EFFECT OF DIRECT SEEDING AND TRANSPLANTING ON GROWTH AND YIELD OF SELECTED RICE (*Oryza sativa* L.) VARIETIES ON RAIN-FED AND IRRIGATED LOWLANDS OF KENYA

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DECLARATION

This thesis is my original work and no part of this work has been presented for the award of a degree or examination in any other university

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DEDICATION

A special dedication to my family for their unwavering support through prayers and encouragement throughout the entire study period, and to all individuals who make an extra effort towards improvement in sustainable food productivity.

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ABSTRACT

Constraints to optimal rice productivity in Kenya include shortage of water, unavailability of affordable labour, inappropriate agronomic practices in establishment like spacing, plant nutrition, weeds, diseases and insect pests. About 95% of rice production in Kenya is grown under irrigation where farmers raise seedlings in nurseries before transplanting to the main fields. Irrigated rice requires large amounts of water for field operations, subject farmers to drudgery during transplanting and also incurs extra costs in nursery and transplanting. A better understanding of a cost effective method of crop establishment of improved rice varieties will save on labour, reduce associated drudgery and also reduce amount of water wasted in flooded conditions without compromising on grain yields. Previous studies have not clearly stated comparisons between direct seeding and transplanting for rain-fed and irrigated rice varieties on lowland conditions. An experiment was conducted at Ahero and Mwea to assess the effect of direct seeding (DS) and transplanting (TP) method of crop establishment on growth and yield of four rain-fed (NERICA 1&4, Komboka, MWUR4) and four irrigated (SARO5, Komboka, NIBAM 11, MWIR 2) rice varieties, during main rice cropping season between July 2017 and January 2018 on Kenyan lowland environment. The trials objectives were to assess the effect of direct seeding and transplanting on crop growth and yield of rain-fed and irrigated rice varieties, in addition to labour saving practices during establishment. Design used was a randomized complete block design (RCBD) with treatments on a split plot arrangement, three replicates, with establishment method as main plot (4m x 3m) and variety as subplot. Three (3) seeds hill^{-1} were dibbled and later thinned to one on DS plots while one seedling was transplanted on TP plots. Spacing 20cm x 15cm for both direct seeded and transplanted plots was used. Data was subjected to analysis of variance (ANOVA) and separation of means using protected LSD at 5% probability level whenever there was significant difference. Results on rain-fed varieties for plant height, number of productive tillers hill^{-1}, days to flower onset, and number of unfilled grains hill^{-1} were not significantly ($P > 0.05$) effected by method of crop establishment though significant ($P < 0.05$) effects were confirmed across varieties and on site location on these crop factors. Grain yield (t ha^{-1}) and thousand seed weight (g) means were not significantly $P > 0.05$) affected by method of crop establishment, site location and across varieties. However, Komboka (5.3 t ha^{-1}) and MWUR4 (4.6 t ha^{-1}) were highest and lowest respectively on grain yield among rain fed varieties. Irrigated varieties recorded significant ($P < 0.05$) differences in number of productive tillers hill^{-1} and days to flower on set under direct seeding and transplanting. Significant variations also existed on plant height, number of productive tillers hill^{-1}, number of unfilled grains hill^{-1}, 50% and 100% days to flower onset across the sites and among tested varieties. In contrast, grain yield (t ha^{-1}) and 1000 seed weight (g) were statistically ($P > 0.05$) similar and not influenced by method of crop establishment and similarly not affected among tested varieties and across the sites. Nevertheless, MWIR2 had highest grain yield mean at 6.3 t ha^{-1} and lowest mean was on NIBAM 11(4.8 t ha^{-1}) among irrigated varieties. Total variable costs were higher on transplanted (KES 84,850) compared to direct seeded (KES 60,300) crop. Although direct seeding method of crop establishment yielded lower compared to transplanting, on both rain-fed and irrigated varieties, savings on variable costs would motivate its wide adoption. Rain-fed Komboka and irrigated MWIR2 exhibited better growth and yield factors and thus would be recommended for Mwea and Ahero lowlands.

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LIST OF ACRONYNMS

CAN	Calcium Ammonium Nitrate
DAS	Days after sowing
DS	Direct seeding
DSR	Direct Seeded Rice
ERA	Economic Review of Agriculture
FAO	Food and Agricultural Organization of the United Nations
IRRI	International Rice Research Institute
KALRO	Kenya Agricultural and Livestock Research Organization
MOA	Ministry of Agriculture
NERICA	New Rice for Africa.
NIB	National Irrigation Board
SRI	System of Rice Intensification
SSA	sub-Saharan Africa
TP	Transplanting
TPR	Transplanted Rice
USAID	US-Aid on International Development
WARDA	West African Rice Development Association.

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Rice is an extensively grown crop in sub-Saharan Africa (SSA), whose grains importance has continued to increase both as a staple food as well as for food security measures (Seck *et al*., 2012). This has necessitated an increase in production due to consumer preference for rice coupled with an estimated global population growth of 4% per annum (Africa Rice Center, 2008; Kijima *et al*., 2006)**.** The crop is grown under irrigated lowlands, rain-fed upland and rain-fed lowland conditions. Rain-fed and irrigated lowlands comprised 64% of the total area under rice in SSA and covered 73% of the total production while production was estimated at 1.9 t ha^{-1} in rain-fed and 2.2 t ha^{-1} in irrigated lowlands (Diagne *et al*., 2013). Nevertheless, previous trials on NERICA rice varieties proved that high yields of 5.4 t $ha^{-1}$and 6 t ha^{-1} are achievable under ideal conditions of Nigeria and Ethiopia, respectively (Seyuom *et al*., 2011). Rice is the third most important cereal crop in Kenya after maize and wheat and forms a major part of diet for the urban populations as well as increased popularity in the rural areas. Household consumption surveys reveal that urban consumers on lower incomes tend to spend greater share of their total budget on rice than higher income households (AfricaRice, 2013), thus eliminates the perception of rice being a luxury food commodity but rather equally a key source of calories for low income households.

Due to the increasing demand for rice, there is urgent need to increase productivity despite continued increase in variable costs of production in terms of labor and farm inputs, coupled with a decline in production resources of water and land. Previous studies indicated that there was an annual average of 1% global decrease in rice, thus not adequate to meet the rising demands (Nguyen and Ferrero, 2006). Rice production decreased by 10.4 % between 2013 and 2014 (ERA, 2015, creating a major gap in demand that led to importation of rice to meet the deficit. An improvement on rice production levels will consequently ensure food security, increase smallholder farmers' income, and reduce the country's import bill on rice.

1.2 Problem Statement

Rice production is far below the demand where deficit is met through imports (Mati *et al.*, 2011). This means that there exists a production gap which requires to be met in order to keep pace with consumption demand due to increasing population. Existing deficit of rice grain is met through importation as reported by the global agricultural information network (2015) that rice consumption was estimated at 1.18 million tons compared to production estimates of 126,400 tons. Prevailing scenario is that the land potential suitable for production of irrigated rice in Kenya is about 540 000 ha but with only 19.4 % of this total area was under paddy rice cultivation (MoA, 2008). The increase in expenditure on imports is attributed to production decline that results to a wider gap between demand and production levels (MoA, 2009). Constraints to rice production in Kenya are water shortages, unavailability of good quality seeds at the right time and place, limited farmer knowledge on appropriate agronomic practices throughout the cropping season, declined soil fertility, high price of inputs and low market prices, labour shortages and land ownership systems (Emong'or *et al.*, 2009) and (Onyango, 2014)

Direct seeding of rice is gaining popularity owing to the varied constraints linked to rice establishment through transplanting. Higher yields have been reported by direct seeding of rice compared to transplanting (IRRI, 1991; Adair *et al*., 1992). Direct seeding is also being practiced in many developed countries where labour is scarce and expensive. Transplanting shock in young seedlings delayed tillering by 15 days, in addition to, delayed crop establishment, reduce number of tillers and leaf area (Dingkuhn *et al.*, 1990). Manual transplanting is also linked to high labour costs and uneven plant population and thus becomes a major constraint to achieving potential yields. Labour scarcity is more common in rice farms especially during the peak seasons of land preparation, sowing and harvesting. Direct seeding as an establishment method for rice saves labour by up to 50%, reduce low plant density risk and saves water (Pandey and Velasco, 1999). Labour shortage at time of planting may result to delayed planting and consequently affecting tillering behavior which greatly depends on age of seedling at transplanting (Pasuquin *et al.*, 2008). This trial, was therefore meant to address issues of low productivity when rice is established through transplanting, owing to reduced water for complete flooded systems. Direct seeding as a method of rice established is believed to be an alternative towards up scaling rice grain productivity and thus a reduction on rice imports. The study was also assessing direct seeding as a cost effective method of rice establishment that eventually reduce cost of production.

