EFFECT OF PLANT SPACING AND INTERMITTENT FLOODING ON GROWTH AND YIELD OF SELECTED LOWLAND RICE VARIETIES IN MWEA IRRIGATION SCHEME

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DECLARATION

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

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DEDICATION

This thesis is dedicated to my parents Cosmus Musyoka and Grace Munyithya.

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GENERAL ABSTRACT

Paddy rice productivity in Mwea Irrigation Scheme is low partly due to water shortage, inappropriate plant spacing and low yielding varieties. There is need for water saving practices and appropriate agronomic practices to enhance paddy rice productivity. A study with the main objective of enhancing rice productivity in Mwea Irrigation Scheme through optimal plant spacing and improved water management was conducted during March to July 2015 season and August to December 2015. The specific objectives of the study were: (1) to establish farmers' agronomic practices for paddy rice production with respect to spacing and water management; (2) to determine the effect of intermittent flooding on growth and yield of selected rice varieties; and (3) to determine the effect of plant spacing on growth and yield of selected rice varieties. For the first objective, a detailed farmer survey was conducted across five sections of Mwea Irrigation Scheme namely: Karaba, Wamumu, Thiba, Tebere and Mwea. Two hundred farmers were interviewed using a pre-tested semi structured questionnaire with 40 farmers randomly selected from each of the five sections. Data collected included: method of transplanting, age of seedlings at transplanting, number of seedlings per hole, depth of transplanting, number of years farmers had been in rice production, sizes of land owned by farmers, whether soil testing was done in the fields, net grain yield attained in the field, frequency of irrigation, stages at which irrigation was done, knowledge on when to irrigate the rice fields, depth of irrigation, whether farmers drained the fields , plant spacing used in the fields, the reasons for choice of the type of spacing and challenges in rice production. Descriptive statistics analyses using frequencies and means were performed using Statistical Package for the Social Sciences (SPSS) program version 20. The field experiment was set up in a randomized complete block design with a split-split plot arrangement and replicated three times. The treatments consisted of two irrigation regimes (intermittent flooding and continuous flooding), three varieties (Saro5, Basmati and IR-2793-80-

1) and four different spacing arrangements (15 cm ×15 cm, 20 cm×15 cm, 25 cm×15 cm and 30 cm×15 cm). Data on plant height, number of tillers, number of effective tillers, number of days to maturity for each variety, panicle length, grain yield adjusted to 14% moisture content and 1000-grain weight were collected. Data were analyzed using Genstat 15th edition and treatment means were compared using the least significant difference (LSD) test at $P \leq 0.05$.

All interviewed farmers reported that they transplanted seedlings rather than direct seeded. Over 90% of the farmers transplanted one month or older seedlings at a rate of two seedlings per hole and at a depth of 2 cm. Most interviewed farmers had been in rice cultivation for 6-20 years, owned 1-2 acres and produced 2001-5000 kg/ha. Most farmers irrigated their fields once a week at a depth of ≤ 10 cm. Majority of interviewed farmers used plant spacing of 30 × 15 cm and 20 × 20 cm which they associated with increased yields. Water shortage, high input prices and low market prices were the major challenges farmers faced in rice production. Rice variety Basmati 370 had significantly taller plants and longer panicles than IR-2793-80-1 and Saro 5. Variety IR-2793-80-1 had significantly higher number of tillers per plant and number of panicles per plant than Saro 5 and Basmati 370. In the first season, IR-2793-80-1 had significantly higher net grain yield than Saro 5 and Basmati 370 while in the second season Saro 5 had significantly higher net grain yield than Basmati 370 and IR-2793-80-1. Basmati 370 had significantly lower 1000 grain-weight than Saro 5 and IR-2793-80-1 in both seasons. Plant spacing did not have a significant effect on plant height and panicle length. Number of tillers significantly increased with increase in plant spacing. Irrigation regime had no significant effect on number of tillers per plant in the first season, but continuous flooding significantly increased the number of tillers per plant at reproductive and maturity stages. Plant spacing of 30×15 cm had higher panicles per plant than all other plant spacing arrangements in both seasons. Plant spacing of 15 × 15 cm had higher

grain yield than all other spacing arrangements in the first and second season. Irrigation regime did not have a significant effect on plant height, panicle length, panicle number and 1000 grain-weight in both seasons. Intermittent flooding had significantly higher grain yield than continuous flooding in the second season. Variety and plant spacing interaction effects on the number of tillers per plant and number of panicles were significant in both seasons.

Transplanting was the most preferred method of planting. Most farmers used plant spacing of 30 × 15 cm and practiced continuous flooding of their rice fields. Plant spacing of 15× 15 cm was the most productive in net grain yield followed by 20 ×15 cm. Variety Saro 5 and IR-2793-80-1 had the highest net grain yield in both seasons. Intermittent flooding recorded higher net grain yield than continuous flooding and saved 44.4% water. This study has therefore demonstrated that cultivation of the recently introduced variety Saro 5 and intermittent flooding have the potential to improve rice productivity in Mwea Irrigation Scheme.

CHAPTER ONE: INTRODUCTION

1.1 Background information

Rice belongs to the grass species *Oryza sativa* (Asian rice) or *Oryza glaberrima* (African rice) (IRRI, 1994). *Oryza sativa* is widely grown in different parts of the world while *O. glaberrima* is restricted only to West African countries (Fuller. 2011). The *O. sativa* has two sub species; *indica* and *japonica* that originated from two independent domestication events (Crawford *et al*., 1998). Rice is often grown as an annual crop but can grow perennially as a ratoon crop for almost 30 years (IRRI, 2009). It can grow up to 1-1.8 m tall, depending on the genotype and soil nutrition. It has long and slender leaves; ranging from 50 cm to 100 cm in length and 2 cm to 2.5 cm in breadth (Wassmann *et al*., 2009).

Rice is one of the most important food security crops globally as it is the main staple food for half of the world's population (FAOSTAT, 2014). It provides 20% of the world's dietary energy supply compared to maize and wheat that supply 5% and 19%, respectively (FAO, 2011). Globally, rice production is at 500 million metric tonnes annually (equivalent to 29% total grain production worldwide) produced on 150 million hectares globally (EUCORD, 2012). According to the Africa Rice Centre, Africa produces about 3% of the total global rice production. Asia produces and consumes most of the rice with China being the biggest producer (EUCORD, 2012; USAID, 2010). Rice has also become a very important crop in Africa (FAOSTAT, 2014). It is the fastest growing source of food in Sub-Saharan Africa (FAO, 2004) and it is no longer a luxury food. Annual rice consumption in Africa is increasing at a rate of 12% compared to 4% for wheat and 1% for maize and this can be associated with population growth, increase in incomes and urbanization. However, rice production has been declining in the past decade (2000-2011) despite its increasing popularity. According to Global Agricultural Information

Network (GAIN) report, (2015), about 80% of rice production is under irrigation schemes and the annual production in the Kenya is at 126,400 tonnes. Eastern and Southern Africa (ESA) alone imports about 36% of its total rice (IRRI, 2007). The situation is expected to worsen with the rapid human population growth and the shift in consumer preferences from traditional food eating habits in favor of rice, especially in urban areas (WARDA, 2007). Kenya has a potential of 540 000 ha that could be used to produce paddy rice, but only 105 000 ha of these are being exploited (MOA, 2009). Lake Victoria basin and Coast region are some of the areas with the greatest potential. Other irrigated areas in Tana Delta, Bura and Hola irrigation schemes and Vanga in Kwale County have potential for expansion too (Onyango, 2014).

Rice is extremely sensitive to water shortage and is commonly grown under flooded conditions. However, with increasing global water scarcity in most areas due to drought associated with climate change, it is virtually impossible to maintain flooding conditions (Wassmann *et al.*, 2004). In Kenya, about 80% of the rice grown is under schemes established by the Government while the remaining 20% is produced under rain-fed conditions (MOA, 2009). The production in the schemes has been declining over time due to diminishing water resources and poor agronomic practices. Rice farmers are faced by water shortages during the growing season and this reduces yields considerably (Ndiiri *et al.,* 2013). The appropriate plant density is a very important component of cultural technologies and is essential for optimizing yield (Faisul-ur-Rasoo *et al*., 2012). Plant spacing influences plant physiological activities via intra-specific competition (Oad *et al.,* 2001).

1.2 Problem statement and justification

Mwea Irrigation Scheme, which produces most of the rice in Kenya, does not have adequate water for paddy rice production. Water in the canals has to be rationed in order to meet the farmers' needs. The increased demand for domestic, industrial and other uses of water coupled with recurrent drought and climatic changes in Kenya, a country which has limited water resources, reduces the share of fresh water used in irrigation. The high demand and water scarcity have resulted to diversion of water to other uses, thus the amount left for agricultural use has reduced. This has reduced the soil moisture which plays a critical role in the crop cycle.

It is estimated that over 75% of the world's rice is produced using continuous flooding water management practices (Van der Hoek *et al*., 2001). According to Sharma (1989) the controlled flooding method is very inefficient because about 50-80 of the water input is wasted. To increase the level of rice production, it is necessary to develop water use-efficient practices. Intermittent flooding enables soil to hold air allowing roots to grow more profusely due to presence of oxygen in the soil leading to effective nutrient uptake healthier plants and better grain. Intermittent flooding therefore offers opportunities to increase crop productivity while saving water, incomes and reducing the national rice import bill as well as improving food security (Mati, 2011). Intermittent flooding is an alternative system that can be considered to increase crop water productivity (Ceesay *et al*., 2006). However, the impact of intermittent flooding on rice productivity in Mwea has not been well established so farmers are still using continuous flooding.

Appropriate plant spacing is a very important component of crop husbandry practices and is essential for optimizing yield. Optimum spacing ensures that plants efficiently utilize solar radiation and nutrients (Mohaddesi *et al.*, 2011). Plant spacing influences normal plant physiological activities due to intra-specific competition (Oad *et al.,* 2001). An increase in plant population above the optimal level increases competition among rice plants for the above and below ground resources, thereby slowing plant growth and decreasing net grain yield. Similarly, much lower plant population often results to increased number of tillers per plant but reduced number of hills per unit area resulting in lower net grain yield (Baloch *et al*., 2002). The optimum plant population varies with variety of rice. However, extension agents in Mwea recommend the same spacing for old and newly released varieties. For example, there is a newly released variety namely TDX 306 (Saro 5) whose plant population has not been determined. Currently, farmers in Mwea are using the same spacing for all the rice varieties grown indicating that the optimum plant spacing for new rice varieties has not been determined (Ndiiri *et al*.,2013). There is therefore need to identify the best plant spacing for improved varieties in order to improve rice productivity and reduce importation. The national rice consumption is estimated at 300 000 metric tons compared to an annual production range of 45,000 to 80,000 metric tons (Emongor *et al*., 2009). The deficit is met through imports. In 2008, rice imports in Kenya were valued at Ksh 7 billion (Emongor *et al*., 2009).

1.3 Objectives

The main objective of the study was to enhance rice productivity in Mwea Irrigation Scheme through optimized plant spacing and improved water management.

The specific objectives were:

1. To establish farmers' plant spacing and water management practices for lowland rice production.

2. To determine the effect of intermittent flooding on growth and yield of selected lowland rice varieties.

3. To determine the effect of plant spacing on growth and yield of selected lowland rice varieties.

1.4 Hypotheses

1. Water management and plant spacing practices in lowland rice production vary from farmer to farmer.

2. Intermittent flooding does not reduce growth and yield of selected lowland rice varieties.

3. Growth and yield of selected lowland rice varieties depend on the plant spacing.

CHAPTER TWO: LITERATURE REVIEW

2.1 Botany, ecology and importance of rice

Rice (*Oryza sativa* L.) is a graminae plant in the family of wheat and oats that can grow up to 1.8 m tall. It has a hollow stem, lanceolate leaves with tapered endings and parallel venation (Chang *et al*., 1964). The most important part is the spike, formed by a deciduous panicle where seeds or grains are found. Rice is a self-pollinating plant; each flower contains both male and female parts (Bhat *et al*., 2004).

Rice plants require warm temperatures with a minimum temperature for growth being 10 ^{0}C. The minimum temperature for rice plant flowering and ripening ranges from 22 to 23^{0}C and 20 to 25^{0}C respectively. Temperature greatly influences growth duration and pattern. Temperatures beyond 35^{0}C affect grain filling (Prasada Rao, 2008). Rice grows in a wide range of soils from the podzolic alluvium of China to the impermeable heavy clays of Thailand (Jaetzold and Schmidt, 1982). Its optimum pH range is 5.5 to 6.5 in dry soils and 7 to 7.2 upon flooding (Mumbala *et al*., 2007).

Rice plants go through vegetative, reproductive and maturity stages. Vegetative stage is characterized by seed germination, seedling emergence, pre-tillering, tillering and end of tillering (IRRI, 2002). At reproductive phase, there is decline of tillering, culm elongation, booting, heading and flowering. At ripening stage grain increases in size and weight as starch and sugars are translocated from culms and leaf sheaths where they have accumulated and the grain changes color from green to gold or straw color at maturity (Moldenhauer *et al*., 2003).

