishment of the crop as a result of organic fertilizers which can be confirmed from the results of this study. These findings are also in agreement with those of Anon, (2009) who reported improved stand count of cereals as an integration effect of organic manures and nitrogen under System of Rice Intensification. According to Hussain *et al.* (2018) use of System of Rice Intensification practices had the potential of increasing overall stand count of the rice plants compared to the conventional practices which can be derived from the findings of this study.

4.1.7 Number of tillers (productive tillers)

Significant differences ($P \leq 0.05$) were observed on the number of tillers per plant due to SRI fertilizer practices and varieties in two study sites. In all the varieties, the control had the least number of tillers at all the days of data collection from 21 DAT to harvesting. In Arize 6444 Gold, the Evergrow+200 Kg/ha SA and Evergrow+100 Kg/ha SA had significantly the highest number of tillers from 21 days after transplanting to harvesting with no significant differences observed between the two treatments. In variety Arize Tej Gold, the Evergrow+200 Kg/ha SA fertilizer had the highest number of tillers per plant all through from 21 days after transplanting to harvesting. The local check, IR2793-80-1, showed the highest variety in the Evergrow+100 Kg/ha SA fertilizer treatment at day 21 from transplanting to harvesting. The number of tillers increased steadily with time at Ahero in all the treatments with the highest (60) observed at harvesting on the 200 kg/ha SA treatment of Arize Tej Gold variety (figure 4.2). The same treatment also showed

highest number of tillers in the other two varieties however with the local variety IR2793-80-1 indicating the lowest (54) at harvesting. The control showed the lowest number of tillers (27) in all the varieties with the improved varieties having a lower number compared to the local check in both sites as shown in figure 4.1 and 4.2.