1.3 Justification

Kenyans living in rural and urban centers consume considerable amounts of rice as a result of progressive change in feeding behaviors. In addition, the high costs of fuel makes rice a better and preferred choice as it cooks fast thus saving time and energy requirements (Mati, 2009). Labour scarcity is more common in rice farms especially during the peak seasons of land preparation, sowing and harvesting. Direct seeding as an establishment method for rice can save on labour costs by up to 50%, reduce low plant density risk and saves water (Pandey and Velasco, 1999). On the other hand, water for flooded rice ecosystems has rapidly decreased and this may reduce yields owing to drought (Mati, 2009), probably as a result of climate change effects (Fischer *et al*., 2007). Similarly, water has been identified as a major constraint facing rain-fed rice in sub-Saharan Africa where agro systems depend on natural rain.

Furthermore, the Kenyan ministry of agriculture (2009) classifies the country as one facing water scarcity. Yield of BASMATI 370 rice variety was not affected under the system of Rice intensification (SRI) (Kipkorir *et al*., 2011). Transplanting rice seedlings may cause transplanting check before proper root development (Dingkuhn *et al.*, 1990) leading to physiological stress to the young seedlings. Despite the lower average grain yield of NIBAM varieties at 4.1 t ha^{-1} (MoA, 2010) under flooded irrigation, majority of farmers are still inclined to them probably due to the appealing aroma of grains that fetch a higher market price compared to other rice varieties. Better understanding of cost effective methods of crop establishment of improved varieties will save on labor, reduce associated drudgery and also reduce amount of water wasted in flooded ecosystems. Direct seeded rice will eliminate unwarranted use of water for puddling and transplanting operations that may constitute 30% of total rice requirements (Chauhan, 2012) and at the same time reduce methane emissions as observed by Ko and Kang (2000). Direct seeded rice would adapt well with minimal precipitation compared to transplanted paddy and thus reduces chances of total crop failure during drier seasons. Transplanted rice on puddled fields requires continuous stagnant water as opposed to direct seeded and therefore high chances of nutrient loss through leaching. Flooded paddy creates anaerobic microbial processes that results to methane gas production (Ma *et al*., 2010), a greenhouse gas emitted through agricultural activities and contributing heavily to climate change. However, puddling leads to good weed control in submerged rice. In contrast, the level of soil degradation as a result of puddling process is more detrimental to the soil structure and becomes even more difficult to prepare such fields in subsequent seasons. Farmers in Mwea have also tried other technologies including the system of rice intensification (SRI) in which seedlings are transplanted after only two weeks in the nursery and adopts intermittent water supply. Normally farmers at Mwea practice complete flooding after transplanting 21-28 days old seedlings. The SRI practice was found to increase tillers and higher grain yields compared to complete flooding of rice during entire growing season (Ceesay *et al*., 2006; Kabir and Uphoff, 2007; Katambara *et al.*, 2013). This trial was meant to assess the effect of direct seeding and transplanting on growth and productivity of rain-fed and irrigated rice varieties on Kenyan lowlands. In addition, the trial purposed to identify a suitable establishment method that could help farmers save on labour as well as increase yields.

1.4 Objectives

1.4.1 Broad objective

To improve rice productivity through appropriate crop establishment methods and varietal assessment on rain-fed and irrigated lowland environment

1.4.2 Specific Objectives

(i) To assess crop growth and yield of transplanted and direct seeded rice varieties

(ii) To assess labour saving aspect under direct seeding and transplanting methods of rice establishment

1.5 Hypothesis

i. There is a difference in crop growth and yield of direct seeded and transplanted rice on rain-fed and irrigated lowlands

ii. There is a saving on labour cost when rice is direct-seeded and transplanted on rain-fed and irrigated lowlands

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Rice belongs to *Poaceae* (grass) family and out of 25 known species of wild rice that are distributed throughout tropical and subtropical regions of all continents (Veasey *et al.*, 2004), only two are cultivated. These are the African rice, *Oryza glaberrima, Steud* and Asian rice, *O. sativa* Linn., the latter being widely grown due to its suitable agronomic traits. On the other hand, *O. glaberrima,* though low yielding, has continued to provide breeding materials and thus important to the west- African countries (Jones *et al.*, 1997). According to Pandey *et al*., (2010), an estimated 900 million of world's poor rely on rice as producers or consumers. The crop is the third most important cereal crop in Kenya, after maize and wheat where it forms a very important diet for a majority of urban dwellers as well as the rural communities. *Oryza sativa* originates from South-East Asia and is grown worldwide whereas *O. glaberrima* is grown solely in West Africa, its area of origin (Linares, 2002; Fageria and Baligar, 2003).

2.2 Importance of rice

Rice grains have continued to gain popularity amongst a large world population. Healthy and adequately dried grains can be stored for relatively longer time at the farm level (Global rice science partnership, 2013), and thus a sustainable source of calorific requirements for human diet. Furthermore, rice grains have diversified uses for instance, according to Calpe (2006), rice which is mainly carbohydrate contributes 20% dietary energy rations, where 361 kcal and 6g of proteins can be obtained from 100g of uncooked white rice. Rice flour obtained from dried grain can also be used to make food products like cakes, baby food and other simple snacks. Rice variety, production practices and processing method largely determines the final nutritive status of rice grains (Rohman *et al*., 2014).

2.3 Rice farming

2.3.1 World perspective

Rice has over time been perceived an aquatic crop adapting to varied water supply regimes despite the fact that the crop evolved in a semi-aquatic environment, (Bouman *et al*., 2007, Wassmann *et al*., 2009). This adaptation attribute has led to 50% of rice cultivation taking place under irrigated conditions, about 34% of the rice being grown in rain-fed lowlands, 9% on rain-fed upland systems, and flooded rice farming covering 7% of the world rice area (IRRI, 2008). Cultivars adapted to flooding and anaerobic environments are more responsive to high nutrient inputs compared to upland cultivars and are more drought sensitive (Kumar *et al*., 2014a), while on the other hand, rice cultivars adaptable to upland conditions perform well in limited water supply though their productivity may be lower compared to the flooded lowland cultivars that are not limited to water supply.

Major producers of rice are China, India, Indonesia, Bangladesh, Thailand, Vietnam, Burma and the Philippines with the first seven major producers accounting for 80 % of total rice production in the world (Global rice science partnership, 2013). Africa's major rice producers include Egypt, Madagascar and Nigeria**.**

Key achievements have been realized through breeding for hybrid rice varieties, among them new rice for Africa (NERICA) varieties that are early maturing and therefore can be planted for two seasons within one year and have high productive potential (Guimaraes, 2009). Varieties with efficient use of inputs have higher yields, increased harvest index, and shows improved grain filling in inferior spikelets (Yang, 2015). Some of the problems associated with unnecessary use of higher amounts of nitrogen are lodging, increased disease incidence, delayed maturity and low grain quality (Bhiah *et al*., 2010; Zhang *et al*., 2014).

However, it is important to support farmers in the quest for adoption of sustainable cultural practices that increases yields with efficient use of available resource base such as synchronized wetting and drying and mulching (Zhang *et al*., 2012). Presently, there are negative effects due to climate change posing a great impediment to any significant increase in grain yield. Rice production may decrease by 10% on current yields on every 1°C increase in minimum night temperatures (Global rice science partnership, 2013).