Rice originated in Asia and there is evidence of its cultivation in China, India and Indonesia 7000, 4000 and 500 years ago respectively (MoA, 2009). It is the third world most important cereal after maize and wheat (MOA 2010; USAID, 2010). It has been a staple food for over a half of the world's population thus making it a very important crop. As the global population increases, so does the demand for rice (Satyanarayana, 2005). Together with maize and wheat it supplies more than 42% of the calories to the world's population (Onyango, 2014). Rice is mostly consumed as a source of carbohydrates. Its starch is used to make ice-cream, puddings and distillation of portable alcohol. Rice bran is used in confectionery products like bread, snacks, cookies and biscuits. Broken rice is used for making food items like breakfast cereals, baby foods, rice flour, noodles, and rice cakes among others (Onyango, 2014). It is also used as poultry feed. Rice is a good source of insoluble fiber which reduces the risk of bowel disorders and fights constipation. Rice is low in fat, contains some protein and plenty of B vitamins (MOA, 2010).

Rice cultivation in Kenya was introduced in 1907 from Asia (MoA, 2009). Production of rice in Kenya is mainly done in irrigation schemes which include: Mwea Irrigation Scheme-9000 ha, Bunyala scheme-516 ha, Tana Delta-Msambweni, Ahero and West Kano- 3120 ha, Migori and Kuria by about 300,000 ha small scale farmers (MOA, 2010). The national rice consumption in Kenya estimated at 540, 000 tonnes have been rising steadily at an average rate of 12% compared to 4% for wheat and 1% for maize (Onyango, 2014). The deficit is met through imports, valued at over 13.8 billion in 2014 (GAIN Report, 2015). Rice productivity has remained low with marked fluctuations over the years (Emong`or *et al.,* 2009). Rice yields in Kenya research centers and irrigation schemes have been declining over the years, for instance they reduced from 4200 kg/ha to 2900 kg /ha during 2000-2007 (Emong'or *et al.*, 2009), mainly due to the use of low quality rice seeds, poor agronomic practices and poor infrastructure.

2.2 Constraints in rice production

Rice production is faced by many constraints which can be socio-economic, abiotic or biotic and they include: unavailability of quality seed, inadequate farmer knowledge and training, high price of inputs and low market prices, inadequate water, low soil fertility, high and very low temperatures, pests and diseases, poor post-harvest handling practices, poor extension services, land tenure problems, poor infrastructure, social challenges, unfavorable trans-boundary trade practice and labor scarcity (Emong`or et al., 2009; Onyango, 2014).

Seed quality is critical for agricultural production hence the lack of it leads to great loses in rice production. Improper channels of seed distribution could lead to use of uncertified seed by farmers affecting their yields and profits (Emong`or *et al*; 2009). Farmers have limited knowledge on the best practices for rice production with respect to crop nutrition requirements, proper planting dates and crop management (MoA, 2010).

The prices for most inputs like fertilizers and seeds are very high thus farmers tend not to use quality input thus affecting the rice production. At the same time the little produce they get from their fields is sold at low market prices resulting in low profitability (Onyango, 2014).

Farmers are forced to spend a lot of resources on fertility enhancement due to land degradation and loss of soil nutrients. Some farmers are not able to afford adequate fertilizers and, in most cases, have either withdrawn from rice production or suffered severe losses (Onyango, 2014).

High temperatures cause heat stress and water scarcity while very low temperatures cause rice blast (IRRI, 2010). Exposure to cold temperature affects all phenological stages of rice and lowers grain production and yield too. Low temperature at vegetative stage causes slow growth and reduces seedling vigor (Naylor *et al*., 2006), reduces tillering, increases plant mortality, increases growth period and in reproductive stage can cause panicle sterility (Shimono *et al*., 2007)

Rice diseases are caused by fungi, bacteria, nematodes and viruses (Sinha and Sharma, 2008). Some of the most important rice diseases in Kenya are bacterial blight, rice blast, rice yellow mottle virus and sheath blight causing farmers to lose so much of their yields (Onyango, 2014). Pests make farmers lose an estimated average of 37% of their rice yields (IRRI, 2008). Some of the pests affecting rice production include: rice hispa, termites, stalked-eye fly, rice root aphid, seed corn maggot, African mole cricket, cut worm, rice water weevil, rice leaf bettle, paddy stripper, rice stem borer and rice bug (Ora et al., 2011). Rice is also susceptible to attack by birds from the milk stage to maturity stage. Birds can destroy a whole rice field mostly early morning and late in the evening (Ora et al., 2011).

There is inadequate water supply in Mwea Irrigation Scheme thus affecting rice production and causing yield reduction (Ndiiri *et al*., 2013). Rice needs water for transpiration and evaporation (Widawsky and O'Toole, 1990). Another cause of water shortage is poor management of canals preventing continuous flow of water.

Majority of farmers lose their yield after harvesting because of poor post-harvest handling. Great losses are experienced during harvesting, threshing, winnowing, and drying. If at the time of storage the seeds are not treated they are prone to attack by storage pests like rodents. Poor air circulation during storage causes contamination and grain quality deterioration.

Farmers in most cases are not able to access extension services possibly as a result of the changes in institutions providing extension to rice farmers. Before restructuring in early 2000, National Irrigation Board used to offer extension services to rice farmers, especially in irrigation schemes (Emong'or *et al.*, 2009).

The land tenure system does not favor the farmers as they do not own land tittles. This reduces the chances of rice farmers acquiring credit to improve their production as they do not own titles to the land which can be used as collateral to secure loans. Social challenges in the irrigation schemes which include high prevalence of waterborne diseases such as malaria and bilharzia affect the productive ability of farmers. In addition, HIV/AIDS has greatly affected the production work force of the rural farming communities (MOA, 2010).

Poor infrastructure development of dams, roads, irrigation and drainage, electricity, communication and viable public/private sector affect the farming systems of small scale rice farmers (Fonteh and Assoumou, 2013). There has been migration of young energetic people to the urban centers that has rendered labor unavailable and expensive. Most families depend on family labor to carry out various farm activities partly to reduce production costs during labor peaks (MOA 2010).

There is a lot of informal cross border trade leading to unfavorable trans-boundary trade practice with Uganda and Tanzania. There is also rice seed movement across borders which may not have undergone formal certification that could be detrimental to the rice sub sector development in the country (MOA, 2010).

2.3 Effect of drought stress on rice

Climate change, increasing human population and drought stress have made it difficult to meet the food, feed and shelter needs of human beings (Akram, 2007). Climate change, could seriously threaten production levels required to feed future generations all over the world (IPCC, 2007). Climate change aggravates a variety of stresses for rice plants which include drought and heat stresses.

Drought is one of the major abiotic stresses that constrain rice production and yield stability (Lanceras *et al*., 2004). Widawsky and O'Toole (1990) also described drought stress as the most severe limiting factor to rice production. Drought is a meteorological term and is commonly defined as the inadequacy of water availability, including the period without significant rainfall that affects crop growth and soil moisture storage capacity (Hanson *et al*., 1995). Drought occurs when the available water in the soil is reduced and atmospheric conditions cause continuous loss of water by transpiration or evaporation. Drought stress is considered to be a loss of water, which leads to stomata closure and limitation of gas exchange (Kamoshita *et al*., 2008).

Drought stress is characterized by reduction of water content, leaf water potential, turgor pressure and stomata activity as well as decrease in cell enlargement and growth. It causes reduced plant growth by affecting various physiological and biochemical processes, such as photosynthesis, respiration, translocation, ion uptake, nutrient metabolism and growth regulation (Farooq *et al*., 2009). Severe water stress may result in the arrest of photosynthesis, disturbance in metabolism and finally the death of plants (Jaleel *et al.*, 2008). Drought stress in plant cells leads to physiological closure of leaf stomata which affects carbohydrate economy (Chaves *et al*., 2002). Drought stress can interrupt floret initiation and grain filling in rice leading to sterile spikelet and poor seed yield (Kamoshita *et al*., 2008). Rice is most susceptible to drought stress at the reproductive stage (Pantuwan *et al*., 2000). The response of rice yield to soil water status varies with growth stage, being most sensitive at flowering, booting and grain filling stage (O'Toole, 1982).

Water stress limits a crop's ability to reach its genetically determined theoretical maximum yield (Begg and Turner, 1976). The reactions of plants to water stress differ significantly at various organizational levels depending on intensity, duration of stress, plant species and its growth stages (Chaves et *al*., 2002; Jaleel *et al*., 2008). Water stress affects plant growth and development and ultimately reduces grain yield of rice. The reduction of yield may depend on the developmental stage of the crop. More reduction in rice grain yield due to water stress in flowering stage is as a result of reduction in fertile panicles and filled grain percentage (Xie *et al*., 2001). Fundamental research has provided insights in the understanding of the physiological and molecular responses of plants to water deficits, but there is still a large gap between yields in optimal and stress conditions (Park *et al*., 2011).

Bouman and Toung (2001) showed that different cultivars might have different responses to drought timing and intensity. Rahman *et al*., (2002) reported that plant height, number of tillers per plant, panicles numbers, panicle length, harvest index and yield of different varieties decreased with water stress. The percentage of drought affected land areas more than doubled from 1970's to early 2000's in the world (Isendah *et al*., 2006). It is estimated that 50% of the world rice production is affected more or less by drought (Bouman et al., 2005). Swain *et al*., 2010 evaluated eighteen rice genotypes and they found the reduction in panicle numbers (72%) and grain yield (12%). Singh *et al*., 2010 evaluated the six generations (P1, P2, B1, B2, F1 and F2) of six crosses of rice under drought and irrigated conditions and observed a reduction in grain yield under drought conditions. Audebert (2000) observed a reduction in plant height, tiller abortion, changes in rooting pattern and delayed development under drought conditions. Pantuwan et al., (2000), found that grain yield of genotypes under drought stress condition was reduced from 18% to 52% compared to irrigated condition. They also found delay in flowering time that was associated with greater reduction in net grain yield and filled grain percentage.

2.4 Irrigation management and effect of intermittent watering in rice production

Availability of freshwater is one of the greatest issues facing the human kind because problems associated with its availability affect the lives of millions of people, particularly those in the developing countries (Bouman and Toung, 2001). In Southern and Eastern countries of the Mediterranean, the agriculture sector is, by far, the largest water user. On a consumptive-use basis, 80 to 90% of all the available water resources are consumed by the agriculture sector (MOA, 2010). The amount of moisture in the soil has been of interest in agriculture for many years. Soil moisture is also of importance to the hydrologist, forester, and soil engineer. There is need therefore to conserve water for future sustainability in terms of storage and applications. According to Maclean *et al*., (2002), effectiveness in water saving, equity in water sharing, efficiency in water delivery and use are important for sustainable use of available surface and ground water resources. Studies show that it takes 1,432 litres of water to produce one kilogram of rice on average, in an irrigated lowland production system (IRRI, 2010). Daily consumptive use of rice varies from 6-10 mm of the total water required for the crop, 3% or 40 mm is used for nursery, 16% or 200 mm for land preparation (i.e. puddling) and 81% for field irrigation (IRRI, 2010). The growth of rice plant in relation to water management can be divided into four stages i.e. seedling, vegetative (germination to panicle initiation), (reproductive to heading), and grain filling and ripening or maturation (heading to maturity) (IRRI, 2010). Less water is consumed during seedling stage. At transplanting time, a shallow depth of 2 cm is maintained up to 7 days and thereafter 5 cm of submergence is necessary to facilitate development of new roots. The same water level is required for tiller production during the vegetative phase. At the start of maximum tillering stage the entire water in the field can be drained and left as such for two days, this is termed as mid-season drainage (IRRI, 2010). The mid-season drainage may improve the respiratory functions of the roots, stimulate vigorous growth of roots and check the development of non-effective tillers. During the flowering phase 5 cm submergence should be maintained because it is a critical stage of water requirement. Stress during this stage will impair all yield components and cause severe reduction in yield. Excess water may lead to delayed heading. Water requirement during ripening phase is less and water is not necessary after yellow ripening. Water can be gradually drained from the field 15-21 days ahead of harvest crop (IRRI, 2010; MOA, 2010).

Water use efficiency (WUE) is the amount of crop production or output per unit of water consumed during the production of that yield (Chapagain and Yamaji, 2010). To reduce water use in irrigated rice, water-saving regimes can be introduced, that aim to reduce non-beneficial water flows from rice fields during crop growth namely seepage, percolation and evaporation by irrigation and aerobic rice system (Bouman *et al.*, 2005). About 80% of rice in Kenya is grown under continuous flooding as is typified in gravity operated Mwea irrigation scheme, and in the three western Kenya irrigation schemes that are pump operated (Japan International Cooperation Agency, 1998). Rice production is often affected by water scarcity in times of drought (Mohandrass *et al*., 1995). To ensure food security and mitigate climate change in rice producing areas, intermittent irrigation with a depth of 3-5 cm could be promoted to replace continuous flooding irrigation (Fonteh and Assoumou, 2013).

Bouman *et al*., (2007) defined intermittent flooding as the practice of withholding irrigation until several days after the disappearance of ponded water. Intermittent flooding is now promoted as a water-saving technology which entails irrigation when water falls to a threshold depth below the soil surface. Safe alternate wetting and drying results in saving of irrigation water, increased water productivity, and no decline in rice yield (Bouman *et al.,* 2007).