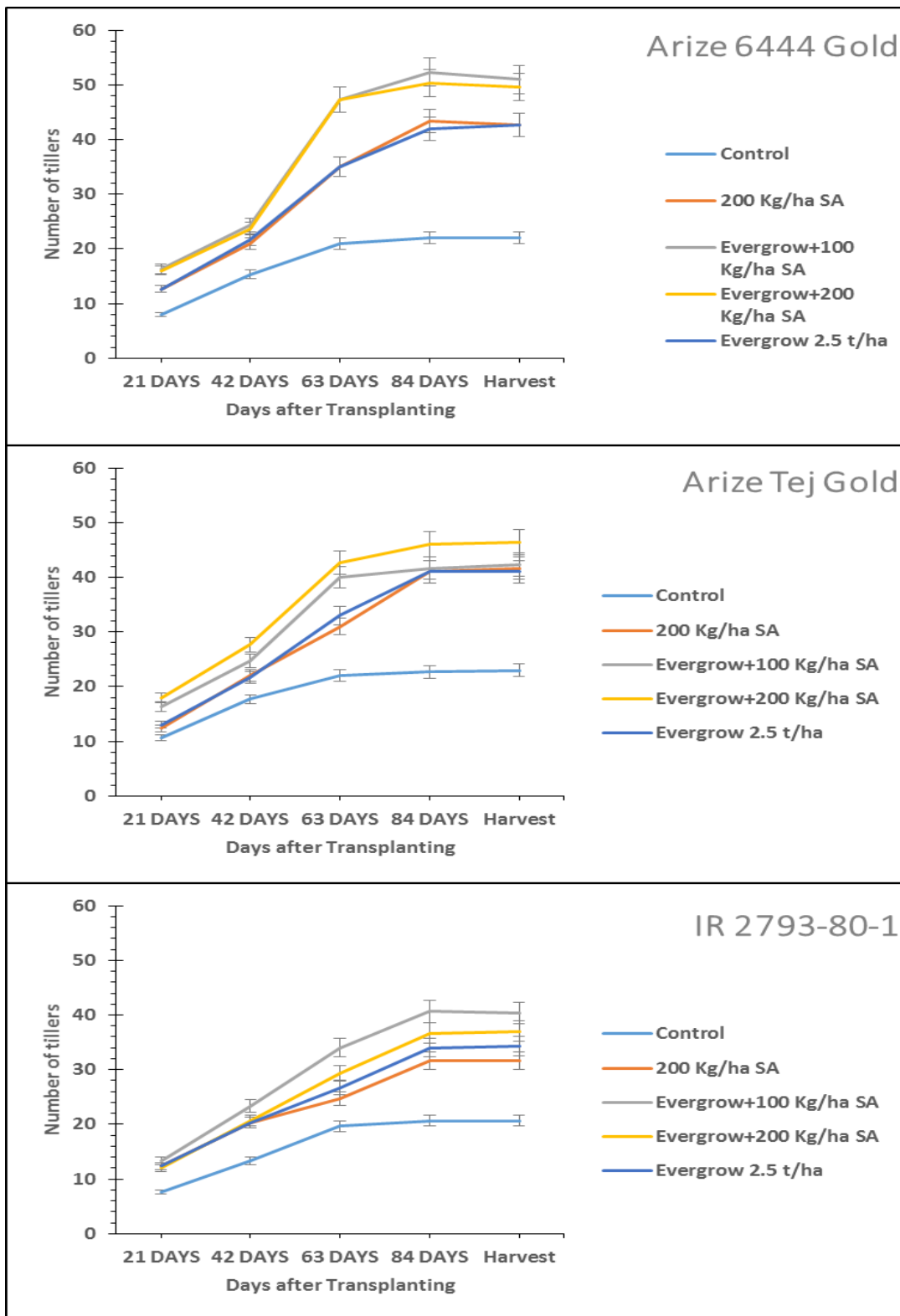


Figure 4.1: Number of tillers as influenced by the SRI fertilizer practices in the 3 varieties at Mwea

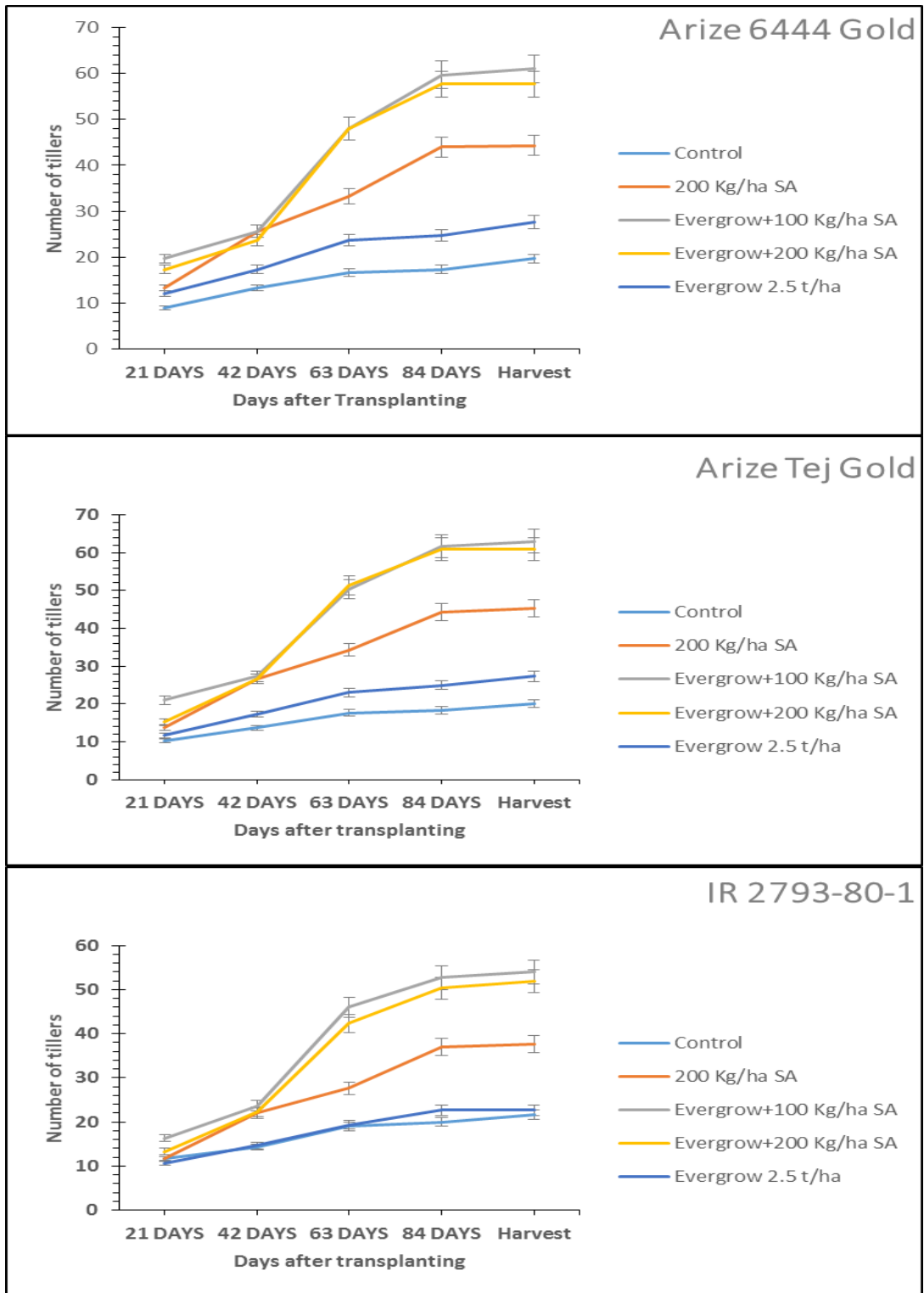


Figure 4.2: Number of tillers as influenced by the SRI fertilizer practices in the 3 varieties at Ahero

The improved percentage of productive tillers in the SRI could have been facilitated by the conducive conditions created and efficient use of resources of the plant such as nutrients, solar radiation and water in the vegetative stage of plant. These results agrees with those of Miller, (2007) who reported higher number of tillers in cereal plants as a result of organic manure application that supplies micro nutrients that enhance and promote growth. This increase in productive tillers is as a result of more nitrogen supply over the entire crop growth period under good aerobic conditions provided under System of Rice Intensification, resulting in more photosynthates and a strong source to sink relationship Manzoor *et al.* (2006); Islam *et al.* (2008).