2.3.2 Rice production in Kenya

Rice farming in Kenya was first practiced by the Asians around 1907 (MoA, 2009). However, rice is still grown for domestic consumption in most of regions in Kenya. Majority of Kenyan communities have appreciated the value of rice grains as human food as well as valued source of revenue for the people along the rice crop value chain (Olembo *et al*., 2010). This variation in opinion has greatly influenced the balance between production and consumption of rice in many African countries, including Kenya.

Rice is mainly cultivated under irrigated schemes that are managed by the National Irrigation Board and include Mwea, Ahero, Bunyala, West Kano, and Yala Swamp (MoA, 2011). However, the Economic Review of Agriculture (ERA, 2015) under the state department of agriculture provides basis for citation on rice production and the acreage under irrigation where a production decline of 12,993 metric tons of grain was observed in the period between 2013 and 2014. The decline in yield was associated with inadequate water supply on rice under irrigation and also unreliable rainfall in rice growing areas. In 2013, there were 31,349 ha under irrigated and upland rice compared to 29,630 ha in 2012 (ERA, 2015), however, 2014 recorded a sudden decline (28,390 ha) mainly due to a dry spell that affected rice cultivation on upland rain-fed ecology (ERA, 2015). Rice production gap is bridged through rice importation whose bill was valued at

100 million US dollars (Mati, 2011).

Table 2.1 Rice Production in Kenyan Counties

Year	2012			2013			2014		
County	**Ha**	**Production tons**	**Yield ton/ha**	**Ha**	**Production ton/ha**	**Yield ton/ha**	**Ha**	**Production ton/ha**	**Yield ton/ha**
Muranga	295.7	874	3.0	110	95	0.9	102.6	261.4	2.5
Kirinyaga	13 572	80 075	5.9	10	68 492	6.4	10 465	68 988.2	6.6
Kilifi	494	967	2.0	1 903	1 016	0.5	179	95.12	0.5
Kwale	1 486	5 349	3.6	1 490	6 349	4.3	1 273	1 355.7	1.1
T.Taveta	1 200	3 920	3.3	248	1 306	5.3	265	1 396	5.3
Tana	1 647	8 070	4.9	1 576	10 570	6.7	1 355	2 244.2	1.7
Homa	310	1 302	4.2	4 789	5 056	1.1	5 223	7 713.3	1.5
Kisumu	3 395	14 958	4.3	4 930	18 633	3.8	4 540	18 390	4.1
Siaya	2 300	9 890	4.3	2 655	7 163	2.7	2 648	8 137.8	3.1
Baringo	820	2 952	3.6	900	3 820	4.2	40	89.9	2.2
Busia	2 547	5 858	2.3	964	1 947	2.0	964	1 947	2.0

Adopted from: Economic Review of Agriculture page, 67; 2015.

A report by Kimani (2011) indicated that 95% of the rice cultivated in Kenya is under the major irrigated schemes in Kenya with only 5% produced under rain-fed conditions. The four main National Irrigation schemes are Mwea , Ahero, Bunyala and West Kano where production continues to be hindered by water shortages (USAID, 2010), while rain-fed rice is currently being grown under low scales in more than half of the counties in Kenya (Economic Review of Agriculture, 2015). Mwea irrigation scheme in Kirinyaga leads in production with 80% compared to other schemes under the National Irrigation Board management (Economic Review of Agriculture, 2010). There were relatively low grain yield on rain-fed rice due to complete reliance on rain as source of water throughout entire crop growth cycle, however, with improved rain-fed varieties (NERICAs) grain yield has continued to improve through adoption of appropriate crop establishment and management practices (Kimani, 2011).

2.4 Methods of Rice Establishment

Direct seeding as a method of rice establishment can be done in three different ways which include; dibbling of dry seeds directly into soil, sowing of pre-germinated seeds on wet puddle and seeding onto fields with minimal standing water which compares to transplanting by use of seedlings raised in nursery (Farooq *et al*., 2011). Pandey and

Velasco, (2005) asserts that use of dry seeds has been practiced in developing countries and dates back to 1950s. Factors that determine choice of an establishment method largely depend on suitability of available land, presence of adequate supply of quality water and how labour is readily available especially during critical field operations within a growing season (Nguyen and Ferrero, 2006). With present climate change scenario, more research is definitely focused on efficient use of available resources, as a means of adaptation and mitigation to climate change effects that are more severe in SSA. Direct seeding of rice has gained popularity because of its low demand for inputs among other advantages compared to transplanting (Farooq *et al*., 2011) and basically saves on amount of water and labour though the crop could adversely be affected by moisture stress in more drier or arid areas (Mahajan *et al*., 2006).

Conventionally, transplanted rice does well in submerged fields due to adequate moisture supply where water is maintained above 7cm depth with adequate suppression of weeds throughout the growing season**.** Fields are soaked for about two months prior to land preparation, a practice that consumes large amount of water especially under uncontrolled water use (Bouman *et al*., 2007). The field is drained to leave a wet/muddy ground from day of transplanting to the seventh day. Later on, water is re-introduced at depth 5-10cm throughout the growth period and fields drained off water 7-14 days before harvest date. Transplanted rice is labour demanding in executing field activities like field puddling, nursery establishment and management as well as transplanting. On the other hand, direct seeding of rice saves labour by up to 50%, reduce low plant density risk and saves on water (Pandey and Velasco, 1999). Trials by Adair *et al*., (1992) revealed that growth and yield of rice significantly depended on establishment method and hence important in selection of a sustainable method like direct seeding.

2.5 Constraints to rice production

2.5.1 Irrigation water management

The present inverse relationship between existing fresh water resources and human population continues to create stiff competition for this scarce commodity between agricultural activities, urbanization and improved industrialization. Reliance on natural precipitation by majority of sub-Saharan small holders for food production has been negatively impacted by partial and temporal rainfall pattern and thus a great threat to food safety and security. There is need to enhance water productivity in agricultural practices as a response to rising water shortage, and also allow adequate amounts of water to flow through rivers into lakes for ecosystem sustainability and industrial growth. Rice production under irrigated lowlands has declined over the past years due to limited moisture supply (Farooq *et al*., 2009a) to crops as a result of dwindling surface and underground water resources. Sustainable rice production particularly in SSA could be achieved by adopting water saving practices as opposed to the continuous flooded practice. One such practice is by alternate wetting and drying where water is supplied to plants at intervals with no flooded fields at any one point. The factors influencing water consumption by the plant are the field evaporation, seepage, initial land preparation and the initial flooding in case of flooded paddy. However these factors are dependent on climatic conditions of the location, soil characteristics, duration or length of irrigation, the ground water table in some areas, the method of crop establishment as well as the irrigation method used. Drought conditions are problematic to growth of upland rice. Water shortage, particularly at panicle initiation delays flowering of upland rice (Fukai and cooper, 1999). The extent to which flowering for upland rice delays is also associated with field practices during severe drought (Lilley and Fukai, 1994). Panicle initiation stage in the development of a rice plant is very sensitive where a slight moisture shortage reduces or even halts physiological processes completely.

Flooded irrigation above 7cm is more common in irrigated lowlands and this practice utilizes excess water than what is required by the rice plant. Field trials revealed that intermittent irrigation at depth of 3-5cm does not affect grain yield compared to uninterrupted water supply (Foteh *et al*., 2013). The same study affirmed that 100% greater water use efficiency can be achieved at a depth of 3cm through intermittent irrigation compared to the same depth of continuous flooding. Thus, great emphasis should be geared towards practices that promote better water use efficiency for more food productivity, hence improve food security status in areas affected by unreliable rainfall.