Intermittent flooding (alternate wetting and drying) is claimed to be a high-yielding and environmentally friendly technology that relies on changing farmers' agronomic practices towards a more efficient use of natural resources (Uphoff and Randriamiharisoa, 2002). Rice grown under intermittent flooding was reported to be more robust against extreme weather events, pests, and diseases due to improved plant vigor and root strength (Stoop *et al*., 2002). In Kenya, intermittent flooding offers opportunities to increase crop productivity while saving water, incomes and reducing the national rice import bill as well as improving food security (Mati, 2011). Improving the yield of rice in existing irrigated areas rather than further expansion is more likely to be the main source of growth for the crop in Kenya, especially due to limited land and water resources (Nyamai *et al*., 2012**)**.

2.5 Effect of plant spacing on growth, yield and quality of selected rice varieties

Plants depend largely on temperature, solar radiation, moisture and soil fertility for their growth and nutrition requirements. A dense population of crops may have limitations in the optimum availability of these factors. It is, therefore, necessary to determine the optimum density of plants per area unit for obtaining maximum yield (Baloch *et al*., 2002). The appropriate plant density is a very important component of cultural technologies and is essential for optimizing yield (Faisul-ur-Rasoo *et al*., 2012). Plant spacing influences plant physiological activities via intra-specific competition (Oad *et al.,* 2001). Plant populations above the optimal levels cause an increased competition for above and below ground resources, resulting in slow plant growth and reduced grain yield, whereas plant populations below the optimal levels cause increased numbers of tillers per plant but also result in decreased grain yield because of a low number of hills per unit area (Baloch *et al.,* 2002).

Optimum plant spacing is dependent on the variety of rice. Optimum spacing ensures both above and below growth with optimum solar radiation and nutrients utilization (Khan *et al.,* 2005; Moaddesi *et al.,* 2011). Closer spacing of plants hampers intercultural operations and increases competition among plants for nutrients, air and light thus reducing yield (Azad *et al*., 1995). Effects of plant spacing on Basmati 370 grain yield planted under a system of alternate wetting and drying in Mwea Irrigation Scheme was tested between plant spacing of 20 cm to 45 cm. A spacing of 25 × 25cm proved beneficial to Mwea farmers practicing alternate wetting and drying yielding 6t/ha (Nyang'au *et al*., 2014). Mohapatra *et al*., (1989) reported that plant spacing of 20 × 20 cm was better than that of 15 × 15 cm under normal soil for rice production. Currently in Mwea, Kenya, a spacing of 30 × 15 cm is being used by most of the farmers in the paddy rice production. Maske *et al*., (1997) reported that plant height, yield and yield components of rice were higher in plant spacing of 15 × 10 cm than plant spacing of 15 × 15 cm and 15 × 20 cm. No plant spacing studies have been conducted for most recently released rice varieties such as Saro 5.

CHAPTER THREE: TRANSPLANTING, PLANT SPACING AND WATER MANAGEMENT PRACTICES BY PADDY RICE FARMERS IN MWEA IRRIGATION SCHEME

3.1 Abstract

Use of optimum plant spacing and appropriate water management practices, in the face of declining water resources due to drought has the potential to improve productivity of paddy rice in Kenya. A study was conducted to determine the transplanting, plant spacing and water management practices for paddy rice in Mwea Irrigation Scheme. A survey was done in 2016 across five units of the Mwea Irrigation Scheme using a semi-structured questionnaire in a stratified random sampling approach. Two hundred farmers were interviewed in Wamumu, Karaba, Thiba, Tebere and Mwea sections of the Scheme. In each section, 40 randomly selected farmers were interviewed. Data collected included: method of transplanting, age of seedlings at transplanting, number of seedlings per hole, depth of transplanting, number of years farmers had been in rice production, sizes of land owned by farmers, whether soil testing was done in the fields, net grain yield attained in the field, frequency of irrigation, stages at which irrigation was done, knowledge on when to irrigate the rice fields, depth of irrigation, whether farmers drained the fields, plant spacing used in the fields, the reasons for choice of the type of spacing and challenges in rice production. Descriptive statistics analyses using frequencies and means were performed using Statistical Package for the Social Sciences (SPSS) program version 20.

All interviewed farmers reported that they transplanted seedlings rather than direct seeding. Over 90% of the farmers transplanted one month or older seedlings at a rate of two seedlings per hole and at a depth of 2 cm. Most interviewed farmers had been in rice cultivation for 6-20 years, owned 1-2 acres and produced 2001-5000 kg/ha. Farmers irrigated their fields once a week,

depending on the field water level at a depth of ≤ 10 cm. Majority of interviewed farmers used spacing of 30 × 15 cm and 20 × 20 cm which they associated with increased yields. Water shortage, high input prices, low market prices and pests and diseases were the major challenges in paddy rice production.

3.2 Introduction

Rice is the third most important crop in Kenya and requires the best growing conditions for maximum production. Kenya has a potential of about 540 000 ha that could be used to produce irrigated paddy rice, but only 105 000 ha are being utilized (MOA, 2009). According to GAIN report, (2015), the annual rice production in the Kenya is estimated at 126,400 tonnes compared to the annual consumption of 1.18 million tonnes. Rice production is faced by many constraints: unavailability of quality seed, inadequate farmer knowledge and training, high price of inputs and low market prices, inadequate water, low soil fertility, high temperatures and very low temperatures, pests and diseases, poor post-harvest handling practices, poor extension services, land tenure, poor infrastructure, unfavorable trans-boundary trade practices and labor scarcity (Emong'or et al., 2009; Onyango 2014).

Agronomic practices like transplanting, plant spacing and good water management are skills that when put into practice by farmers can greatly increase rice yields within the same area of production. Baloch *et al*., (2002) found that transplanting method recorded the highest average yields compared to direct seeding. Proper spacing can increase yields by 25-40% over improper spacing and helps save on inputs, labor and materials (IRRI, 2008). Rice requires abundant water environment but water is becoming increasingly scarce. Growing rice accounts for one-quarter to one-third of the global fresh water withdrawals (Bouman *et al*., 2007). Agriculture's share of water will decline at even faster rate because of increasing competition for available water from urban and industrial sectors. The future of rice production entirely depends on developing and adopting strategies and practices that will use water efficient methods (Bouman *et al*., 2007). Farmers need to come up with ways to the save on amount of water used; capitalizing on new varieties that use less water, reducing water use during land preparation, reducing percolation and seepage during crop growth period, water distribution strategies, water recycling and conjunctive use of ground water (Bouman *et al*.,2005). These water saving methods when incorporated with proper spacing can greatly improve rice production (Bouman *et al*., 2001). The objective of the study was supposed to determine the plant spacing and water management practices used by farmers in Mwea Irrigation Scheme.

3.3 Materials and methods

3.3.1 Study site

The survey was carried out in Mwea Irrigation Scheme, Kirinyaga district. Mwea Irrigation Scheme is one of the seven public schemes under the management of the National Irrigation Board. The scheme lies in the agro-ecological zone 3 and has a gazzeted area of 30,350 acres, 16,000 acres of which have been developed for paddy production. It is designated into seven sections (Karaba, Thiba, Wamumu, Mwea, Tebere, Ndekia and Mutithi) and has a total of 77 units and about 5,000 farmer households. Each farmer holds about 2.8 acres, according to a survey done by Rice Mapp in 2012. Initially each farmer used to hold about 4 acres but land size per household has declined due to an increase in population. Each farmer produces 2500-3000 kg per acre (Japan International Cooperation Agency, 2012). The Scheme is served by Nyamindi and Thiba rivers which have fixed intake weirs. A link canal joins the two rivers which transfers water from Nyamindi to Thiba River which serves about 80% of the Scheme (Mburu *et al.*, 2011). Soils in the area are black cotton soils (vertisols) that shrink and swell with changes in moisture content.

3.3.2 Sampling design

Two hundred farmers' were interviewed in five different sections of Mwea Irrigation Scheme namely: Karaba, Wamumu, Thiba, Tebere and Mwea in 2016 using a stratified random sampling approach. In each section, 40 randomly selected farmers were interviewed using a semi structured questionnaire which had been pre-tested by 20 farmers (Appendix 1). The survey was done under guidance of agricultural extension officers of the National Irrigation Board in Mwea.

3.3.3 Data collection

Information from both males and females was collected on: method of transplanting, age of seedlings at transplanting, number of seedlings per hole, depth of transplanting, number of years farmers had been in rice production, sizes of land owned by farmers, whether soil testing was done in the fields, net grain yield attained in the field, frequency of irrigation, stages at which irrigation was done, knowledge on when to irrigate the rice fields, depth of irrigation, whether farmers drained the fields, plant spacing used in the fields, the reasons for the choice of the plant spacing and challenges in rice production.

3.3.4 Data analysis

Descriptive statistics analyses using frequencies and means were performed using Statistical Package for the Social Sciences (SPSS) program version 20.

3.4 Results

3.4.1 Transplanting practices in the Mwea Irrigation Scheme

All interviewed farmers reported that they transplanted their seedlings from the nursery to the fields and none practiced direct seeding (Table 3.1). Majority of farmers (90.5%) in all units transplanted one month old or older seedlings. Less than 9 and 1% of farmers used three and two weeks old seedlings, respectively. At Thiba, all farmers planted one month old seedlings. Only Karaba and Tebere had farmers (2 – 2.6%) who grew two-week old and younger seedlings. The number of seedlings planted per hole varied across the Scheme (Table 3.1). Majority of the farmers planted two seedlings per hole (61.1%) and some used more than two seedlings per hole (30.5%). Few farmers (7.9%) from the survey planted one seedling per hole. Tebere had the highest number of people planting two seedlings per hole (73.7%). Depth of transplanting used varied in all units (Table 3.1). Majority of farmers used 2 cm depth (72.1%) with a few using 1 cm (21.3 %). Tebere had the highest number of farmers (78.9%) that used 2 cm as the depth of transplanting.

Table 3.1: Transplanting practices by farmers in the Mwea Irrigation Scheme (% respondents)

N= 200	Sections in Mwea Irrigation Scheme					
	Karaba	Mwea	Thiba	Wamumu	Tebere	Mean
Method of planting						
Direct seeding	0.0	0.0	0.0	0.0	0.0	0.0
Transplanting	100.0	100.0	100.0	100.0	100.0	100.0
Age of transplanted seedling						
≤2weeks	2.0	0.0	0.0	0.0	2.6	0.9
3 weeks	6.1	10.8	0.0	12.8	13.2	8.6
≥1 month	91.8	89.2	100.0	87.2	84.2	90.5
Number of seedlings/hole						
1 seedling	8.2	8.1	5.0	5.1	13.2	7.9
2 seedlings	53.1	64.9	52.5	61.5	73.7	61.1
>2 seedlings	38.8	27.0	40.0	33.3	13.2	30.5
Depth of transplanting						
1 cm	20.4	24.3	17.5	25.6	18.4	21.3
2 cm	69.4	73.0	75.0	64.1	78.9	72.1
>2 cm	10.2	2.7	7.5	7.7	2.6	6.1

3.4.2 Farmers' experience in rice production, land size under rice and rice yields in Mwea Irrigation Scheme

Farmers' experience in rice farming varied across units (Table 3.2). Majority of the farmers' reported to have been producing rice for 6-20 years (39.3%) followed by those who had been producing rice for more than 20 years (32.8%). Farmers who had less than 5 years experience in rice production were the minority. Karaba had the most experienced rice farmers with about 80% farmers being in rice production for over 6 years. Thiba had the highest percentage of farmers with five years or less experience in rice production.

Most of the respondents in the Scheme (60%) owned 1-2 acres of land (Table 3.2). 0nly 1% of the farmers reported to own more than five acres across the five units in Mwea Irrigation Scheme. None of the farmers in Karaba and Tebere had more than 5 acres of land. Karaba and Thiba had higher proportion of farmers with less than 1 acre of land than Wamumu and Mwea.

Across the units, majority of the farmers (52.3%) produced rice yield of 2001-5000 kg/acre (Table 3.2). Few farmers (7%) produced less than 1000 kg of rice/acre while about 21% produced more than 5000 kg of rice/acre. Wamumu had the highest number of farmers (60.5%) that produced rice yields of 2001-5000 kg/acre.

Majority of farmers indicated that their soils were not tested before any planting season. In Thiba and Tebere, 100% farmers had not had their soils tested for soil chemical characteristics. Wamumu had the highest number of interviewed farmers (5.3%) that reported their soils to have been tested.

Table 3.2: Number of years in production, land size owned, soil testing, and rice yield (%respondents)

N=200	Sections in Mwea Irrigation Scheme					
	Karaba	Mwea	Thiba	Wamumu	Tebere	Mean
Years of production						
≤5 years	20.4	27.0	40.0	28.2	23.7	27.9
6-20 years	53.1	45.9	25.0	35.9	36.8	39.3
≥20 years	26.5	27.0	35.0	35.9	39.5	32.8
Land size						
< 1 acre	21.1	8.2	25.6	7.9	27.5	18.1
1-2 acres	57.8	69.4	61.6	68.4	45.0	60.4
2.1- 5 acres	18.5	22.4	12.8	21.1	27.5	20.5
> 5 acres	2.6	0.0	0.0	2.6	0.0	1.0
Soil testing						
Yes	2	2.6	0	5.3	0	1.98
No	98	97.4	100	94.7	100	98.02
Yield (kg/acre)						
≤1000	10.5	4.1	15.4	2.6	2.5	7.0
1000-2000	23.7	18.3	25.6	13.2	20.0	20.2
2001-5000	42.1	55.2	51.3	60.5	52.5	52.3
≥5000	23.7	22.4	7.7	23.7	25.0	20.5

3.4.3 Irrigation practices in the Mwea Irrigation Scheme

Majority of the farmers (59 to 82%) in the sampled sections irrigated their fields once a week (Table 3.3). Some 21% of the farmers reported that they did not have specific frequencies of irrigation due to inconsistency in water distribution, poor drainage system in the scheme, and general water scarcity faced in the country. The highest proportion of farmers' that carried out irrigation once a week across the five sections was in Wamumu area. Karaba registered the highest proportion of farmers who irrigated their rice crops once in two weeks and once a month. Mwea, Thiba, Wamumu and Tebere did not have farmers who irrigated once a month.