4.1.8 Number of unproductive tillers

There were significant differences ($P \leq 0.05$) on the number of unproductive tillers among the rice varieties due to the SRI fertilizer practices in both Mwea and Ahero study sites. In the Evergrow+100 Kg/ha SA fertilizer treatment there were no unproductive tillers recorded under all the 3 varieties while the control exhibited the highest with the local variety, IR2793-80-1 having significantly the highest recording 5 unproductive tiller as shown in table 4.6

Table 4.6: Unproductive tillers of the 3 rice varieties as influenced by the SRI fertilizer treatments at Mwea and Ahero

Variety	SRI Treatments	Mwea	Ahero
Arize 6444 Gold	Control	4a	5a
	200 Kg/ha	2b	0f
	Evergrow+100 Kg/ha	0d	2d
	Evergrow+200 Kg/ha	0d	0f
	Evergrow 2.5 t/ha	1c	4b
Arize Tej Gold	Control	4a	5a
	200 Kg/ha	1c	0f
	Evergrow+100 Kg/ha	0d	2d
	Evergrow+200 Kg/ha	0d	0f
	Evergrow 2.5 t/ha	1c	3c
IR2793-80-1	Control	5a	3c
	200 Kg/ha	4a	0f
	Evergrow+100 Kg/ha	0d	2d
	Evergrow+200 Kg/ha	0d	0f
	Evergrow 2.5 t/ha	1c	1e
	LSD	0.584	0.632
	P-Value	0.009	<0.001
	CV%	16.2	12.3

Values with the same letters within the column are not significantly different, SRI- System of Rice Intensification

The results agrees with those of Ceesay *et al.* (2006) who reported adoption of System of Rice Intensification (SRI) having the potential to promote healthy growth of the plants leading to a minimized number of the unproductive tillers. In another study by Gopalakrishnan *et al.* (2014) adoption of SRI strategies helps in reducing inter-plant competition and wide spacing, at the same time improving soil structure and functioning by applying organic amendments, facilitating soil-surface aeration during weeding, and managing water to avoid both continuous flooding and water-stressed conditions hence resulting to less production of unproductive tillers which can be derived from the findings of this study. Wu and Uphoff, (2015) also observed similar findings to this study that a combination of management practices results in

better rice growth and yield compared with standard cultivation methods thus the reduction on the number of unproductive tillers in the current study.

4.2 The yield components and grain yield of hybrid rice varieties under System of Rice Intensification (SRI) fertilizer practices

4.2.1 1000-Seed Weight

The weight of a thousand seeds was significantly influenced ($P \leq 0.05$) by the SRI fertilizer practices in the 3 varieties in the two study sites. The lowest weight was recorded under the control for all the varieties where the local variety had the least (20.0 g) as illustrated in figure 4.3. In Mwea, the highest 1000-seed weight (33.0 g) was recorded under variety Arize Tej Gold on the Evergrow+200 Kg/ha SA fertilizer treatment which was however not significantly different from that on the Evergrow+100 Kg/ha SA fertilizer treatment in the same variety as shown in figure 4.3. At Ahero, the highest 1000-seed weight was recorded on the Evergrow+200 Kg/ha SA under all the treatments with variety Arize 6444 Gold showing the peak with weight of 32 g. The lowest 1000-seed weight was under the control (with no fertilizer treatments) for Arize Tej Gold recording 24.33 g (figure 4.3).