2.5.2 Weed losses

Weeds infestation hampers rice growth and development by competing for essential resources including light and nutrients. In Kenya, average yield losses due to uncontrolled weed growth are in the range of 50–60% (Mwanda, 2000). Majority of small holder farmers identify weed incidence as key constraint in their farming systems (Vissoh *et al*., 2004) because 50-70% of all the labour in crop production is spent on weeding (Chikoye *et al.*, 2007) and therefore increased labour costs. Weeds also habour pest and disease pathogens, negatively modify the micro-climate around the crop, increase cost of production and subsequent lowering crop yield and quality. Crop-weed competition for necessary plant resources is basically favoured by nitrogen application owing to the fact that weeds possess inherent superior competitive ability over the crop.

2.5.3 Insect Pests

Dipterous and lepidopterous stem borers are pests of economic importance in rain-fed upland, rain-fed lowland and irrigated lowland rice (Nwilene *et al*, 2009a). Larvae of stemborers cause significant yield losses during vegetative and reproductive stages by producing ‘dead hearts’ and ‘whiteheads’ respectively, which prevent panicle development and considerable yield reduction.

2.5.4. Diseases

Disease incidence occurring in rice farms results to considerable reduction in yields per unit area and the major ones include; sheath blight, rice blast, and bacterial blight**.** Management of these diseases is through avoidance of pre-disposing factors, appropriate disposal of straw, use of resistant varieties and rotation with different varieties.

2.5.6 Low soil fertility

Continuous farming practices in SSA have led to extensive mining of soil nutrients where studies show annual loss of nitrogen, phosphorus, and potassium on average of 22, 2.5 and 15kg ha^{-1}, respectively in a span of 30 years, leading to declining crop yields (IFDC, 2006; Gilbert, 2012). Yield potential of crops grown on nutrient depleted soils is certainly negatively affected due to less uptake of nutrients compared to a healthy one within a nutrient rich growth medium. Continuous cultivation is a common practice among the rice small holders who have subdivided their land into small sizes as a result of the increasing population. Inappropriate farm practices have also resulted to degradation of land and loss of soil fertility due to leaching and deep percolation of available nutrients. Crop harvesting (grain and/or vegetative) mines nutrients from the soils and contributes to a reduction in rice production per unit area. Greater number of sub-Saharan farmers may not afford to enhance soil fertility due to their limited resources and poor access to credit facilities. Land ownership at Mwea irrigation scheme is under leasehold, which makes majority of them skeptical in acquiring credit facilities for fear of their land being auctioned by credit providers for cases where rice farms are used as collateral. A higher percentage (63%) of farmers within the study area of Mwea were not able to access credit facilities (Emong'or *et al*, 2009).

2.6 Growth stages of rice plant

Rice varieties exhibit varied growth pattern depending on factors such as varietal inherent traits, ecology, soils and location and usually takes 3-5 months from seed to maturity. However, there are generalized growth stages which include sowing vegetative, reproductive and ripening phases. These stages are very important in terms of agronomic interventions required to maximize on water and nutrient utilization for improved grain productivity on both irrigated and rain-fed rice varieties.

Vegetative phase begins with seed germination, seedling growth and tillering. Seeds requires certain levels of moisture and later placed in an open area of 10-35^{o}C to help break dormancy. Germination of seeds occurs when the first shoots and roots start to emerge from the seed and the rice plant begins to grow. Select healthy seeds to minimize disease and pest incidence and to ensure uniform seedling emergence and growth. Seedling progresses in height and develops into a main stem. Normally, tillers begin to appear when the main stem attains a fifth leaf. At this stage, primary tillers develop at the base of each leaf starting with the second leaf. The second tiller emerge when the sixth leaf appear and this sequence goes on for primary tillers and at the same time, each primary tiller is capable of producing secondary tillers.

Reproductive stage begins with bulging of leaf stem concealing the emerging panicle, also called the booting stage. The panicle emerge from the stem and increases in length. Heading stage is attained once the panicle is visible. Flowering begins a day after completion of heading and may spread over two to three weeks depending on location.

Ripening phase starts after completion of flowering and continues to physiological maturity when plant foliage turns yellowish/brown and grains moisture content average between 18 to 23%.

Figure 2.1 acts as guide (IR64 rice variety) to the grower in making timely decisions on management practices within the farm.

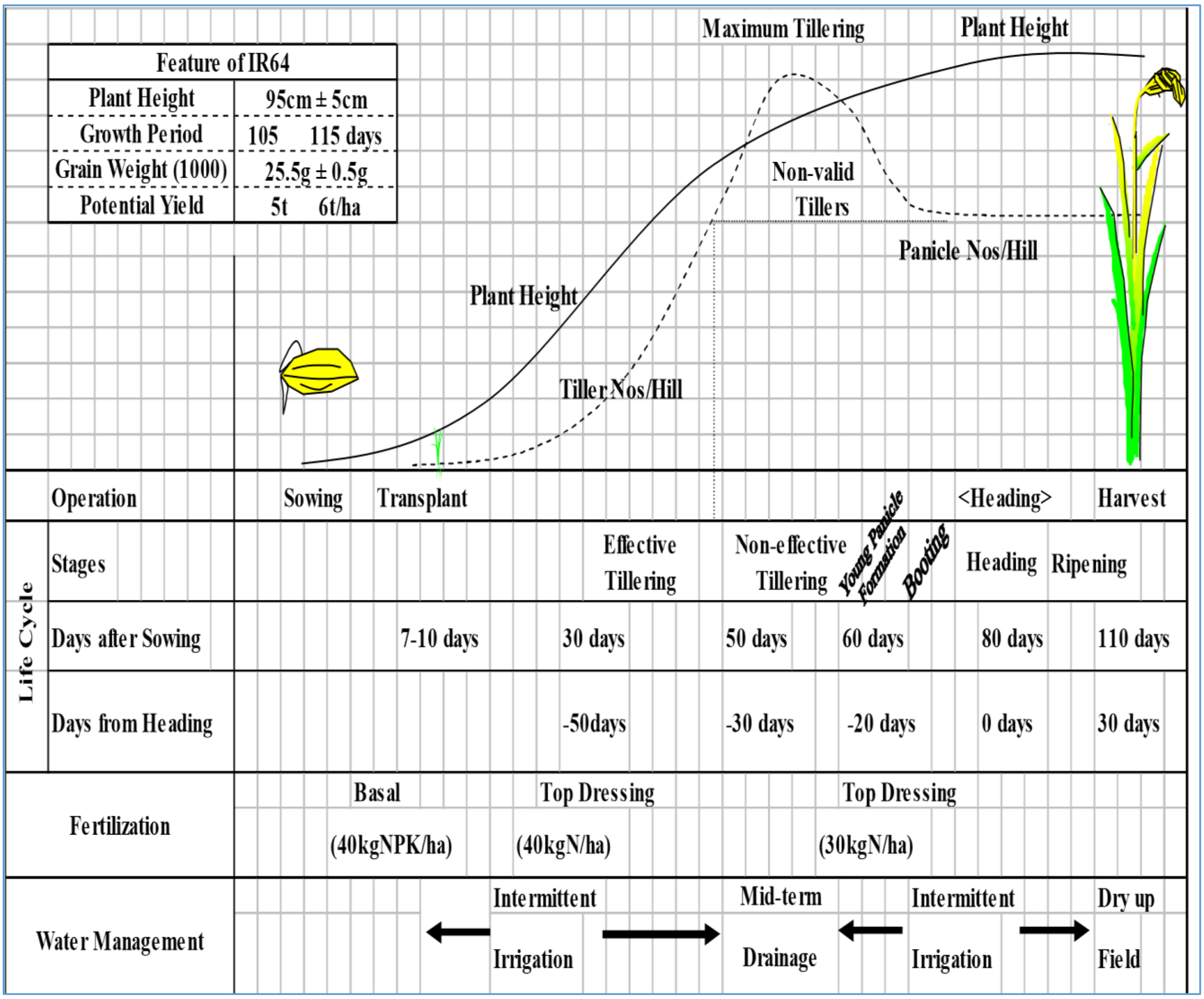


Figure 2.1 Distinctive growth phases of IR 64 rice variety
Adopted from IRRI Knowledge bank.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Trial sites

The study was conducted in two lowlands of Kenya where rice is widely grown in Mwea and Ahero irrigation schemes

Mwea Irrigation Scheme

The trial was carried out during the 2017 main rice growing season usually between July and December every year. This site is estimated at 1159 meters above sea level, located 0^o 37' S; 37^o 20' E and situated in Mwea East sub-county, Kirinyaga County, in Kenya (Figure 3.1). The area is characterized by bimodal rainfall pattern with two seasons whose peaks are in months of April and November (Jaetzold *et al*., 2005).Temperatures range between 15.6^oC and 28.6^oC with a mean of 22^oC while the soils are classified as deep nitosol, well drained dusky-red to dark reddish-brown, friable clay and with low fertility (Jaetzold *et al.,* 2005)

Ahero Irrigation Scheme

Site is located in Nyachonda within Ahero irrigation scheme at 00 09'S; 34^0 58' E and 1168 meters above sea level, 25 Km along Kisumu-Kericho highway in Kisumu County (Figure 3.2). The site lies in the middle of Kano plains whose climate is relatively dry with average temperatures that are high during the day, soils are deep black cotton and fertile with high contents of clay (Jaetzold *et al.*, 2005) which cracks when dry due to shrinkage and swells on wetting.