An average of 71% of the farmers interviewed in the Scheme reported that they irrigated their rice fields up to two weeks before harvesting, whereas 29.3% of them irrigated their fields during the entire growing season (Table 3.3). In Karaba, 35% of the farmers irrigated the rice crop during the entire growing season. Mwea and Thiba had the most number of farmers that irrigated rice up to two weeks before harvesting.

Farmers in the scheme the used irrigation field water level and crop appearance to determine when to irrigate their rice fields (Table 3.3). Majority of them (60.7%) used the irrigation field water level to determine the right time to irrigate while 21%reported that they looked at the crop physical appearance. Wamumu had the highest proportion of farmers (84.6%), followed by Karaba (77.6%) that irrigated their rice fields depending on the field water level.

The depth of irrigation varied across the sections (Table 3.3). Majority of the respondents in Tebere, Wamumu and Thiba irrigated to a depth of less than 10 cm while majority of respondents in Karaba and Mwea irrigated to more than 10 cm.

On average, drainage of fields was done by 97.5% of the farmers' interviewed. In Thiba, all farmers reported that they drained their fields two weeks before harvesting when crops had matured. Tebere had the highest number of farmers (5.3%) that did not drain their fields during the whole crop growing period.

Table 3.3: Frequency of irrigation, irrigation crop stages, indicators of when to irrigate, depth of irrigation and drainage of paddy fields (% respondents)

N=200	Sections in Mwea Irrigation Scheme					
	Karaba	Mwea	Thiba	Wamumu	Tebere	Mean
Irrigation Frequency						
Once a week	59.2	64.9	67.5	82.1	76.3	70.0
Once in two weeks	18.4	0.0	7.5	7.7	7.9	8.3
Once a month	4.1	0.0	0.0	0.0	0.0	0.8
Others (unspecified)	18.4	35.1	25.0	10.3	15.8	20.9
Irrigation stages						
The entire growing season	34.7	24.3	25.0	33.3	28.9	29.3
Up to two weeks before harvesting	65.3	75.7	75.0	66.7	71.1	70.7
Indicators of need to irrigate						
Irrigation field water level	77.6	67.6	0.0	84.6	73.7	60.7
Crop physical appearance	16.3	29.7	20.0	12.8	26.3	21.0
Others (unspecified)	6.1	2.7	80	2.6	0.0	18.3
Irrigation depth						
≤10 cm	49.0	48.6	55.0	61.5	76.3	58.1
>10 cm	51.0	51.4	45.0	38.5	23.7	41.9
Draining						
No	2.0	2.7	0.0	2.6	5.3	2.5
Yes	98.0	97.3	100.0	97.4	94.7	97.5

Where unspecified refers to irregular irrigation

3.4.4 Plant spacing used and reason for choice of plant spacing in Mwea Irrigation Scheme

Plant spacing for rice varied across the units in the Scheme (Table 3.4). The most commonly used plant spacing arrangements by the farmers across the sites were 30 ×15 cm (27.5%), 20 ×20 cm (26.6%) and 15 ×15 cm (23.9%). A sizable proportion (15%) of the farmers also reported to have been using 20 cm by 15 cm. Very few farmers (1%) used 25 cm by 15 cm. About 6% of the farmers reported that they didn't have a specific spacing but only estimated manually when planting their crop.

Most of the farmers in all the units chose the respective plant spacing to increase their yields (53%) and to increase the number of tillers (26%). A small proportion (10%) did it to ease the crop management while less than 1% of the farmers chose plant spacing to either control weeds or based on their neighbors' practices.

Table 3.4: Plant spacing and the reasons for the choice of spacing adopted by farmers in the Mwea Irrigation Scheme (% respondents)

N=200	Sections in Mwea Irrigation Scheme					
	Karaba	Thiba	Mwea	Wamumu	Tebere	Mean
Plant spacing						
15*15cm	27.5	31.0	20.0	24.2	16.7	23.9
20*15cm	17.5	20.7	2.9	12.1	22.2	15.1
20*20cm	27.5	10.3	37.1	27.3	30.6	26.6
25*15cm	2.5	0.0	0.0	0.0	2.8	1.1
30*15cm	20.0	31.0	34.3	24.2	27.8	27.5
Others (unspecified)	5.0	6.9	5.7	12.1	0.0	5.9
Choice of spacing						
To increase yields	40.8	48.6	52.5	59.0	65.8	53.3
Ease of crop management	4.1	24.3	7.5	5.1	10.5	10.3
Control weeds	0.0	2.7	0.0	0.0	0.0	0.5
Increase no. of tillers	34.7	18.9	30.0	23.1	23.7	26.1
Neighbors' practice	0.0	2.7	0.0	0.0	0.0	0.5

3.4.5: Challenges in rice production in Mwea Irrigation Scheme

The leading challenge for the interviewed farmers was lack of adequate water for irrigation (63%). Farmers also noted high input prices (37%), low market prices for their produce (26%), pests and diseases (25%), poor infrastructure (21%), weed infestation (13%) and attack by birds as major constraints. Farmers in Wamumu and Mwea were most affected by shortage of water, 74 and 71 % respondents, respectively, while farmers in Karaba were the least affected by the shortage of water (49%). Most complaints of pests and diseases were reported by farmers in Tebere, Mwea and Thiba. Respondents in Karaba did not consider pests and diseases as a major challenge. Poor infrastructure was mostly reported in Wamumu (34%) and Karaba (33%).

Table 3.5: Challenges faced by the farmers in rice production in Mwea Irrigation Scheme (% respondents)

	Sections in Mwea Irrigation Scheme					
N=200	Karaba	Thiba	Mwea	Wamumu	Tebere	**Mean**
Lack of enough water for irrigation	49.0	52.5	71.1	73.7	69.2	63.1
High input prices	40.8	32.5	44.7	28.9	35.9	36.6
Low market prices for produce	18.4	27.5	26.3	34.2	25.6	26.4
Pests and diseases	0.0	35.0	36.8	13.2	38.5	24.7
Poor infrastructure	32.7	12.5	10.5	34.2	12.8	20.5
Weeds	20.4	10.0	5.3	7.9	20.5	12.8
Labor expenses	12.2	7.5	21.1	10.5	2.5	10.8
Birds' infestation	4.1	7.5	2.6	7.9	0.0	4.4

3.5 Discussion

All the farmers in the Mwea Irrigation Scheme transplanted rice seedlings rather than direct seeded. Transplanting is a popular method of establishing rice in irrigated areas due to perceived higher grain than direct seeding (Allkas *et al*., 2006). Ehsanullah *et al*., (2000) also found that transplanting significantly gave higher paddy yield than direct seeding. This agrees with IRRI (2008) that transplanting enables optimal spacing which leads to an increase in number of tillers per plant and net grain yield over poor spacing caused by direct seeding. According to Baloch *et al*., (2002) the transplanting method recorded the highest average yield because the wider distance between plants allowed air circulation, water and light which are basic for photosynthetic activity. However, transplanted rice takes a longer time to start tillering because it needs time to recover from the shock of transplanting unlike direct seeded rice. Farooq *et al*., (2011) pointed out that yield in direct seeding system of rice production is often lower than the transplanting system of rice production. Transplanting is preferred by most farmers because it gives uniform stands in the rice fields unlike direct sowing (Faisul-ur-Rasoo *et al*., 2012). However, transplanting is time consuming because of the need to establish a seedling nursery before planting seedling in the field (Faisul-ur-Rasoo *et al*., 2012). This implies that the farming practices employed by these farmers are yield-driven and may suggest that a lack of proper resources to carry out farming may be at play. The preference for transplanting may also be attributed to the fact that yields in direct seeded rice is often lower than transplanted rice (Farooq et al., 2011).

Most of the farmers transplanted one month old seedlings. Seedling age at transplanting is an important factor for the establishment of a uniform stands of rice and regulation of its growth and yield (Bassi *et al*., 1994). Mobasser *et al*., (2007) observed that when seedlings stay for long in the nursery beds, primary tiller buds on the lower nodes of the main culm become degenerated leading to reduced tiller production. In recent studies of Makarim *et al*., (2002), 14-day old seedlings performed better than 21-23 day old seedlings. Krishna *et al* ., (2009) also observed higher grain yields with 12 day old seedlings than 8-16 and 25 day old seedlings and the yield decline was attributed to reduction in number of tillers per plant. One month old seedlings may be strong enough to survive the first few days of transplanting but could have over stayed in the nursery hence reduced the effectiveness of tillers. This implied that farmers want to ensure survival of the seedlings.

Most farmers transplanted two seedlings per hole. This concurs with some studies that have shown that transplanting two seedlings per hill increased grain yield relative to transplanting one seedling per hill (Farooq *et al*. 2009). Sanico *et al*. (2002) also reported that increasing the seedling number per hill decreased or increased grain yield depending on the season and seedling age. This, however, differs with study a by Mishra *et al*., (2006) who reported that one seedling per hill increases root length, density and activity and their independence with above-ground canopy development resulting to prolonged photosynthetic activity. San-oh *et al*., (2006) also reported that planting a single seedling per hill had higher yield than two or more seedlings per hill. Horie *et al*., (2005) studied that a single seedling per hill reduces competition and minimizes the shading effect of lower leaves thus helping the leaves remain photosynthetically active for much longer. A high number of seedlings per hill can cause competition between the plants which sometimes results in gradual shading and lodging thus increasing production of straw instead of grain. It is therefore important to determine the optimum seedling number per hill for high yield (Hossain *et al*., 2003). Too many seedlings per hole could also be un-economical for farmers because that requires them to set up large nurseries that translate to buying more seed.

Besides, transplanting one seedling per hole may be considered risky by farmers because the seedling could fail to survive after transplanting. Farmers' mostly transplanted seedlings at a depth of 2 cm. This concurs with IRRI knowledge bank (2010) where farmers are advised to plant seedlings to the depth of 1.5-3 cm.

Most interviewed farmers owned 1-2 acres of land. The land size has reduced from the original NIB allocation of 4 acres per person (Japan International Cooperation Agency, 2012). A survey done by Rice Mapp 2012 showed that each farmer holds 2.8 acres of land. The current observation is attributed to the increasing population leading to sub-division of land among family members. Interviewed farmers have been cultivating paddy rice for 6-20 years. The Scheme having been established in 1956, it is possible to have farmers that have been in rice production for this long. Most interviewed farmers had a production of 2001 to 5000 kg/acre. This concurs with a study by (Japan International Cooperation Agency, 2012) that each farmer in Mwea Irrigation Scheme produces 2500 to 5000 kg/ha.

Most farmers irrigated their rice fields once a week. Under continuously flooded conditions, rice receives two to three times more water than other irrigated cereals (Bouman *et al*., 2007). Most farmers determined the proper time of irrigation depending on field water level to a depth of $\leq$10 cm. All farmers in Mwea drained their rice fields two weeks before harvesting to promote grain filling and ripening and also allow drying of soil for easier movement during harvesting. This concurs with Bouman *et al*., (2007) who reported that after crop establishment, the soil is kept ponded with 5-10 cm layer of water until 1-2 weeks before harvesting.

The major plant spacing arrangements used by farmers in Mwea were 30×15 cm and 20×20 cm for all varieties because the farmers interviewed claimed that these increased grain yields. This concurs with (Baloch *et al*., 2002) who reported that the plant density of spacing 20 × 20 cm was more effective than 20 × 15 cm and gave significantly higher grain yield. However, a bigger spacing promotes more tillers per plant which is directly proportional to yield. Studies have demonstrated that plant spacing influences plant physiological activities via intra-specific competition (Oad *et al*., 2001). Farmers chose their kind of plant spacing due to various reasons: increase in yields, ease of crop management, control of weeds and increase in number of tillers per plant and due to neighbors' practices. Studies have shown that people could choose optimum spacing to ensure that plants grow in both aerial and underground parts through efficient utilization of solar radiation nutrients (Mohadessi *et al*., 2011). Use of inappropriate plant spacing can result in net grain yield reduction of 20-30% (IRRI, 1997).

The three leading challenges facing farmers in the units were inadequate water, high input prices and low market prices. These challenges have continuously affected the economic status of farmers because they contribute to low yields which after harvesting are sold at poor prices. Ceesay *et al*., (2006) reported that high yields were significantly increased by water saving methods like intermittent flooding.

Almost all farmers did not do soil tests in their farms before planting. Yield depends not only on genetic characteristics but also on agronomic practices including nutrient management (Zhou *et al*., 2003). A soil test is important before planting because it enables farmers to know what nutrients are deficient in their farms and by what amounts hence only providing enough to avoid excess or under application.

3.6 Conclusions

This survey has shown that transplanting of one-month old seedlings at a plant spacing of 30×15 cm irrespective of the rice variety was preferred by almost all the farmers interviewed. Majority of the farmers in the Scheme irrigated the fields once a week to a depth of ≤10 cm and drained fields two weeks before harvesting.