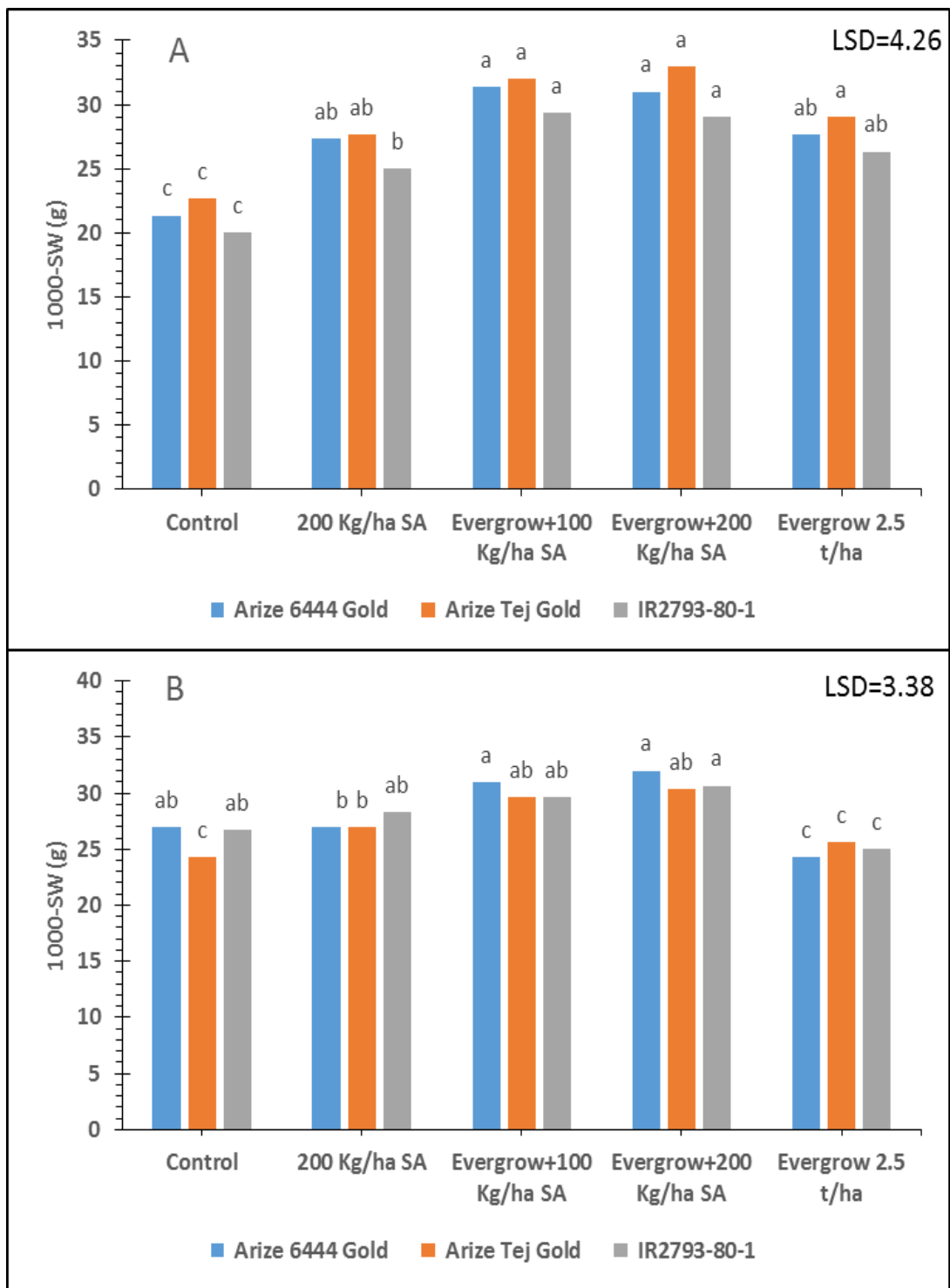


Figure 4.3: The influence of System of rice intensification fertilizer practices treatments and variety on the 1000-seed weight of rice at Mwea (A) and Ahero (B) irrigation schemes

These findings agrees with those of Chen *et al.* (2013) in SRI rice plants produce heavy panicles that lead to high yield performance playing an important role in single panicle development from the strong individual tiller associated which agrees with the findings of this study. Suswadi and Suharto, (2011) also reported that SRI method can increase rice productivity by efficient plant, soil, water, and nutrient management Soil health maintenance was done to preserve rhizosphere availability that can support root growth and provide nutrient for plants which can be derived from the current study. Another study that agrees with the current results is that of Mutakin, (2007) who reported that organic fertilizers have excellent nutrient content for plants if applied in the right time.

4.2.2 Number of grains per plant

The number of grains per panicle showed significant differences at $P \leq 0.05$ between the SRI fertilizer practice treatments under the 3 rice varieties in the two study sites. The highest number of grains per panicle was exhibited on the Arize Tej Gold variety under the Evergrow+100 Kg/ha SA fertilizer treatment (293 grains) while the lowest was recorded under the control treatment of variety Arize 6444 Gold 98 grains as shown in figure 4.4a in mwea. The fertilizer treatments showed significant positive influence compared to the control at Ahero with the highest recorded on the 200 kg/ha SA treatment that however was not significantly different from that of Evergrow+100 Kg/ha SA treatment.