3.2 Soil sampling

A stratified random sampling method was used to sample soil (0-20 cm depth) using a panga to dig out soils from nine different points within the trial plots (Okalebo *et al.,* 2002). Later, the soils from the nine points were mixed thoroughly in a clean bucket and a sample of 2kg scoped into a sample bag and detailed labelling done according to site, date and depth of sampling. Samples were delivered to National agricultural research soil laboratory for analysis. Soil colour on both rain-fed and irrigated blocks at Ahero were homogenous and only one sample was collected, as opposed to Mwea site where samples were taken from rain- fed block and irrigated block separately due to their differences in colour. Methods used to analyze the soils were Mehlich Double Acid for P, K, Na, Ca, Mg, Mn and soil pH, Calorimetric method for total organic carbon, Kjeldahl method for total nitrogen, Hydrometer method for soil texture while Fe, Zn & Cu were extracted with 0.1 M Hcl and determined with Atomic Absorption Spectrophotometer (Appendix 22 and 23)

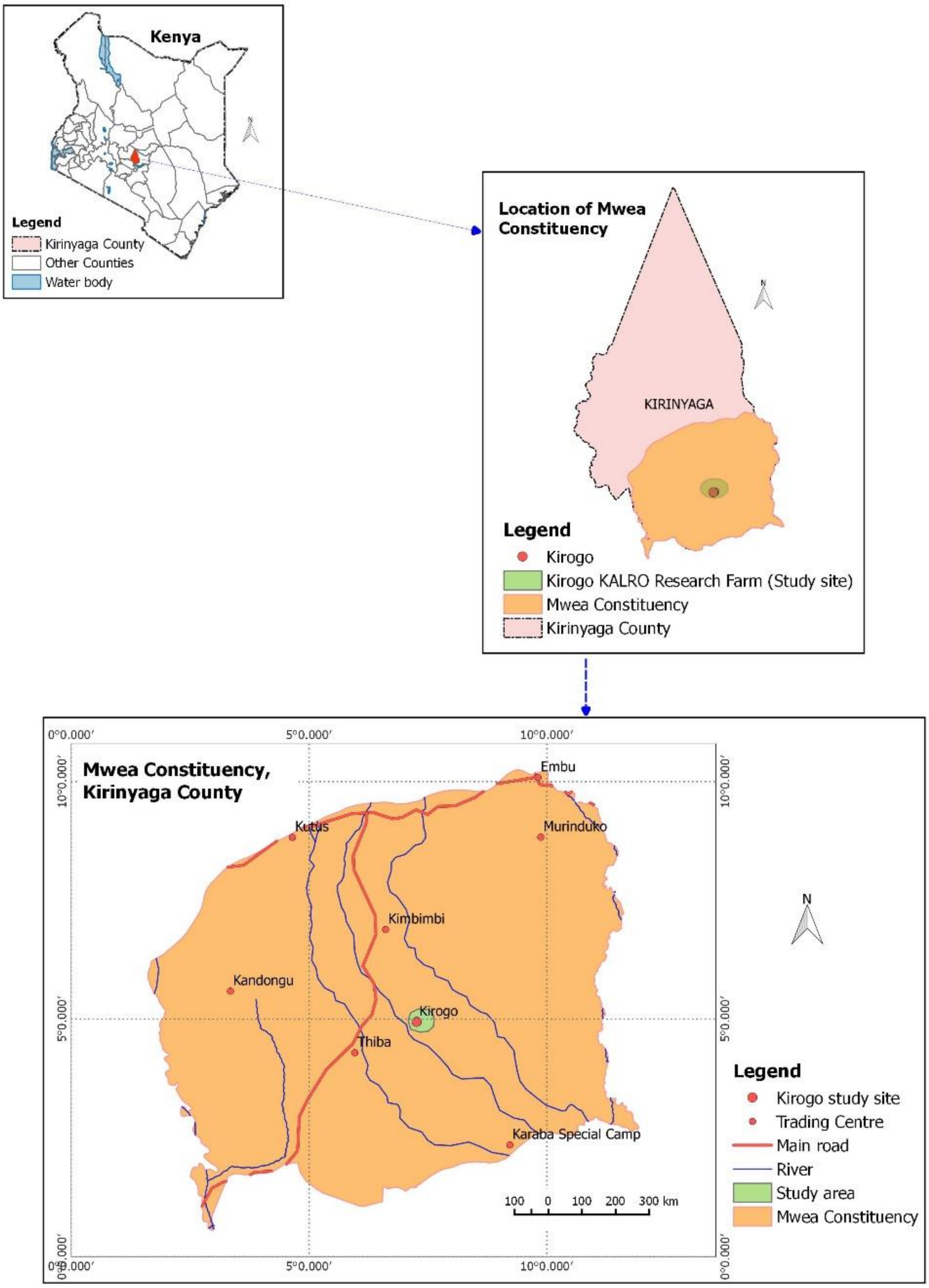


Figure 3.1 Map of Kenya and location of Mwea study site

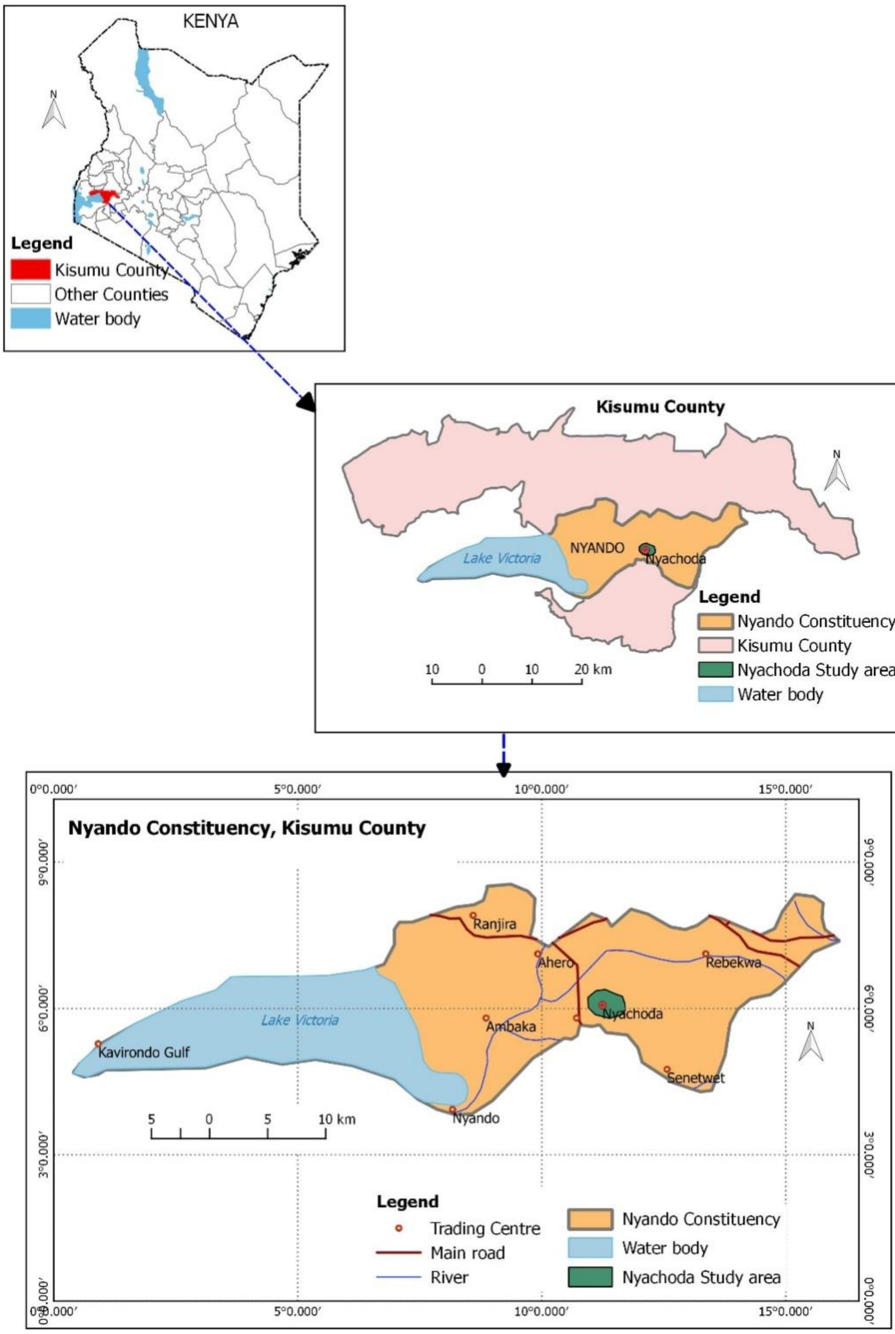


Figure 3.2 Map of Kenya and location of Ahero study site

3.3 Planting materials

Planting seed material were out-sourced from KALRO, Mwea seed unit and comprised of four rain-fed and four irrigated varieties that possess distinct inherent characteristics (Table 3.1). Other requirements included, harvesting sickles, a meter rule for length and height measurements, surgical blades, sample bags, weighing balance, seed counter, moisture meter and an oven all aimed at attaining reliable data.

Table 3.1 Varieties under assessment on rain-fed and irrigated lowland ecologies of Mwea and Ahero sites

Rain-fed varieties			**Flooded/paddy varieties**		
Variety (V)		**Attributes**	**Variety (V)**		**Attributes**
1	NERICA1 (N1)	Early maturing Crosses (O. *sativa* x O.*glaberrima*	1	SARO 5 (TXD306)	Relatively high yield potential. Fairly aromatic, susceptible to drought bacterial leaf blight and blast
2	NERICA4 (N4)	High yielding Drought tolerant Crosses (O. *sativa* x O.*glaberrima*	2	Komboka IRO5 221	High yield potential. Good aroma Moderate resistance to leaf blast, bacteria blight. Drought tolerant
3	Komboka IRO5 221	High yield potential. Good aroma Moderate resistance to leaf blast, bacteria blight. Drought tolerant	3	NIBAM 11	Local, aromatic Susceptible to water stress, low tiller number
4	Mwea Upland 4 (MWUR 4)	Medium high yielding. Drought tolerant Bred at Mwea for low input tolerance	4	Mwea Irrigated 2 (MWIR 2)	Medium high yielding. Bred at Mwea for low input tolerance

The new rice for Africa (NERICA) varieties have been bred and developed for rain-fed conditions, and performs well on moderately and well drained soils, on relatively low moisture which is just enough to support the crop through the entire growth phase within any rain-fed agro-ecosystem. However, the varieties do not withstand waterlogged conditions. Generally, rain-fed cultivars will grow and produce acceptable yields when supplied with at least 15-20mm of five-day rainfall during the growing period particularly during critical stages of early growth, vegetative stage and seed set (AfricaRice Center, 2008). NERICAs have also been found to grow well on both low and relatively high altitudes, such as the lowlands of Wabe Shebelle river valley in Ethiopia where NERICA1-4 matured within 80-90 days compared to NERICA 4 grown in Ethiopia at higher altitude of 1,900 meters above sea level and matured in 130–140 days. In this study irrigated rice refers to rice supplied with irrigation water, in budded plots to contain irrigation water, while on the other hand, rain-fed rice was grown on arable plots that were also leveled and budded around each main plot to so as retain supplied water within the plot. Rain-fed rice was dependent on natural rain at Ahero while supplemental irrigation supported crop growth and development at Mwea as a result of prevailing dry spell during crop establishment and at initial stages of rice growth.