CHAPTER FOUR: EFFECT OF PLANT SPACING AND INTERMITTENT FLOODING ON GROWTH AND YIELD OF SELECTED LOWLAND RICE VARIETIES IN MWEA IRRIGATION SCHEME

4.1Abstract

Paddy rice is a great consumer of water, thus the increasing water scarcity in Mwea Irrigation Scheme has caused a decline in rice yields. Improper plant spacing also adversely affects rice yields. A study was carried out in Mwea Irrigation Scheme to determine the effect of plant spacing and intermittent flooding on the growth and yield of selected rice varieties. The experiment was set up in a randomized complete block design with a split-split plot arrangement and replicated three times. The treatments consisted of two irrigation regimes (intermittent flooding and continuous flooding), three varieties (Saro5, Basmati and IR-2793-80-1) and four different plant spacing arrangements (15 cm ×15 cm, 20 cm×15 cm, 25 cm×15 cm and 30 cm×15 cm). Data collected included: plant height (cm), number of tillers, number of effective tillers, days to maturity for each variety, panicle length, grain yield adjusted to 14% moisture content and 1000-grain weight. Data were analyzed using Genstat 15th edition and treatment means compared using the Least Significant Difference (LSD) test at p=0.05. Varieties were significantly different in plant height in both seasons. Basmati 370 had significantly taller plants and higher panicle length than IR-2798-80-1 and Saro 5 in both seasons. Variety IR-2793-80-1 had significantly higher number of tillers and panicles per plant than Basmati 370 and Saro 5. In the first season, IR-2793-80-1 had significantly higher net grain yield than Basmati 370 and Saro 5 while in the second season Saro 5 had significantly higher net grain yield than the former two varieties. Basmati 370 had significantly lower 1000 grain-weight than Saro 5 and IR-2793-80-1 in both seasons. Plant spacing did not have a significant effect on plant height in both seasons at all growth stages. The number of tillers increased significantly with increase in spacing. Plant

spacing did not significantly affect panicle length but significantly affected the number of panicles per plant. Plant spacing of 30×15 cm had highest number of panicles per plant in both seasons. Plant spacing of 15 × 15 cm had higher net grain yield than 25×15 cm and 30×15 cm in both seasons. Irrigation regime had no significant effect on the number of tillers, plant height, panicle length, panicles numbers and 1000 grain-weight in both seasons. Intermittent flooding had higher net grain yield than continuous flooding and saved 44.4% irrigation water. The variety and plant spacing interaction effects on the number of tillers per plant and number of panicles were significant in both seasons. This study has demonstrated that cultivation of the recently introduced variety Saro 5 and intermittent flooding have a potential to improve rice productivity in Mwea Irrigation Scheme.

4.2 Introduction

Increased water demand is constrained by lack of sufficient water availability as rice is the largest consumer of water in the agricultural sector (Bera *et al*., 2009). Rice production in Kenya is based on a conventional practice of continuously flooding the paddy fields (Republic of Kenya, 2008). This method is not sustainable due to the already existing competition for water among farmers within and outside the Scheme (Mati *et al*., 2011). Thus, innovative ways for efficient use of water need to be put in place to ensure sustainable rice production (Bouman *et al*., 2005). Kenya is classified as water scarce, which arises from the uneven distribution of water resources and frequency of extreme weather events. The pressure to reduce water use in irrigated agriculture is mounting thus rice is an obvious target for water conservation. Producing more rice using less water is very important in water scarce areas so as to feed the growing population. A reduction of 10% of water used in irrigated rice would free 150,000 million m^3, corresponding to about 20% of total fresh water used globally for non-agricultural purposes (Kleem *et al*., 1999).

To achieve good yields, there is need for coming up with water use-efficient practices (Chapagain *et al*., 2010). Water use efficiency is the ratio between grain yield and the amount of water used (Borrel *et al*., 1997) and can be achieved by either increasing grain yield without reducing water input or reducing the amount of water used by a crop while sustaining yield or combination of both (Tabbal *et al*., 2002). Intermittent flooding is a promising method in irrigated rice cultivation with benefits of both water and environmental savings while maintaining rice yields at the same level (Yang *et al*., 2009). Studies in Kenya indicate that intermittent irrigation could result in water saving of up to 25%, with yields of 100-110 kg per bag (Mati *et al*., 2012; Ndiiri *et al*., 2013). In Madagascar it has been reported that water saving can increase yield by 25-100% while reducing water used by 25-50% (Satyanarayana, 2007). In China it has been reported that up to 46% of water saving was attained and yield increase of similar value (Xiaoyun *et al*., 2005). The newly released varieties such as Saro 5 have not been tested under intermittent flooding conditions.

Plant spacing is an important production factor in transplanted rice (Gorgy *et al*., 2010). Optimum spacing ensures efficient utilization of solar radiation by plants hence optimum production of yields (Mohaddesi *et al.*, 2011). It also ensures that plants grow properly both in their aerial and underground parts (Shirtliffe *et al*., 2002). Plant spacing affects plant population, biomass, tillering of rice hills and number of grains per panicle (Hasanuzzaman *et al*., 2009). Farmers in Kenya have various plant spacing ranging from 15×15 cm to 30×15 cm, however, the optimum plant spacing for different varieties have not been established. The objective of this study is to determine the effect of intermittent flooding and plant spacing on the growth and yield of selected lowland rice varieties.

4.3 Materials and methods

4.3.1 Site description

The study was done at the Mwea Irrigation Scheme [0°39′ N, 37º17′E, 1195 m above sea level] in Kirinyaga South district. The site is located about 100 km North East of Nairobi. The Scheme is one of the seven public schemes under the management of the National Irrigation Board. The site lies in the agro-ecological zone 3 and receives 1000 mm of rainfall in a year, 600 mm in the long rains and 400 mm in short rains with 66% reliability. The average temperature in the area is 22^0C, with minimum and maximum temperatures of 17^0C and 28 ^{0}C respectively. The area experiences a relative humidity of 54.7% to 87.2%. The weather data during the experimental period is shown in Appendix 2. Mwea Irrigation Scheme has a gazzeted area of 30,350 acres. Of these, 16,000 acres have been developed for paddy rice production. In addition, the Scheme has a total of 4,000 acres of out grower and "jua kali" (non-out grower) areas under paddy rice production. It is divided into seven sections with a total of 77 units and about 5,000 farmer households. Each farmer holds about 2.8 acres according to a survey done by Rice Mapp in 2012. Initially each farmer used to hold about 4 acres. Each farmer produces 2500-3000 kg per acre (Japan International Cooperation Agency, 2012). The Scheme is served by Nyamindi and Thiba rivers which have fixed intake weirs. The irrigation water is abstracted from the rivers by gravity and is conveyed and distributed in the scheme via unlined open channels. A link canal joins the two rivers which transfers water from Nyamindi to Thiba River which serves about 80% of the Scheme (Mburu *et al.*, 2011). Soils in the area are black cotton soils (vertisols) that shrink and swell with changes in moisture content (Sombroek *et al.*, 1982). Soil at the experimental field was sampled at depths of 0-15 cm and 15-30 cm and analyzed for pH, N, K, Ca, Mg and cation exchange (Table 4.1).

Table 4.1: Chemical composition of soil at the Mwea Irrigation Scheme

Parameter	pH	%N	%K	%Ca	%Mg	C.E.C
Top soil	5.29	0.17	0.17	32.43	22.61	64
Sub soil	6.9	0.09	1.4	51.29	36.56	46
Average	6.10	0.13	0.79	41.86	29.59	55.00

Where, CEC is cation exchange capacity

4.3.2 Experimental design and treatments

The experimental design was a randomized complete block with a split-split plot arrangement and replicated three times. The subplot measured 3 m by 3 m while the total area covered by the experiment was 1596 m^2 with 2 m between blocks and 1 m between plots. The study involved three factors namely: plant spacing, variety and irrigation regime. The plant spacing treatments comprised 15 x 15 cm, 20 x 15 cm, 25 x 15 cm and 30 x 15 cm; varieties comprised Basmati 370, Saro 5 and IR 2793-80-1; and irrigation regimes comprised intermittent flooding and continuous flooding. Variety Basmati 370 and IR-2793-80-1 are locally grown varieties while Saro 5 is an improved and recently released variety. Table 4.2 shows the main characteristics of the varieties tested in the current study. Two irrigation schedules were applied: continuous and intermittent/ controlled flooding. Continuous flooding involved maintaining 5 cm depth of water in the field while water was only refilled when the water level in the field dropped to below 1 cm in the intermittent flooding treatment. Irrigation schedules were assigned to the main plots, variety to sub-plots and spacing to the sub sub-plots. Each main plot was surrounded by bunds lined with 0.5 m deep plastic sheets to prevent seepage of water and 2 m wide channels for irrigation.

Table 4.2: The main characteristics of rice varieties tested in the study

Variety	Origin	Characteristics
BASMATI 370	Kenya	Aromatic, high yielding, fast cooking, high elongation ratio, has a yield potential of 3-5 t/ha (Republic of Kenya, 2008) and early maturing (120 days) (Chandi, 2008).
IR 2793-80-1	Kenya	Non-aromatic, late maturing (135 days), has a yield potential of (6-10 ton/ha) and is susceptible to most diseases and pests (Nyang'au 2014).
TDX 360 (Saro 5)	Tanzania	Early maturing (120 days), semi-aromatic, high yielding potential (8-10 ton/ha), moderate resistance to diseases such as leaf blast and bacterial leaf blight (IRRI,2013: MOA, 2011)

4.3.3 Crop establishment and maintenance

Land preparation was done by first flooding the fields for three days, then puddling to soften and mix the mud (Wanjogu *et al.*, 1995). A nursery of 1 m by 2 m for each of the three varieties was prepared. The nursery was watered daily, except on days when there was rainfall, to keep the soil saturated but not flooded. The nursery was adjacent to the main experimental field for transplanting to be performed quickly to minimize stress for the young plants (WBI, 2008). Twenty one day old seedlings were transplanted at a rate of one seedling per hill for all the plant spacing. Plots received the same basal fertilizer supply of 46 kg P_2O_5/ha as triple super-phosphate and 60 kg K_2O/ha as muriate of potash one day before transplanting. All plots received an additional 120 kg/ha of sulphate of ammonia with split applications of 1:2:2 at 10, 30 and 60 days after transplanting as elaborated by Wanjogu *et al.*, (1995). Mechanical weeding (hand weeding) was used to control weeds effectively and provide aeration to the soil. Plots were hand weeded three times during the vegetative stage (twice) and reproductive stage (once). Water was supplied through a concrete channel to the main plots and subsequently up to the sub sub-plots. Each main plot was irrigated separately and a water depth level of 5 cm was maintained in the continuously flooded plots while water was added only after the water level reached a depth of less than 1 cm in the intermittently flooded plots. All plots were drained two weeks before harvesting to promote ripening of the grain and harden the soil for effective harvesting.

Water saved was calculated as follows (Bouman *et al.*, 2001):

$$\text{Water saved (\%)} = \frac{\text{water applied in CF plot} - \text{water applied in IF plot}}{\text{Water applied in CF plot}} \times 100$$

Where: CF and IF are continuous flooding and intermittent flooding, respectively. The unit for water applied was cubic meters (m^3).

Water saved by using intermittent flooding was 44.4% (Appendix 3).

4.3.4 Data collection

Data was collected according to the standard evaluation system of rice (IRRI 2002) using a transect line of 10 plants that were retained for the whole season. Data collected included: plant height (cm), number of total tillers, number of effective tillers, days to maturity for each variety, panicle length, grain yield adjusted to 14% moisture content and 1000-grain weight.

Plant height was measured using a metre rule from the base of the plant to the tip of the tallest plant at 35, 45, 55 and 75 days after transplanting and at harvesting stage. The number of tillers at 35, 45, 55 and 75 days after transplanting and at harvesting stage was determined by visual counts. Days to 50% flowering was determined by averaging the number of days it took for half of the plants in the plot to flower. Panicle length was measured as the length from the base of the panicle to the tip of the last grain at the top of the panicle using a 30 cm rule (Surajit, 1981).

Ten hills in each plot were randomly marked at the time of planting and number of tiller per plant counted periodically at intervals of 10 days up to the panicle initiation stage. All the panicles from one of the 10 plants in each plot were clipped and put in a separate paper for counting. The process of harvesting involved cutting the rice plants using a sickle at 15 cm above the ground and threshing the rice immediately on a mat (IRRI, 1978). In order to get a good estimate of grain yield by minimizing grain damage and quality deterioration, the threshing was done immediately following Surajit (1981) guidelines. Grains were dried after harvesting and moisture content measured using a moisture meter. Grain weight was adjusted to 14% grain moisture content. One thousand grains were counted using a 1000 grain counter and their weight was taken using a sensitive weighing scale.

4.5 Data analysis

Data collected were subjected to analysis of variance using Genstat 15th edition and treatment means were compared using the least significant difference (LSD) test at p=0.05.

4.6 Results

4.6.1 Effect of variety, plant spacing and irrigation regimes on rice plant height

Varieties of rice were significantly different in plant height in both seasons at all stages of growth (Table 4.3). Basmati 370 had significantly taller plants than Saro 5 and IR-2793-80-1 at all stages of growth. There were no significant differences in plant height between Saro 5 and IR-2793-80-1 except at maturity in the first season where Saro 5 had significantly taller plants than IR-2793-80-1. The average plant height at maturity ranged from 83.8 (IR-2793-80-1) cm to 135.1 cm (Basmati 370) and 58.9 cm (IR-2793-80-1) to 103.4 cm (Basmati 370) in season one and two, respectively.