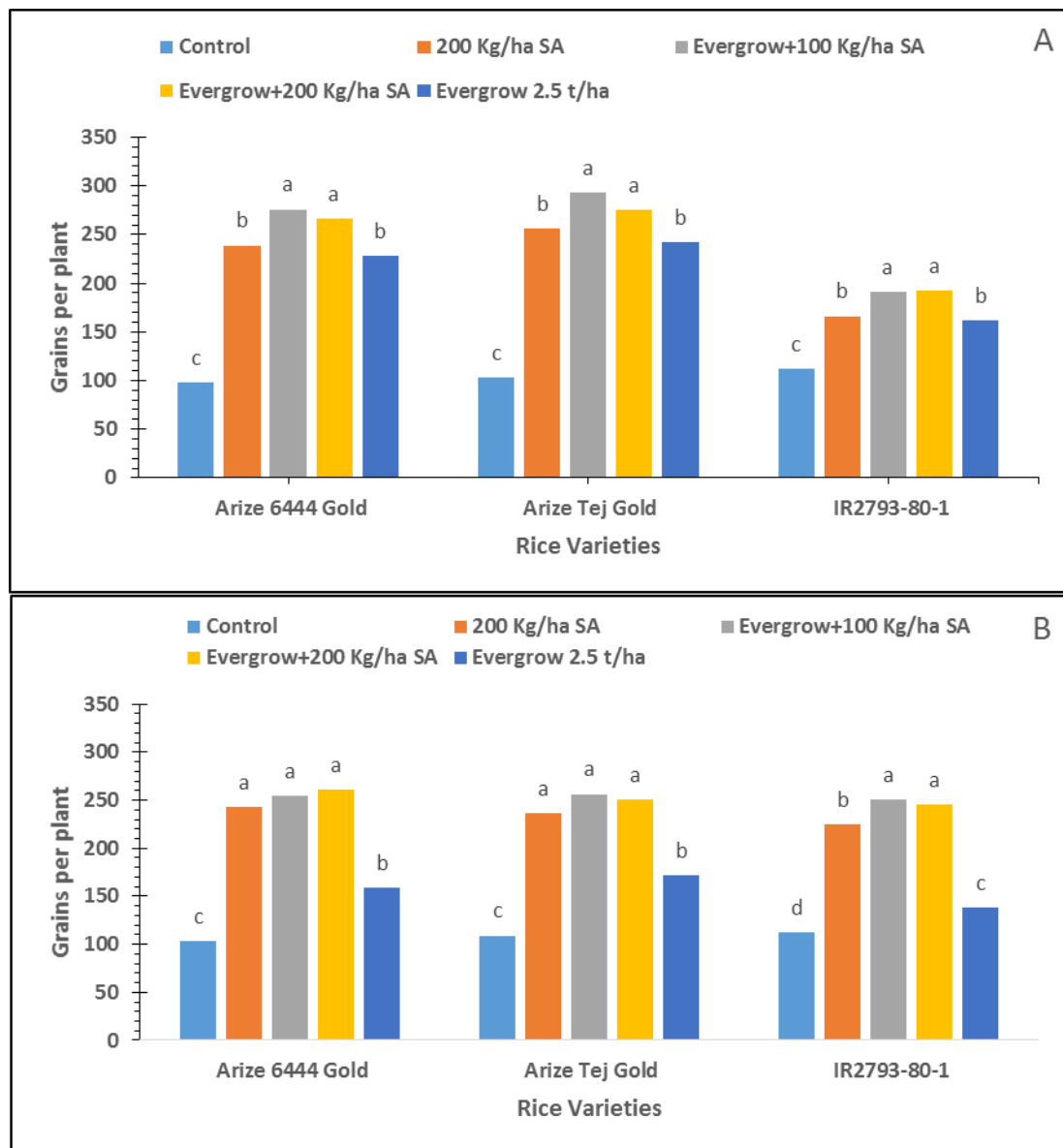


Figure 4.4: Number of grains per plant as influenced by SRI fertilizer practices and rice varieties at Mwea (A) and Ahero (B) Irrigation Schemes

The findings of this study agrees with those of Srivastava *et al.* (2006) found that application of 180 kg N ha⁻¹ significantly decreased the grain sterility and recorded the maximum grain yield over 120 and 60 kg N ha⁻¹ during both the years. In another study by Rajinder *et al.* (2009) reported that spacing and nutrient source are

critical on growth and yield of rice which agrees with the present data. The results of this study also agree with the findings of Ali and Izhar, (2017), who reported that grain yield did not increase significantly over conventional method when rice was grown with System of Rice Intensification technique, but closer spacing of 20 x 15 cm and inorganic source of nutrient had significant influence on yield as evident in this study.

4.2.3 Grain yield per hectare

The grain yield of rice varieties per hectare differed significantly at $P \leq 0.05$ under the SRI fertilizer practices treatments in both Mwea and Ahero study sites. The highest grain yield was recorded on variety Arize Tej Gold under the Evergrow+200 Kg/ha SA fertilizer treatment with weight of 6.40 t/ha and 4.32 t/ha in Mwea and Ahero respectively. On the other hand, Arize 6444 Gold under control had the lowest yield of 1.43 t/ha and 0.97 t/ha in Mwea and Ahero respectively as illustrated in table 4.7.