3.4 Experiment design and treatments

The trial was laid in a randomized complete block design (RCBD) with split plot arrangement, and replicated three times. Main plots were direct seeding and transplanting methods of crop establishment, while sub-plots were the four rain-fed and four irrigated rice varieties that were randomly assigned to their respective plots (Table 3.2). Main plot measured 4m x3m with variety inter and intra spacing at 20cm x 15cm respectively that gave a plant population of 105 plants /sub-plot. Main plots were separated by 1m path.

Table 3.2 Field layout at Mwea and Ahero sites

Trial 1:		RAIN-FED VARIETIES		
	PLOT	DIRECT	PLOT	TRANSPLANTED
Block 1	1	V2	5	V3
	2	V4	6	V1
	3	V1	7	V2
	4	V3	8	V4
		TRANSPLANTED		DIRECT
Block 2	9	V4	13	V3
	10	V3	14	V2
	11	V1	15	V4
	12	V2	16	V1
		DIRECT		TRANSPLANTED
Block 3	17	V3	21	V4
	18	V1	22	V2
	19	V4	23	V3
	20	V2	24	V1

Trial 2:		IRRIGATED VARIETIES		
	PLOT	TRANSPLANTED	PLOT	DIRECT
Block 1	1	V3	5	V4
	2	V2	6	V1
	3	V4	7	V2
	4	V1	8	V3
		DIRECT		TRANSPLANTED
Block 2	9	V1	13	V2
	10	V4	14	V3
	11	V3	15	V4
	12	V2	16	V1
		TRANSPLANTED		DIRECT
Block 3	17	V2	21	V2
	18	V1	22	V3
	19	V4	23	V1
	20	V3	24	V4

3.5 Land preparation

3.5.1 Irrigated lowland ecology

Wet land preparation on irrigated lowland involved shallow soaking of the field with water before rotavation. Well decomposed cattle manure at a rate of 2 tons acre^{-1} was applied and worked on during land preparation to improve on nitrogen status. In addition, puddling and levelling was done to facilitate transplanting, help control weeds and improve capacity of soil to retain water on root zone through reduced soil permeability. Levelling ensured uniformity in crop emergence and also helped maintain a uniform water depth of 3-5 cm after crop establishment. Well compacted bunds were maintained at 20cm high to reduce chances of overflow in the event of excess rainfall.

Plate 3.1 Manual wet land preparation at Ahero
Source: Author

3.5.2 Rain-fed lowland ecology

Land was ploughed two months before crop establishment to allow complete decomposition of organic materials and later harrowed to incorporate the applied organic manure and to reduce large-sized soil clods. Levelling was done few days before sowing to control emerging weeds and acquire a fine tilth ensuring uniform crop emergence and a good stand with rapid growth. Paddocks were formed around the main plots to hold supplemented water as well as easier draining of excess water from the fields in case of a continuous downpour.

3.6 Rice establishment and management practices

3.6.1 Direct seeding on rain-fed and irrigated ecologies

Seeds for the trial were separated by floatation in water and later tested for germination on petri-dishes. Seeding on rain-fed plot was done with an aid of a marked sisal twine to guide rows on demarcated plots thus planting was faster and saved on time taken to complete the task and maintain the right plant population within subplot. Due to the prevailing limited soil moisture during establishment, there was initial soil wetting with flush irrigation and later dibbling of dry seeds (3/hill) at 2-4cm deep, spacing 20cm x 15cm. Thinning and gapping was done four weeks after emergence, leaving one plant per hill to reduce inter space competition and reduce shading effect that may affect maximum duration of photosynthetic activities (Horie *et al*., 2005).