Table 4.3: Effect of variety on rice plant height (cm) at different growth stages at Mwea Irrigation Scheme

Season 1				
Variety	35 DAT	55 DAT	75 DAT	Maturity
Basmati 370	56.8	79.1	110.9	135.1
Saro 5	44.7	58.1	76.5	98.0
IR 2793-80-1	43.0	53.0	67.9	83.8
p-value	<.001	<.001	<.001	<.001
LSD (p=0.05)	4.8	6.0	11.7	11.2
CV (%)	7.4	7.2	10.4	8.0
Season 2				
Basmati 370	32.6	52.0	73.7	103.4
Saro 5	27.2	35.8	51.0	62.7
IR 2793-80-1	26.3	34.3	48.3	58.9
p-value	<.001	<.001	<.001	<.001
LSD (p=0.05)	1.8	2.5	2.7	6.8
CV (%)	4.7	4.6	3.5	6.8

Where, DAT is days after transplanting,

Plant spacing did not have a significant effect on plant height in both seasons at all stages of growth (Table 4.4). Mean plant height ranged from 103.7 cm (15 × 15 cm) to 106.4 cm (20 × 15 cm) in the first season and 74.4 cm (15 × 15 cm) to 75.3 cm (30 × 15 cm) in the second season.

Table 4.4: Effect of plant spacing on rice plant height (cm) at different growth stages at Mwea Irrigation Scheme

Season 1				
Spacing	35 DAT	55 DAT	75 DAT	Maturity
15 cm× 15 cm	47.2	63.7	83.7	103.7
20 cm× 15 cm	48.7	65.2	87.4	106.8
25 cm× 15 cm	50.4	63.3	85.0	105.6
30 cm× 15 cm	46.4	61.4	84.3	106.4
p-value	0.356	0.446	0.572	0.57
LSD (p=0.05)	NS	NS	NS	NS
CV (%)	14.7	10.7	9.8	6.7
Season 2				
15 cm× 15 cm	29.7	39.9	55.9	74.4
20 cm× 15 cm	29.0	40.2	57.4	74.9
25 cm× 15 cm	29.3	41.1	58.6	75.4
30 cm× 15 cm	26.8	41.7	58.7	75.3
p-value	0.098	0.087	0.09	0.877
LSD (p=0.05)	NS	NS	NS	NS
CV (%)	12.8	5.5	6.1	5.5

Where, DAT is days after transplanting

Irrigation regime did not significantly affect plant height in both seasons at all stages of growth (Table 4. 5). However, the height progressively increased during the growth stages in both seasons. Mean plant height ranged from 104 cm (intermittent flooding) to 107.2 cm (continuous flooding) in the first season and 74 cm (intermittent flooding) to 76 cm (continuous flooding) in the second season.

Table 4.5: Effect of irrigation regime on height (cm) at different growth stages at Mwea Irrigation Scheme

Season 1				
Regime	35 DAT	55 DAT	75 DAT	Maturity
IF	47.3	61.6	82.9	104.0
CF	49.0	65.2	87.2	107.2
p-value	0.512	0.195	0.097	0.285
LSD (p=0.05)	NS	NS	NS	NS
CV (%)	5.7	3.7	2.1	2.5
Season 2				
IF	28.3	41.2	57.7	74.0
CF	29.1	40.2	57.6	76.0
p-value	0.109	0.498	0.964	0.478
LSD (p=0.05)	NS	NS	NS	NS
CV (%)	1.1	3.4	3.3	3.7

Where, DAT is days after transplanting, IF and CF are intermittent flooding and continuous flooding, respectively.

4.6.2 Effect of selected varieties on the number of tillers per plant

The number of rice tillers per plant increased across the growth stages (Table 4. 6). Varieties were significantly different in number of tillers per plant in both seasons. VarietyIR-2793-80-1 had significantly higher number of tillers per plant than other varieties at three stages of growth in both seasons. The average number of tillers ranged from 15.7 to 21.1 in the first season and 20.1 in the second season for Basmati 370 and IR 2793-80-1 respectively.

Table 4.6: Effect of variety on the number of tillers per plant at different growth stages in Mwea Irrigation Scheme

Season 1				
Variety	35 DAT	55 DAT	75 DAT	Maturity
Basmati 370	12.4	18.1	15.6	15.7
Saro 5	16.0	21.6	17.5	16.6
IR 2793-80-1	19.6	27.2	23.6	21.1
p-value	0.007	0.001	<.001	0.007
LSD (p=0.05)	3.8	3.6	3.1	3.1
CV (%)	17.8	12.2	12.2	13.0
Season 2				
Basmati 370	4.1	14.4	19.5	20.1
Saro 5	4.9	17.9	25.1	23.8
IR 2793-80-1	5.8	20.3	32.5	29.1
p-value	<.001	<.001	<.001	0.002
LSD (p=0.05)	0.5	2.1	2.2	3.8
CV (%)	8.4	8.8	6.4	11.6

Where, DAT is days after transplanting.

4.6.3 Effect of plant spacing on the number of tillers per plant

Plant spacing significantly affected the number of tillers per plant in both seasons at all growth stages except at 35 DAT in the second season (Table 4.7). At 35 DAT, 15 × 15 cm plant spacing had a lower number of tillers per plant than 25 × 15 cm and 30 × 15 cm plant spacing treatments in the first season; however, there was no difference in the number of tillers between 15 × 15 cm and 20 × 15 cm plant spacing arrangements and among 20 × 15 cm, 25 × 15 cm and 30 × 15 cm plant spacing treatments. In the first season, at vegetative and reproductive stages, 15 ×15 cm plant spacing had a significantly lower number of tillers per plant than 20 × 15 cm plant spacing which, in turn, had a lower number of tillers per plant than 25 × 15 cm plant spacing. There were no significant differences in the number of tillers per plant between 25 × 15 cm and 30 × 15 cm plant spacing treatment. At the reproductive stage, in the second season, and maturity stage in both seasons, the number of tillers per plant increased significantly with each increase in plant spacing. The average number of tillers per plant ranged from 13 (15 × 15 cm) to 21.6 (30 × 15 cm) in the first season and 18.2 (15 × 15 cm) to 29.4 (30 × 15 cm) in the second season.

4.6.4 Effect of irrigation regime on the number of tillers per plant

Irrigation regime had no significant effect on the number of tillers per plant at all growth stages, except at 75 DAT (reproductive stage) in the second season (Table 4.8). At 75 DAT (reproductive stage) and maturity stage continuous flooding had significantly more tillers per plant than intermittent flooding in the second season. The average number of tillers per plant ranged from 23.7 to 27.7 at 75 DAT and 22.8 to 25.9 at maturity stage in the second season.

Table 4.7: Effect of plant spacing on the number of tillers per plant at different growth stages at Mwea Irrigation Scheme

Season 1				
Spacing	35 DAT	55 DAT	75 DAT	Maturity
15 cm× 15 cm	14.2	16.9	13.9	13.0
20 cm× 15 cm	16.0	21.7	17.8	17.0
25 cm× 15 cm	17.4	24.8	21.3	19.5
30 cm× 15 cm	16.5	25.6	22.5	21.6
p-value	0.035	<.001	<.001	<.001
LSD (p=0.05)	2.1	2.4	2.1	1.7
CV (%)	19.8	16.0	16.8	14.1
Season 2				
15 cm× 15 cm	4.9	13.9	19.3	18.2
20 cm× 15 cm	4.7	17.3	24.7	23.3
25 cm× 15 cm	5.0	19.0	28.0	26.4
30 cm× 15 cm	4.9	19.9	30.6	29.4
p-value	0.643	<.001	<.001	<.001
LSD (p=0.05)	NS	1.8	1.8	2.1
CV (%)	14.4	15.1	10.2	12.5

Where, DAT, 35 DAT, 55 DAT and 75 DAT is days after transplanting, vegetative stage, reproductive stage

Table 4.8: Effect of irrigation regime on the number of tillers per plant at different growth stages at Mwea Irrigation Scheme

Season 1				
Regime	35 DAT	55 DAT	75 DAT	Maturity
IF	15.9	22.0	18.9	18.1
CF	16.1	22.6	18.9	17.5
p-value	0.787	0.537	0.998	0.554
LSD (p=0.05)	NS	NS	NS	NS
CV (%)	6.7	4.8	10.4	5.3
Season 2				
IF	4.7	17.3	23.7	22.8
CF	5.1	17.8	27.7	25.9
p-value	0.228	0.445	0.009	0.013
LSD (p=0.05)	NS	NS	1.7	1.5
CV (%)	5.0	3.4	1.8	1.8

Where, DAT is days after transplanting, IF and CF is intermittent flooding and controlled flooding respectively.

4.6.5 Effect of rice variety on panicle length, number of panicles per plant, net weight and 1000 grain weight

There were significant varietal differences in panicle length in both seasons (Table 4.9). Basmati 370 had significantly higher panicle length than IR-2793-80-1 and Saro 5 in both seasons. However, IR-2793-80-1 had significantly higher panicle length than Basmati 370 in the second season. Panicle length ranged from 22 cm (IR-2793-80-1) to 24.4 cm (Basmati 370).

In both seasons, there were significant varietal differences in the number of panicles per plant. Variety IR-2793-80-1 had significantly higher number of panicles per plant than Saro 5 and Basmati 370 in both seasons. In the first season, IR-2793-80-1 had significantly higher number of panicles per plant than Saro 5 and Basmati 370 while in the second season Basmati 370 had a significantly higher number of panicles per plant than Saro 5. The number of panicles per plant ranged from 12.9 to 18.1 in the first season and 14.3 to 19.1 in the second season.

There were significant varietal differences in net grain yield in both seasons. In the first season, IR-2793-80-1 had significantly higher net grain yield than Saro 5 and Basmati while in the second season Saro 5 had significantly higher net grain yield than IR-2793-80-1 and Basmati. Basmati 370 had significantly the lowest net grain yield in both seasons. Saro 5 and IR 2793-80-1 out-yielded Basmati 370 in both seasons. The net grain yield ranged from 2.1 t/ha (Basmati 370) to 4.8 t/ha (IR-2793-80-1) in the first season and 4.7 t/ha (Basmati 370) to 9 t/ha (Saro 5) in the second season.

Variety had a significant effect on 1000-grain weight in both seasons. In both seasons, Basmati 370 had significantly lower1000 grain weight than Saro 5 and IR-2793-80-1. In the second season, Saro5 had significantly higher 1000 grain weight than IR-2793-80-1, but the two varieties were not significantly different in 1000 grain weight in the first season. A thousand grain weight ranged from 22.4 g (Basmati 370) to 29.3 g (IR-2793-80-1) in the first season and 25.5 g (Basmati 370) to 32.1 g (Saro 5) in the second season.

Table 4.9: Effect of varieties on panicle length, number of panicles per plant, net grain yield and 1000 grain weight

Variety	Panicle length (cm)	No. of panicles/plant	Net grain yield (t/ha)	1000-grain wt. (g)
Season 1				
Basmati 370	24.4	12.9	2.1	22.4
Saro 5	21.9	14.0	4.2	28.8
IR 2793-80-1	22.0	18.1	4.8	29.3
p-value	0.007	0.004	0.003	<.001
LSD (p=0.05)	1.5	2.6	1.2	2.9
CV (%)	4.9	13.0	26.3	8.0
Season 2				
Basmati 370	25.3	12.1	4.7	25.5
Saro 5	21.9	14.3	9.0	32.1
IR 2793-80-1	22.9	18.1	8.0	28.4
p-value	<.001	<.001	<.001	<.001
LSD (p=0.05)	0.9	1.8	0.2	1.1
CV (%)	3.0	7.7	2.9	3.0

Where No and wt is number and weight respectively

4.6.6 Effect of plant spacing on panicle on length, number of rice panicles per plant, net grain yield and 1000-grain weight

Plant spacing did not have a significant effect on rice panicle length in both seasons (Table 4.10). Panicle length ranged from 22.3 cm (15 × 15 cm plant spacing) to 23.2 cm (25 × 15 cm plant spacing) in the first season and 23.1 cm (15 × 15 cm plant spacing) to 23.7 cm (25 × 15 cm plant spacing) in the second season.

The number of rice panicles per plant was significantly affected by plant spacing in both seasons (Table 4.10). Plant spacing of 30 × 15 cm had significantly higher number of panicles per plant than most other plant spacing treatments in both seasons. Each decrease in plant spacing led to a significant decrease in the number of panicles per plant, except for the decrease from 25 × 15 cm to 30 × 15 cm in the first season. The number of panicles per plant ranged from 11.3 (15 × 15 cm) to 18.1 (30 × 15 cm) in the first season and 14.1 (15 × 15 cm) to 20.5 (30 × 15 cm) in the second season.

There were significant differences in net grain yield among the plant spacing arrangements in both seasons (Table 4.10). Plant spacing of 15 × 15 cm had significantly higher net grain yield than 20 × 15 cm, 25 × 15 cm and 30 × 15 cm in the first and second season. Plant spacing of 30 × 15 cm had lower net grain yield than all other plant spacing arrangements in the first season. No significant differences were noted between 15 × 15 cm and 20 × 15 cm in both seasons and between 25 × 15 cm and 30 × 15 cm in the second season. Net grain yield ranged from 3.0 t/ha (30 × 15 cm plant spacing) to 4.3 t/ha (15 × 15 cm plant spacing) in the first season and 6.9 (30 × 15 cm and 25 × 15 cm plant spacing) to 7.6 t/ha (15 × 15 cm and 20 × 15 cm) in the second season (Table 4.10).