The findings of this study agrees with those of Kihoro *et al.* (2013b), Muhunyu, 2012 and Niki *et al*, 2014 who reported that amount of N fertilizer applied resulted in high-yielding rice cultivation areas in other countries. In another study by Njinju *et al.* (2018) reported that whether rice grain yield could be increased with increases in the amount of nitrogen (N) fertilizer or the current N fertilizer practice, which were determined based on the experiences of farmers and researchers, is sufficient for optimal rice production in this area which agrees with the present findings.

Table 4.7: Grain yield (t/ha) as influenced by System of Rice Intensification fertilizer practices and rice varieties at Ahero and Mwea Irrigation Schemes

Variety	SRI Treatments	Mwea	Ahero
Arize 6444 Gold	Control	1.429e	0.971e
	200 Kg/ha	4.744c	2.320d
	Evergrow+100 Kg/ha	5.819b	4.295a
	Evergrow+200 Kg/ha	5.853b	4.179ab
	Evergrow 2.5 t/ha	4.203d	2.582c
Arize Tej Gold	Control	1.478e	0.993e
	200 Kg/ha	5.029c	2.425c
	Evergrow+100 Kg/ha	6.256a	4.371a
	Evergrow+200 Kg/ha	6.403a	4.327a
	Evergrow 2.5 t/ha	4.498d	2.705c
IR2793-80-1	Control	1.891e	1.047e
	200 Kg/ha	4.515d	2.240d
	Evergrow+100 Kg/ha	5.128c	4.149ab
	Evergrow+200 Kg/ha	5.230c	4.091b
	Evergrow 2.5 t/ha	4.336d	2.560c
	LSD	0.354	0.1906
	P-Value	<0.001	0.002
	CV%	4.8	3.4

Values with the same letters within the column are not significantly different, SRI- System of Rice Intensification

The study by Hasanah *et al.*, (2019) found out that rice N requirements are closely related to yield levels, which in turn are sensitive to weather conditions, supply of other nutrients, and crop management practices which agrees with current findings. Shahid *et al.* (2016) reported that yield advantage on the application of organic sources was due to their capability to supply essential nutrients other than N, P and K. Application of farm yard manure is known to increase concentrations of Fe, Mn, Zn, and Cu in rice which agrees with the findings of this study. Higher nutrients uptake with the application of inorganic fertilizer might be due to higher nutrient concentration along with higher biomass production as reported by Banik and

Sharma, (2006) and agrees with the findings of this study. The findings of Narwal and Chaudhary, (2006) also agrees with this study results that application of organic manure along with chemical fertilizer accelerates the microbial activity increases nutrients use efficiency and enhances the availability of the native nutrients to the plants resulting higher nutrients uptake. The findings of this study agrees with those of Sahu, (2017) who reported an increase of grain yields with System of Rice Intensification ranged from 5.6 to 7.3 t ha⁻¹ and from 4.1 to 6.4 t ha⁻¹ under traditional flooding management. On an average, grain yields under SRI were 21% higher in 2005 and 22% higher in 2006 than with traditional flooding. Dai *et al.* (2019) also observed a similar trend like for this study that optimizing fertilizer N application rates under System of Rice Intensification is important to increase yield, N use efficiency and water use efficiency.

4.3: Effect of System of Rice Intensification fertilizer practices on the grain quality and harvest index of three rice varieties at Mwea Irrigation Scheme

4.3.1 Harvest index

The harvest index of the rice varieties was significantly influenced ($P \leq 0.05$) by the SRI fertilizer practices in both Mwea sites as showed in figure 4.5. The Evergrow+100 Kg/ha SA fertilizer treatments showed the highest harvest index (43.5%) under the Arize 6444 Gold variety with the lowest harvest index (29%) observed on the local variety IR2793-80-1 in the control treatment.