Direct seeding on irrigated plots was done by dibbling 3seeds/hill with inter and intra-row spacing of 20cm by 15cm maintaining a depth of 2-4 cm to ensure uniformity in emergence. Water was drained off from irrigated field two days before direct seeding on wet ground to reduce chances of seed rotting in standing water. A sisal twine knotted on each hill was used to ensure the right plant population was maintained on each plot.

a)

b)

c)

d)

Plate 3.2 (a) & (b) direct seeding on irrigated and rain-fed plot, Mwea
(c) & (d) early growth stages DS- irrigated and DS- rain-fed rice, Mwea
Source*: Author*

Thinning and gapping was done to one plant/hill four weeks after emergence. Fertilizer application was as per recommended rates (Kega *et al.*, 2015) and based on soil test results, a one bag (50kg) acre^{-1} Muriate of potash at 60% K_2O was applied at planting on irrigated plots (Mwea), while Zinc sulphate was broadcasted at 12 kg acre^{-1} at planting (Ahero). Top dressing was done with Suphate of Ammonia (21%) in two splits, a rate of 2 bags (50kg) acre^{-1}. Generally, NIBAM requires less N fertilizer (likely to lodge) compared to other rice varieties cultivated in Mwea and Ahero. Phosphorous levels were adequate on both sites based on soil test results therefore no application was required. Direct seeding on paddy plots was slow thus more man hours spent compared to rain-fed plots due to difficulties in walking on wet clay soils. Weed control started within second week after emergence and repeated after two weeks. In total, there were four weeding operations on direct seeded and transplanted rain-fed rice. On the other hand, weeds that emerged after second weeding on irrigated (TP & DS) plots were suppressed by irrigation water. Mwea site was faced with vagaries of weather that led to prolonged drought which necessitated supplemental irrigation to saturate the soils during direct seeding of rain-fed varieties. A metered pipe was used to distribute 300 litres of water to well leveled paddocks measuring 12m^2. This water was enough to saturate soils and facilitate proper seedling emergence and to avoid rotting of seed. Rain-fed field was maintained in a moist condition until all the plants had about 2-4 leaves when an additional 500 litres of water was added onto each 12m^{2}paddock. The need for consecutive watering was assessed weekly and 200-400 litres added into paddocks depending on soil conditions until the crop attained physiological maturity.

Direct seeding on paddy plots commonly referred to as wet seeding was done on moist soils and maintained moist until the crop attained 3-4 leaves when water was introduced initially through a canal at 3cm depth and later added gradually with increased crop height to 5cm depth for entire growth cycle, and drained off two weeks to harvesting. Daily recording of mean temperature and rainfall were monitored from a weather station within the locality.

3.6.2 Wet nursery bed establishment and management practices

The nursery site was prepared two weeks before sowing to eradicate weeds and mix manure thoroughly acquiring a fine tilth that facilitates uniform seedling emergence. Seeds were first soaked with water for 24 hours to break dormancy and later air-dried under shade for one day. Soaking of seeds for the nursery bed was done on the same day with direct seeding which marked same date when biological processes started for direct seeded and transplanted crop. Birds were scared-off for entire period (20 days) to avoid damage by birds to emerging seedlings hence additional costs in labour man days. The nursery bed was kept weed-free to reduce crop-weed competition. Rice seeds were broadcasted on the wet nursery bed with no standing water. Water was introduced into nursery bed when seedlings had attained about 4-5 cm high with a dense growth and could withstand some level of water logging and seedlings were ready for transplanting 21 days after sowing. Risks encountered on nursery bed were birds that fed on rice seeds due to lack of an off-season crop. This incurred significant labour costs in bird scaring activities especially early in the morning and late evening when birds were most active, and scaring was done until the seedlings were ready for transplanting.

Plate 3.3 Uprooting transplants from nursery- Ahero
Source*: Author*

3.6.3 Transplanting on irrigated and rain-fed ecologies

Seedlings were gently uprooted from nursery and transplanted manually 21 days after sowing. Transplanting has an advantage over direct seeding because seedlings display initial head start in growth and competes well with weeds. However, the seedlings later exhibit slow growth due to damaged roots that causes transplanting shock in addition to drudgery associated with manual transplanting.

Plate 3.4 (a) & (b) transplanting rice seedling on rain-fed plot (Mwea) and irrigated plot ((Ahero)
(c) & (d) early growth stages TP- rain-fed (Mwea) and TP- irrigated rice, Ahero
Source*: Author*

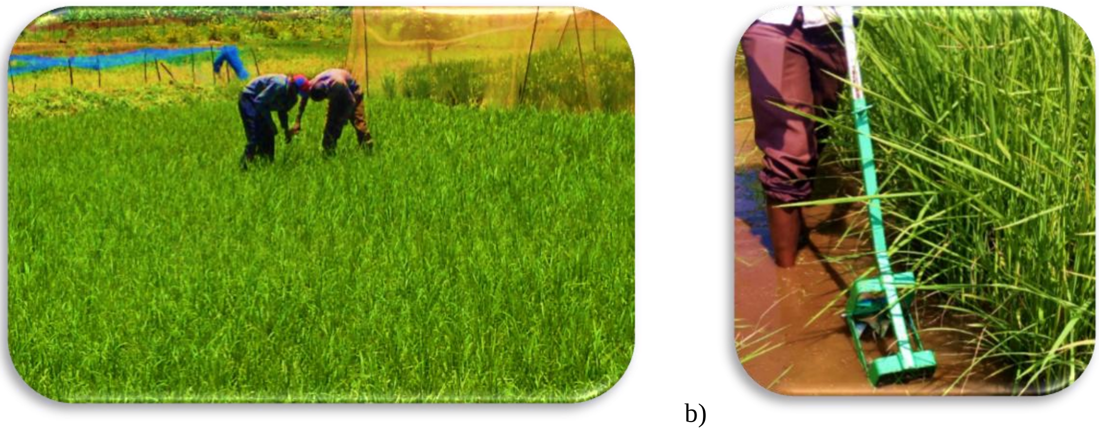
Water was introduced to irrigated plots from adjacent field through gravity flow inlet on the 7^{th} day after transplanting. The level of water was gradually increased to 3-5 cm depth as the crop increased in height, and maintained throughout the growth cycle. Depth of water levels was measured with a meter rule from five random points within the plot twice a week for entire season until the crop was physiologically mature, later fields were drained off 7 days before harvest to facilitate field drying process and to reduce grain losses that may occur in a wet field.

Transplanting on rain-fed plots was more challenging due to absence of enough moisture to support the plants at Mwea compared to Ahero which had adequate soil moisture. Formation of budded paddocks of $12m^2$ was necessary before introducing water through a metered pipe that discharged 500 litres into each paddock, just enough to saturate the soils for ease of transplanting. The field was maintained in a moist condition for the next seven days after which the crop was watered every time the ground assumed thin hairline cracks until the crop was ready for harvest. Fertilizers were applied based on general recommendations (Kega *et al.*, 2015) as per soil analysis results at one bag (50kg) $acre^{-1}$ Muriate of potash at 60% K_2O applied at planting on irrigated plots (Mwea), while Zinc sulphate was broadcasted at 12 kg $acre^{-1}$ at planting (Ahero). Top dressing done with Suphate of Ammonia (21%) in two splits, at rate of 2 bags (50kg) $acre^{-1}$. There were no major pest and disease incidences when crop was in nursery as well as in main field, though a precautionary measure against stem borers was by spraying CYCLONE® 505 EC (active ingredients: chloropyriphos 10% + cypermethrin 35%))a broad spectrum insecticide at 30mls/20litres water.