Plant spacing significantly affected 1000-grain weight in the second season, but had no effect in the first season. Plant spacing of 30×15 cm resulted in significantly lower 1000 grain weight than plant spacing of 20×15 cm and 15×15 cm. No significant differences were noted among plant spacing treatments of 25×15 cm, 20×15 cm and 15×15 cm.

Table 4.10: Effect of plant spacing on panicle length, number of panicles per plant, net grain yield and 1000 grain weight

Season 1				
Spacing	Panicle length (cm)	No. of panicles	Net grain yield (t/ha)	1000 grain wt (g)
15 cm× 15 cm	22.3	11.3	4.3	26.6
20 cm× 15 cm	23.0	14.2	4.0	26.7
25 cm× 15 cm	23.2	16.5	3.7	26.5
30 cm× 15 cm	22.6	18.1	3.0	27.5
p-value	0.150	<.001	<.001	0.334
LSD (p=0.05)	0.8	1.6	0.5	1.3
CV (%)	5.3	15.7	23.1	7.1
Season 2				
15 cm× 15 cm	23.1	14.1	7.6	29.0
20 cm× 15 cm	23.3	15.8	7.6	29.3
25 cm× 15 cm	23.7	18.2	6.9	28.6
30 cm× 15 cm	23.3	20.5	6.9	27.8
p-value	0.229	<.001	0.002	0.020
LSD (p=0.05)	0.6	1.5	0.4	0.9
CV (%)	3.6	5.3	8.5	4.9

Where, No. and wt refers to number and weight respectively.

4.6.7 Effect of irrigation regime on panicle length, number of panicles per plant, net grain yield and 1000 grain weight

The irrigation regime did not have a significant effect on panicle length, number of panicles per plant and 1000-grain weight in both seasons (Table 4:11). Panicle length ranged from 22.5 cm (intermittent flooding) to 23 cm (continuous flooding) in the first season and 23.3 cm (intermittent flooding) to 23.4 cm (continuous flooding) in the second season. The number of panicles per plant ranged from 14.8 (continuous flooding) to 15.2 (intermittent flooding) in the first season and 16.7 (intermittent flooding) to 17.7 (continuous flooding) in the second season. One thousand grain weight ranged from 26.5 (continuous flooding) to 27.1 (intermittent flooding) in the first season and 28.4 (intermittent flooding) to 28.9 (continuous flooding) in the second season. The irrigation regime had a significant effect on net grain yield in the second season but not in the first season. In the second season, intermittent flooding had significantly higher net grain yield than continuous flooding. Net grain yield ranged from 3.6 t/ha (continuous flooding) to 3.9 t/ha (intermittent flooding) in the first season and 7.1 t/ha (continuous flooding) and 7.3 t/ha (intermittent flooding) in the second season.

Table 4.11: Effect of irrigation regime on panicle length, number of panicles per plant, net grain yield and 1000 grain weight

Season 1				
Regime	Panicle length (cm)	No. of panicles	Net grain yield (t/ha)	1000 grain weight (g)
IF	22.5	15.2	3.9	27.1
CF	23.0	14.8	3.6	26.5
p-value	0.498	0.591	0.282	0.195
LSD (p=0.05)	NS	NS	NS	NS
CV (%)	3.2	4.6	7.4	1.3
Season 2				
IF	23.3	16.7	7.3	28.4
CF	23.4	17.7	7.1	28.9
p-value	0.878	0.305	0.004	0.632
LSD (p=0.005)	NS	NS	0.034	NS
CV (%)	3.7	5.3	0.1	3.2

Where, IF and CF is intermittent flooding and continuous flooding respectively.

4.6.8 Effect of plant spacing × variety interaction on the number of tillers per plant

The main effect of variety and plant spacing on the number of tillers per plant was significant in both seasons (Table 4.12). However, variety and plant spacing interaction significantly influenced the number of tillers per plant in the first season only. In the first season, increase in plant spacing from 15 × 15 cm to 20 × 15 cm and above resulted in a significant increase in tiller number in Basmati 370 and IR-2793-80-1. In variety Saro 5, only 30 × 15 cm had significantly higher tillers per plant than other plant spacing treatment. Basmati 370 had significantly lower tiller numbers than IR-2793-80-1 at all plant spacing arrangements and then Saro 5 at 15 × 15 cm plant spacing. VarietyIR-2793-80-1 had significantly higher tiller numbers than all other varieties in all plant spacing except treatments in 15 × 15 cm. In the second season, mean number of tillers per plant were significantly higher in IR-2793-80-1 than in Saro 5 which, in turn, had higher tiller numbers per plant than Basmati 370. An increase in plant spacing led to a significant increase in the number of tillers per plant.

Table 4.13: Effect of the interaction of plant spacing and variety on number of tillers per plant at the maturity stage in Mwea irrigation scheme

	No. of tillers (Season 1)					No. of tillers (Season 2)				
Variety	15×15	20×15	25×15	30×15	MEAN	15×15	20×15	25×15	30×15	MEAN
Basmati 370	10.4	15.3	17.5	19.6	15.7	15.8	19.2	19.7	25.8	20.1
Saro 5	14.4	15.2	17.0	19.7	16.5	16.0	23.5	27.0	28.8	23.8
IR 2793-80-1	14.2	20.5	24.2	25.7	21.1	22.7	27.4	32.5	33.8	29.1
MEAN	13.0	17.0	19.5	21.6	17.8	18.2	23.3	26.4	29.4	24.3
p-value V	0.007					0.002				
p-value S	<.001					<.001				
p-value V × S	0.032					0.118				
LSD V	3.1					0.6				
LSD S	1.7					0.5				
LSD V× S	3.8					0.9				
CV (%)	14.1					12.5				

4.6.9: Effect of variety × plant spacing interaction on the number of panicles per plant and panicle length

The interaction between plant spacing and variety had a significant effect on the number of panicles per plant at vegetative stage in both seasons (Table 4.13). In the first season, there were no differences among varieties at 15×15 cm plant spacing. At 20×15 cm, 25×15 cm and 30×15 cm plant spacing, variety IR 2793-80-1 had significantly higher number of panicles per plant than Basmati 370 and Saro 5 but there was no significant difference in number of panicles between the latter two. The plant spacing of 30×15 cm had significantly higher number of panicles per plant than 15×15 cm and 20×15 cm. However, 15 × 15 cm plant spacing had significantly lower number of panicles per plant than 20 × 15 cm, 25 × 15 cm and 30 × 15 cm in IR-2793-80-1. Similar observations were made in the second season, except that there were no differences in number of panicles per plant between Basmati 370 and IR-2793-80-1 at 20 × 15 cm and 25 × 15 cm.

The interaction between variety and spacing had a significant effect on panicle length in the second season but not in the first season (Table 4.14). In the second season, variety Basmati 370 had significantly higher panicle length than Saro 5 and IR-2793-80-1 in the four plant spacing arrangements. No significant differences were noted in panicle length between Saro 5 and IR-2793-80-1 at plant spacing of 15 × 15 cm, 20 × 15 cm and 25 × 15 cm. However, IR-2793-80-1 had higher panicle length than Saro 5 at a plant spacing of 30 × 15 cm.

Table 4.143: Effect of interaction between variety and plant spacing on the number of panicles per plant at Mwea Irrigation Scheme

	Panicle number (season 1)					Panicle number (season 2)				
Variety	15×15	20×15	25×15	30×15	MEAN	15×15	20×15	25×15	30×15	MEAN
Basmati 370	9.4	11.6	14.1	16.7	12.9	15.6	16.8	19.9	24.3	19.2
Saro 5	12.1	13.1	14.4	16.3	14.0	13.4	13.1	14.4	16.3	14.3
IR 2793-80-1	12.3	17.9	21.0	21.2	18.1	13.3	17.7	20.4	20.8	18.1
MEAN	11.3	14.2	16.5	18.1	15.0	14.1	15.9	18.2	20.5	17.2
p-value V	0.004					<.001				
p-value S	<.001					<.001				
p-value V × S	0.053					0.009				
LSD (V)	2.6					1.8				
LSD (S)	1.6					1.5				
LSD (V× S)	3.3					2.8				
CV (%)	15.7					13.2				

Table 4.154: Effect of the interaction between variety and plant spacing on panicle length

	Panicle length (season 1)					Panicle length (season 2)				
Variety	15×15	20×15	25×15	30×15	MEAN	15×15	20×15	25×15	30×15	MEAN
Basmati 370	23.4	24.9	24.7	24.6	24.4	24.9	24.9	26.0	25.3	25.3
Saro 5	21.8	22.5	22.4	20.9	21.9	21.8	22.5	22.4	20.9	21.9
IR 2793-80-1	21.6	21.6	22.3	22.5	22.0	22.7	22.5	22.7	23.7	22.9
MEAN	22.3	23.0	23.2	22.6	22.8	23.1	23.3	23.7	23.3	23.4
p-value V	0.007					<.001				
p-value S	0.15					0.229				
p-value V × S	0.194					0.005				
LSD (V)	1.5					0.9				
LSD (S)	0.8					0.6				
LSD (V× S)	1.8					1.2				
CV (%)	5.3					3.6				

4.6.10: Effect of irrigation regime, variety and spacing interaction on panicle length

The interaction of regime, variety and plant spacing had a significant effect on panicle length in the second season. In most cases, Basmati 370 had significantly higher panicle length than IR-2793-80-1 and Saro 5 at 15 × 15 cm, 25 × 15 cm and 30 × 15 cm under both intermittent and continuous flooding. No significant differences between Saro 5 and IR-2793-80-1 in both intermittent and continuous flooding except at 30 × 15 cm where IR-2793-80-1 had significantly higher panicle length. Decrease in plant spacing had no significant effect on Basmati 370 and IR-2793-80-1 panicle length under both intermittent and continuous flooding. Increase of plant spacing to 30 × 15 cm led to a significant decline in panicle length of Saro 5 under continuous flooding conditions.

Table 4.16: Effect of the interaction of regime, variety and spacing on panicle length

		Panicle length (season 1)				Panicle length (season 2)			
Regime	variety	15×15 (cm)	20×15 (cm)	25×15 (cm)	30×15 (cm)	15×15 (cm)	20×15 (cm)	25×15 (cm)	30×15 (cm)
IF	Basmati 370	22.7	24.4	24.5	24.3	25.3	24.7	26.1	25.2
	Saro 5	21.3	22.1	21.4	21.8	21.3	22.1	21.4	21.8
	IR 2793-80-1	21.5	21.3	22.6	22.5	22.8	22.8	23.0	23.0
CF	Basmati 370	24.2	25.4	25.0	25.0	24.5	25.1	26.0	25.4
	Saro 5	22.4	22.8	23.5	19.9	22.4	22.8	23.5	19.9
	IR 2793-80-1	21.7	21.9	22.1	22.4	22.5	22.2	22.3	24.3
	MEAN	22.3	23.0	23.2	22.6	23.1	23.3	23.7	23.3
	p-value V	0.007				<.001			
	p-value S	0.15				0.229			
	p-value V × S	0.194				0.005			
	p value R×V×S	0.4				0.004			
	LSD V	1.5				0.9			
	LSD S	0.8				0.6			
	LSD V× S	1.8				1.2			
	LSD R×V×S	2.6				2.5			
	CV (%)	5.3				3.6			

Where; IF, CF, R, V and S refers to intermittent flooding, continuous flooding, regime, variety and plant spacing respectively.

4.7 Discussion

Plant spacing did not have a significant effect on plant height at all growth stages. Om *et al*., (1993) reported that plant spacing of 30×15 cm produced taller plants than plant spacing of 15×15 cm. There was an increase in number of tillers with increase in plant spacing in both seasons. This is supported by similar studies by several authors (Srinivasan, 1990; Shah *et al*., 1991; Patra and Nayak, (2001). For example, Patra and Nayak (2001) reported that rice crop of spacing 20 × 15 cm produced more tillers per hill than rice crop of spacing 15 × 15 cm. Plant spacing 25 × 15 cm had the highest panicle length in both seasons. This implies that at wider plant spacing the panicle length increases because there is less competition of nutrients (Onyango *et al*., 2014). Plant spacing of 30 × 15 cm had significantly higher number of panicles per plant than other plant spacing treatments in both seasons. Padmaja and Reddy (1998) observed that significantly more panicles were produced per m^2 with rice crop planted at 15 × 15 cm plant spacing than rice crop planted with 20 × 15 cm plant spacing. Plant spacing of 15 × 15 cm had significantly higher net grain yield than the other spacing arrangements in both seasons. This concurs with a study by Bhowmik *et al*., (2012) who found out that plant spacing of 15 × 15 cm had the highest grain yield and 25 × 15 cm plant spacing had the lowest grain yield. Nyang'au *et al*., (2014) also reported that 15 × 15 cm plant spacing proved beneficial to Mwea farmers practicing intermittent flooding as it yielded 6t/ha. This study contradicts the findings of Hamid *et al*., 2011 and Naser *et al*., (2011) who found that the highest grain yield of 3.4t/ha was obtained from plant spacing of 30 × 15 cm and lowest grain yield of 3.2 t/ha from 15×15 cm. Mohapatra *et al*., (1989) also reported that 30 × 15 cm plant spacing was better than 15 cm ×15 cm plant spacing under normal soil for rice production. Proper plant spacing ensures good water management (Maclean *et al*., 2002) and photosynthetic activities and assimilate partitioning, thereby resulting in good yield in well-spaced rice fields. This implies that plant spacing linearly affect performance of individual plants because of the area around to draw nutrients and have more water solar radiation to absorb for better photosynthetic activity (Baloch *et al*., 2002).