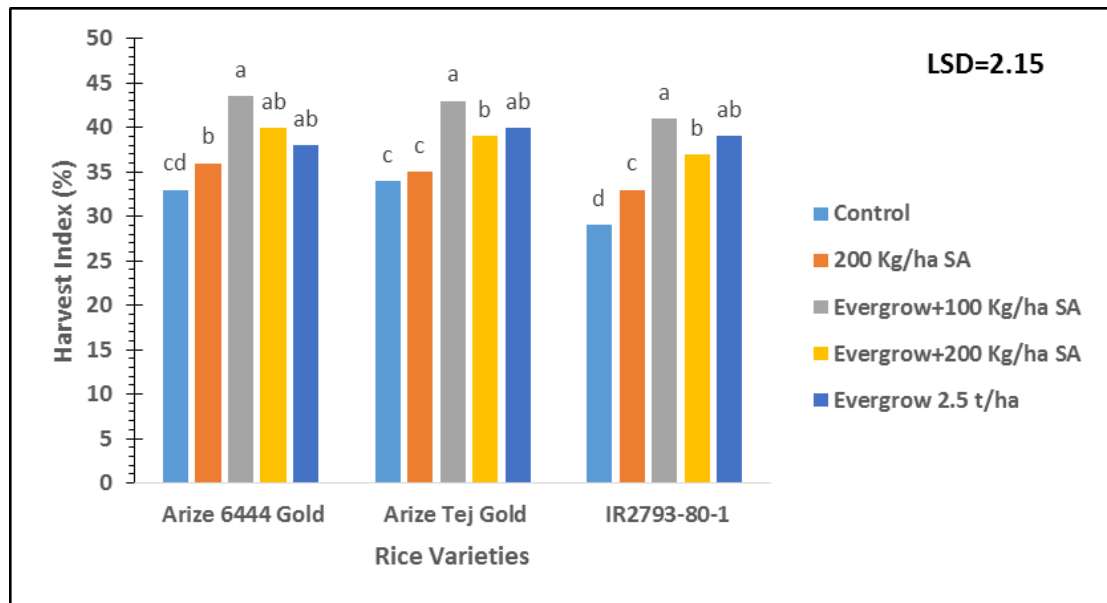


Figure 4.5: Harvest index of rice varieties under the SRI fertilizer treatments at Mwea Irrigation Scheme

Gangaiah and Rao (2000) reported 18.2 and 17.6 percent higher grain and straw production respectively, at higher fertility level (180: 90: 60 kg NPK ha⁻¹) as against 120: 60: 40 kg NPK ha⁻¹ yields when compared with lower rates of application which agrees with the current findings. According to Banik *et al.*, (2004) and Singh *et al.* (2006) beneficial effect of organic manures on N, P and K uptake might be attributed to their faster release of nitrogen during mineralization by virtue of propitious air-moisture proportion prevailed in the field due to SRI and there by resulting in higher N uptake by rice resulting to higher grain yield which concurs with the present results.

Application of organic manure along with chemical fertilizer accelerates the microbial activity increases nutrients use efficiency and enhances the availability of

the native nutrients to the plants resulting in higher nutrients uptake as reported by Narwal and Chaudhary, (2006) and agrees with the current data.

4.3.2 Protein and amylose contents

There were significant differences ($P \leq 0.05$) between the treatments in the amylose contents (Table 4.8). The highest amylose content was recorded under the organic plus half of the inorganic fertilizer (100 kg/ha SA) with 28.8% in Arize Tej Gold variety which was however insignificantly different from the full rate (200 kg/ha SA) of the same variety (28.8%). The findings of this study disagrees with those of Donald, (2002) who reported deterioration in grain quality in modern high yielding cultivars which contradicts findings of this study where the improved varieties Arize Tej Gold and Arize 6444 Gold had higher amylose and protein content compared to the local variety IR2793-80-1. Different rice varieties may have different unique texture after cooking, linked to their main constituent which is starch, and that governs the final texture of rice.

The protein content of the treatments showed significant differences ($P \leq 0.05$). The highest (10.6%) was recorded under organic plus half of the inorganic fertilizer (Evergrow+100 kg/ha SA) with 28.8% of Arize Tej Gold variety (Table 4.8). Nitrogen is used by plants to synthesize amino acids in plants which in turn are used for protein synthesis thus causing an increase in protein content. Rice grain quality is improved when protein content is high which along with protein composition contribute to eating, cooking qualities (ECQs) besides being an important part of the

nutritional composition of the grain (Peng *et al.* 2014). In addition, proteins' contribution to rice quality is directly related to market value of rice which influence farmers' incomes.

1. Table 4.8: Influence of SRI fertilizer treatments on Amylose and Protein contents of rice varieties at Mwea and Ahero Irrigation Schemes

Variety	SRI Treatment	Mwea		Ahero	
		Amylose (%)	Protein (%)	Amylose (%)	Protein (%)
ARIZE TEJ GOLD	Evergrow+100 Kg/ha SA	28.8a	10.6a	23.01a	9.5a
	Evergrow+200 Kg/ha SA	28.8a	10.2b	23.0a	9.2a
	200 Kg/ha SA	27.9d	9.8c	22.3ab	8.9ab
	Evergrow 2.5 t/ha	26.6f	9.4d	21.0b	8.5b
	Control	25.2g	8.2i	20.2c	7.4c
ARIZE 6444 GOLD	Evergrow+100 Kg/ha SA	28.5b	9.1e	22.8a	8.1b
	Evergrow+200 Kg/ha SA	28.1c	8.9f	22.4ab	8.0b
	200 Kg/ha SA	27.2e	8.7g	21.8b	7.8bc
	Evergrow 2.5 t/ha	26.5f	8.4h	21.2b	7.5c
	Control	24.7h	7.5k	19.7d	6.7d
IR2793-80-1	Evergrow+100 Kg/ha SA	21.2i	8.3h	17.0e	7.5d
	Evergrow+200 Kg/ha SA	20.1j	8.1i	16.1f	7.3de
	200 Kg/ha SA	18.4k	7.8j	14.7g	7.1e
	Evergrow 2.5 t/ha	17.6l	7.5k	14.1g	6.7f
	Control	15.3m	6.6l	12.1h	5.9g
LSD		0.13	0.1	0.71	0.42
P-Value		<0.001	<0.001	<0.001	<0.001

Values with the same letters within the column are not significantly different,

SRI- System of Rice Intensification

The findings of this study agrees with those of Abeyundara *et al.*, (2015) who reported that the component present in the endosperm or inner part of rice kernel is

carbohydrate, and consists of 85% - 90% of starch, 2% pentose and 1% sugars. In another study by Ahuja *et al.*, (2008) it was revealed that starch fraction is made up of amylose and amylopectin that determines the cooking quality of rice and is greatly influenced by proper fertilization. Thus, starch characteristics determine the amylose content and gelatinization temperature (Welch and Graham, 2002). Rice varieties with amylose content below 6% remain sticky following cooking. According to Ahuja *et al.*, (2008), some consumers would prefer non sticky rice varieties which have higher amylose content of between 25% - 30% which can be derived from the hybrid varieties used in this study.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

- The SRI fertilizer treatments significantly influenced the growth and tillering of the rice varieties where by The application of 2.5 t/ha Evergrow+100 Kg/ha SA fertilizer led to higher number of tillers in the three rice varieties (Arize 6444 Gold, Arize Tej Gold, and IR2793-80-1) 54, 60 and 48 respectively in Ahero irrigation scheme and 52, 46, and 40 in Mwea irrigation scheme.
- Yield components and grain yield of rice was significantly influenced by the SRI fertilizer practices with the highest grain yield observed under the Evergrow 2.5 t/ha +200 Kg/ha SA fertilizer practice in Arize Tej Gold (6.403t/ha) in Mwea which was not significantly different from Evergrow 2.5t/ha+100 Kg/ha SA fertilizer (6.256t/ha) while in Ahero irrigation scheme the same variety under Evergrow 2.5t/ha+100 Kg/ha SA fertilizer gave the highest yield (4.371t/ha) though not significantly different from Evergrow+200 Kg/ha SA fertilizer (4.327t/ha).
- The highest harvest index was recorded under Evergrow+100 Kg/ha SA fertilizer treatment (43.5%) in Arize 6444 Gold variety while the lowest harvest index (29%) was observed on the local variety IR2793-80-1 in the control treatment.

- Protein and amylose were positively influenced by SRI fertilizer treatments where by the highest amylose content was recorded under Evergrow 2.5t/ha+100 Kg/ha SA fertilizer (28.77%) in Arize Tej Gold variety which was however insignificantly different from Evergrow 2.5t/ha+200 Kg/ha SA fertilizer of the same variety (28.75%). The same variety showed the highest protein content under Evergrow 2.5t/ha+100 Kg/ha SA fertilizer (10.58%) which was significantly different from Evergrow 2.5t/ha+200 Kg/ha SA fertilizer (10.24%).

5.2 RECOMMENDATIONS

- Farmers can use Evergrow (Nitrogen (N) >1.0% Phosphorus (P) >0.4% Potassium (K) >0.5% Calcium (Ca) >1.3%) 2.5 t/ha +100 Kg/ha SA (21% nitrogen) fertilizer System of Rice Intensification for increased growth and tillering of the rice varieties in both Ahero and Mwea.
- The study highly recommends the Evergrow (Nitrogen (N) >1.0% Phosphorus (P) >0.4% Potassium (K) >0.5% Calcium (Ca) >1.3%) 2.5 t/ha + 100 Kg/ha SA fertilizer SRI practice under the improved variety which will lead to realization of the potential grain yield in the two study sites.
- The application of the Evergrow (Nitrogen (N) >1.0% Phosphorus (P) >0.4% Potassium (K) >0.5% Calcium (Ca) >1.3%) 2.5 t/ha + 100 Kg/ha SA fertilizer SRI practice is recommended for increased harvest index of rice varieties.

- The application of the Evergrow (Nitrogen (N) >1.0% Phosphorus (P) >0.4% Potassium (K) >0.5% Calcium (Ca) >1.3%) 2.5 t/ha + 100 Kg/ha SA fertilizer SRI practice is highly recommended for improved rice cooking qualities.

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APPENDICES

Appendix 1: Experimental stages in Mwea and Ahero study sites