Variety Basmati 370 had higher plant height and panicle length than Saro 5 and IR-2793-80-1. Hasanuzzaman *et al*. (2009) reported that Basmati 370 has a higher elongation ratio thus tends to grow taller than other varieties when good growing conditions are provided. Variety IR-2793-80-1 had higher number of tillers per plant and panicles per plant than Basmati 370 and Saro 5. Variety IR-2793-80-1 and Saro 5 had higher net grain yield and one thousand grain weight in the first season and second season, respectively. Basmati 370 had the lowest net grain yield compared to IR-2793-80-1 and Saro 5. This concurs with Li et al., (2000) who reported that tillering determines the number of panicles, grains and grain yield per unit of land area. This implies that plant height, panicle numbers, number of tillers per plant and other yield components affect net grain yield irrespective of variety. Variety Saro 5 which is a recently released variety should be promoted for cultivation by farmers due to its high yields. Net grain yield and one thousand grain weight decreased with increase in spacing in both seasons. Net grain yield for Basmati 370 was 2.1 t/ha and 4.7 t/ha in first and second season respectively. This concurs with yields for Basmati 370 in Mwea Irrigation Scheme that are normally 3-5 t/ha (Republic of Kenya, 2008).

Irrigation regime didn’t have significant effects on plant height and number of tillers per plant. Yang *et al*., (2002) found that maximum tillering stage, number of tillers per hill in all varieties was higher in the intermittent irrigation rather than in continuous flooding. Intermittent flooding had significantly higher net grain yield than continuous flooding. In 31 field experiments analyzed by Bouman and Toung (2001), 92% of the intermittently flooded treatments resulted in yield reductions compared to those continuously flooded. In the current study, intermittent flooding saved 44.4% of irrigation water compared to continuous flooding. This concurs with a study by Fonteh and Assoumou, (2013) who reported that 20-47 % of water under continuous flooding could be saved by adoption of intermittent flooding at 3-5 cm. Keisuke *et al*., (2007) also recorded reductions in irrigation water by 40-70%, while increasing yields under alternate wetting and drying (intermittent flooding) compared to continuous flooding of rice crop. Intermittent and continuous flooding did not have a significant effect on yield and yield components perhaps due to the floods experienced during the time of experiment hence making it hard to control flooding in the paddy fields. Each of the two growing seasons in Mwea Irrigation Scheme experienced two very wet months (452.9 mm in April-May and 563.2 mm in October-November 2015) during the experimental period (Appendix 2), which made it difficult to maintain intermittent flooding throughout the season. Ndiiri *et al*., 2013 reported that water saving through intermittent flooding gave yield increase by 0.6 t/ha and 1.5 t/ha for Basmati 370 and IR 2793-80-1 respectively. Mostafazadeh-Fard *et al*., (2010) reported that decreasing the depth of ponded water on the soil surface in irrigated rice reduced the water use by 23%. The use of modern irrigation techniques like intermittent flooding can also lead to water savings of more than 50% (Bouman *et al*., 2005). This implied that intermittent flooding is important in maintaining the sustainability of rice production (Arif *et al*., 2012). Due to climate change there has been reduced amount of rainfall making it difficult for farmers to have crop in the field due to lack of water saving skills.

Variety and spacing interaction significantly affected the number of tillers and panicles per plant in both seasons while panicle length was only significantly affected in the second season. At 20×15 cm, 25×15 cm and 30×15 cm plant spacing, variety IR 2793-80-1 had significantly higher number of panicles per plant than Basmati 370 and Saro 5. This concurs with results by Naser *et* *al*., (2011) who found interaction effects of plant spacing on grain yield, panicle length and 1000-grain weight significantly different with the highest amount of grain yield, panicle length and number of tillers found in plant spacing of 15 × 15 cm and lowest in plant spacing of 25 × 25 cm. According to Hamid *et al* ., (2011) interactions of plant spacing and variety on grain yield had significant differences, highest grain yield was obtained from plant spacing of 20 × 20 cm (3612 kg/ha) and lowest from plant spacing of 15 × 15 cm. Interaction between irrigation regime, variety and spacing had no significant effect on panicle length in season two. Baloch *et al*., (2002) reported that low yields were as a result of wider spacing that allowed more tillers per plant and less number of hills per unit area. This implies that combination of two favorable growth parameters is likely to improve the yields of rice varieties.

4.8 Conclusions

Plant spacing of 15× 15 cm had the highest net grain yield in both seasons. This study has shown that Saro 5 and IR-2793-80-1 had the highest net grain yield in both seasons. Intermittent flooding recorded higher net grain yield than continuous flooding in both seasons. This study has therefore demonstrated that cultivation of the recently introduced variety Saro 5 and intermittent flooding have the potential to improve rice productivity in Mwea Irrigation Scheme.

CHAPTER FIVE: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion

All farmers from the survey preferred transplanting one-month old seedling at a depth of 2 cm at the rate of two seedlings per hole. Transplanting ensures uniform stands of the crop in the field, one month old seedlings are strong enough to survive the shock involved with transplanting and 2 cm depth of planting ensures maximum support of the seedling. Two seedlings are used by farmers to ensure maximum survival in case one seedling dies after transplanting. The major plant spacing used by farmers in Mwea was 30×15 cm and 20×20 cm. Bigger plant spacing promotes more tillers per plant which is directly proportional to yield. Irrigation of rice fields was done once a week and was drained two weeks before harvesting. This was to maintain a continuously flooded field which is the practice in the scheme and draining was done to promote grain filling and ripening and also allow drying of soil for easier movement during harvesting.

Plant spacing of 15× 15 cm had the highest net grain yield in both seasons IR-2793-80-1 and Saro 5 had highest number of tillers and panicles and net grain yield in the first and second season respectively. This implies that the yield and yield components are determined by variety. Higher net grain was achieved under intermittent flooding than in continuous flooding. This implies that it is possible to achieve maximum yield under same area while saving water. Net grain yield ranged from 3.6 t/ha (continuous flooding) to 3.9 t/ha (intermittent flooding) in the first season and 7.1 t/ha (continuous flooding) and 7.3 t/ha (intermittent flooding) in the second season. Plant spacing of 30 ×15 cm had the highest number of tillers while closer plant spacing of 15 × 15cm had the highest amount of yield. This implies that the number of tillers per plant was not directly proportional to amount of net grain yield.

5.2 Conclusions

The findings of the survey showed that transplanting of one-month old seedlings at a plant spacing of 30×15 cm irrespective of the rice variety was preferred by almost all the farmers interviewed. Majority of the farmers in the scheme irrigated the fields once a week to a depth of ≤10 cm and drained fields two weeks before harvesting. Results revealed that plant spacing and number of seedlings hill-1 have considerable role in increasing yield of rice. Therefore, it can be concluded that spacing 15 cm × 15 cm with two seedlings hill-1 appears as the best combination to obtain maximum grain yield.

The results showed that Basmati 370 had significantly taller plants and lower net grain yield and yield components than Saro 5 and IR-2793-80-1. Plant spacing of 15× 15 cm had the highest net grain yield in both seasons. Intermittent flooding recorded higher net grain yield than continuous flooding. By applying appropriate irrigation management in rice cultivation, a large volume of water can be saved (44.4% saving) which would help bring more land under cultivation using the same available amount of irrigation water.

5.3 Recommendations

On basis of the present study findings, the following recommendations are made:

1. Given that this study has been conducted in only one irrigation scheme and using only three varieties, there is need to conduct a similar study with a wide range of varieties in on-station and farmer managed irrigated fields across the main irrigation schemes in Kenya.
2. Given that there was a lot of rain in the second season, a similar study needs to be carried out over many seasons and across the main irrigation schemes in Kenya to validate the yield benefits from intermittent flooding.
3. It is advisable for farmers in Mwea Irrigation Scheme to adopt a plant spacing of 15×15 cm together with good agronomic practices to improve rice productivity.
4. Variety Saro 5 can be promoted to farmers across Mwea Irrigation Scheme because it exhibited high yields.

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APPENDICES

Appendix 1: **Survey Questionnaire**

PLANT SPACING AND INTERMITTENT WATER MANAGEMENT IN LOWLAND RICE PRODUCTION, MWEA

General objective: To study the farmer's management on plant spacing and intermittent flooding on growth and yield of lowland rice varieties in Mwea Kenya.

Specific objectives

1. Document plant spacing and plant populations used by farmers
2. Document farmers' irrigation and moisture management practices
3. Document status of major weeds and control measures
4. To ascertain which cultural measures the farmers use to maintain moisture in their farms

Name of respondent………………………………Section……………………………….

Phone number………………………… Date of interview……………………………

Interviewer's name……………………………………Phone number………………………

1. What is the size of your landholding in acres? ________________________

   1 acre= 100 m × 40 m

2. How much yields do you get from 1 above in a season? ....

3. What method of planting do you use at your rice farm?

   1 **Transplanting** ☐

   2 **Direct seeding** ☐

4. If your answer is transplanting, what is usually the age of your seedlings?

   1) ≤2 weeks ☐ **2) 3 weeks** ☐ **3)1 month** ☐ **4)>1 month** ☐

5. For how long have you grown rice at your farm?

1) ≤5 years ☐ **2) 6-20 years** ☐ **3) ≥20 years** ☐

6. How often do you irrigate your field in a week?

1 Once a week ☐

2 Once in two weeks ☐

3 Once a month ☐

99 Others (specify) ☐

7. At what stages do you irrigate?

1 The entire growing period ☐ **2 Up to a certain stage of development** ☐

99 Others (Specify) ________________

8. Do you drain your field?

1 Yes ☐ **2 No** ☐

9. How do you know when to irrigate?

1 Previous knowledge of rice ☐ **2 irrigation field water level** ☐

3 Crop physical appearance ☐ **99 Others (Specify) ________________**

10. To what depth do you irrigate your field?

1) **≤10 cm** ☐ **2) ≥10 cm** ☐

11. What plant spacing do you use?

1)15*15 cm ☐ **2)20*15 cm** ☐ **3)20*20 cm** ☐ **4)25*15 cm** ☐

5)30*15 cm ☐ **99) Others (Specify) ________________**

12. Why the choice of the spacing?

1) To increase yield ☐ **2) Ease of crop management** ☐ **3) Control weeds** ☐

4) Increase the number of tillers ☐ **99) Others (Specify) ________________**

13. How many seedlings do you plant per hole?

1)1 ☐ **2) 2** ☐ **3)>2** ☐ **99) Others (Specify) ________________**

14. What is the depth (cm) of transplanting? ....

15. Have you ever carried out a soil test at your farm?

1) No ☐ **2 Yes** ☐

16. Name the three most challenges encountered in crop production. (Start with the most)

i. ……………………………………

Appendix 2: Weather data for Mwea Irrigation Scheme during January to December 2015

Month	**Rainfall/mm**	**Max/^{0}C**	**Min/^{0}C**	**W/Days**
Jan	0.8	32.4	10.0	1
Feb	33.2	34.2	12.8	2
Mar	24.5	34.4	13.0	6
Apr	286.9	33.8	17.0	18
May	166.6	29.6	15.0	17
Jun	28.2	28.6	12.5	6
Jul	17.0	29.2	12.0	7
Aug	8.5	29.8	10.0	7
Sep	0.0	32.6	12.2	0

Oct	189.1	34.0	14.6	15
Nov	374.1	29.6	15.2	23
Dec	115.7	29.8	13.6	12

Where, MAX, MIN, W/DAYS is, Maximum temperature, Minimum temperature, and Wet days, respectively.

Appendix 3: Calculations of water saved through intermittent flooding

Water saved was calculated as follows:

$$\text{Water saved (\%)} = \frac{\text{water applied in CF plot} - \text{water applied in IF plot}}{\text{Water applied in CF plot}} \times 100$$

Where: CF and IF are continuous flooding and intermittent flooding, respectively.

Volume of water applied in continuously flooded plots = (15 m × 11 m) × 0.05 m= 8.25 m^3

= 8.25 m^3 × 1000

= 8250 litres

Volume of water applied in intermittently flooded plot was 8250 liters but was only filled again after 5 days; therefore, in one day an intermittent plot used approximately 1650 litres of water.

In 5 days, the volume of water applied in continuously flooded plots = 8250 – 1650 = 6600 litres

= 8250+ 6600

= 14850 litres

Where, 8250 litres is assumed to be consumed in both continuous and intermittent plots in a period of 5 days and 6600 litres of the 8250 litres applied in the continuously flooded plots remain unused on a daily basis. The season lasted for four months and water was only drained in the last 2 weeks; therefore, water was added to the intermittent plots approximately 21 times in those four months. In four months, continuous flooded plots applied 311850 litres (14850 × 21) while intermittent flooded plots applied 173250 litres (8250 × 21).

$$\text{Water saved (\%)} = \frac{311850 - 173250}{311850} \times 100$$

$$= 44.4\ \%$$