3.7 Weed Control

Weed and rice seeds germinated within the first two weeks after seeding in the direct seeded plots which marked the first weeding operation to reduce crop-weed competition. Control of weeds beyond critical stage negatively affects the final yields even with additional inputs.

Coinciding emergence of weeds and crop seeds makes it a difficult task to control and manage weeds in direct seeded fields. An integration of several weed management and control options was put in place to maintain the fields free from weeds. Most important step was to use clean seeds devoid of weed seeds that in most cases mimic the rice morphology specifically during vegetative growth making them difficult to eradicate. There were four hand weeding operations on direct seeded and transplanted rain-fed- plots as a result of high weed infestation, because weeds emerged as early as from the 6th day after seeding. However, weed flora diversity may largely depend on previous cropping systems amongst other factors. Weeds under irrigated rice systems may not be a major threat to crop growth and development since they are fairy chocked by the irrigation water when third of the crop height is submerged after transplanting. An initial manual weeding was done fourteen days after emergence on direct seeded irrigated plots followed later by two weeding using a row weeder on the same plot after being submerged in water. Since water was introduced seven days after transplanting irrigated plots, weed diversity and abundance was low probably due to chocking by water, and thus only two weeding operations occurred.



a) b)

Plate 3.5 Weed control

a) Manually on rain- fed plot (b) using a row weeder on irrigated plot, Mwea
Source*: Author*

3.8 Sampling and measurements

Growth and yield data were obtained from a sample size of five randomly selected and labeled plants in the middle rows of each plot. The representative plants were tagged and used as reference points during each sampling procedure and thus ensuring reliable data.

3.8.1 Plant growth and development

Plant growth and development was observed after every seven days for both direct seeded and transplanted crop. Plant height, number of tillers and number of leaves recording started seven days after transplanting which coincided with 29 days after direct seeding. These data recording dates were maintained because direct seeding was done the same date with soaking seeds for nursery establishment. Thus, biological processes for direct seeded rice on moist soils and the soaked seeds for nursery establishment started simultaneously. Sampling started seven days after transplanting which coincided with 28 days after direct seeding, and concluded at 10 weeks, when no change was observed on number of tillers, leaves and plant height, with seven samplings in total. Plant height was measured by holding all plants in a hill with one hand and raised up gently to the tallest plant. A meter rule (Plate 3.6) was placed near foot (at soil level) of hill to measure and record the tallest plant of that hill nearest one decimal.

Plate 3.6: Plant height measurement at Mwea
Source*: Author*

Tiller counts and leaf number were noted after holding all plants in a hill and counting done as tillers and leaves were separated from the grabbed plants and their numbers recorded. The weekly counts helped to understand when each variety attained maximum number of tillers and also observe the trend on leaf senescence. Days to flowering were counted from date of sowing and numbers noted when a single plant flowered on each variety (flowering onset) when, approximately half of plants within a treatment attained 50% flowering and at 100% bloom when all plants on each variety had flowered.

3.8.2 Yield and yield components

At physiological maturity when plant foliage turned yellowish or brownish and grains estimated between 18-23% moisture content, the five tagged plants within the three middle rows were harvested separately and used for yield and yield measurements. Number of productive tillers per hill were obtained by selecting tillers with panicles from each of the five plants and counted. Filled and unfilled grains hill^{-1} from all panicles within a hill were threshed and winnowed to separate filled and unfilled grains and their numbers recorded. Thousand seed weight was obtained by scooping a relatively small sample of grain within the plot harvest and 1000 seeds counted manually and weight obtained. Total grain yield was determined by harvesting the middle three rows in a plot in addition to the weight of the five sampled plants and grains dried to 14% moisture meter reading. This weight per unit area was extrapolated to tons per hectare.

3.9: Statistical analysis

Data were subjected to analysis of variance (ANOVA) using GenStat Edition 15th statistical software (VSN International, Jan. 2011). Separation of means was done using protected LSD at 5% probability level whenever there was significant differences. Changes in crop growth characteristics were observed and recorded on a seven-day interval, thus time considered as a factor in analysis. Data for rain-fed and irrigated varieties were analyzed separately due to their differences in growth adaptability with regard to water requirements.

3.10 Gross margin analysis

Total variable costs on farm operations and various input items throughout the cropping season were considered on both direct seeding and transplanting methods of crop establishment practices, while gross margin analysis was established based on varieties with highest yield on direct seeded rain-fed and transplanted irrigated in relation to prevailing market price of rice. Labour was hired and composed of both manual and mechanized. Weeding labour on direct seeded plots spreads throughout growth duration compared to transplanted plots which has lesser weeding frequencies. In total, there were four weeding operations on direct seeded rice to reduce weed–crop competition (Chauhan, 2012) which led to higher labour costs. Weeds were fairly managed by flooding water on transplanted irrigated crop, though one initial weeding and occasional hand pulling of volunteer weed species was necessary.

CHAPTER FOUR: RESULTS

4.1 Rainfall distribution and temperatures during main rice cropping season at Mwea and Ahero sites

Weather pattern at Mwea generally indicated that low and un-even distributed rainfall (Table 4.1) was received in the entire growing season except in fourth week of October and second week in November when higher amount was recorded. Highest amount of rainfall (152mm) was in month of October (Table 4.1) with 66.3% occurring within the last quarter of the month while July (8.1 mm) recorded the least amount (Table 4.1). Direct seeding was done during the dry spell with very little rain and therefore water was supplemented through a metered pipe to rain-fed and irrigated plots.

Similarly, Ahero site had moderately low rainfall amounts with uneven distribution pattern during the growing season. The rains were unequally distributed (Table 4.1) in the 3rd month after establishment (November) when crop attained heading stage though the monthly mean was adequate for good crop performance (68.1mm). The rains were considerably low in August (15mm) during wet land preparation for the irrigated fields. Rain-fed varieties were exclusively dependent on natural rain throughout the growth period an indication that the region is favoured by the effect of conventional rains that are common in that Lake Region. However, on irrigated varieties, water was occasionally replenished with between 360 – 480 litres of water on each 12m^2 paddock.

NERICA varieties have been found to perform well in areas receiving 20mm of well distributed rainfall within a week (AfricaRice Center, 2008). Temperatures at Mwea and Ahero were within the required range of 25-35^{o}C (Table 4.2) during the crop season and presumed not to have any major effect on grain yield of selected varieties (Ali *et al*, 2006)

Table 4.1 Rainfall (mm) distribution during the cropping season at Mwea and Ahero (July 2017-January 2018)

	MWEA							AHERO					
Date	**JUL 2017**	**AUG 2017**	**SEPT 2017**	**OCT 2017**	**NOV 2017**	**DEC 2017**		**AUG 2017**	**SEP 2017**	**OCT 2017**	**NOV 2017**	**DEC 2017**	**JAN 2018**
1	Nil	5.4	Nil	4.6	Nil	Nil		Nil	19	Nil	1	Nil	Nil
2	Nil	Nil	Nil	Nil	Nil	Nil		1.7	Nil	Nil	Nil	Nil	1.6
3	Nil	11.8	Nil	Nil	Nil	Nil		Nil	5	Nil	Nil	9.6	Nil
4	Nil	9.8	1.4	Nil	10.9	Nil		Nil	29	Nil	3.3	Nil	Nil
5	Nil	Nil	Nil	Nil	Nil	Nil		Nil	Nil	Nil	9.8	Nil	Nil
6	Nil	Nil	Nil	Nil	12	Nil		Nil	Nil	Nil	8.7	Nil	1.5
7	Nil	Nil	Nil	Nil	31.2	Nil		3.1	3	16.7	1	3.4	Nil
8	Nil	Nil	0.5	Nil	1.6	Nil		Nil	Nil	Nil	1.3	2.7	Nil
9	Nil	Nil	Nil	Nil	1.3	Nil		Nil	Nil	Nil	6.5	Nil	Nil
10	Nil	Nil	Nil	Nil	9.2	Nil		Nil	Nil	Nil	Nil	Nil	Nil
11	Nil	Nil	Nil	Nil	Nil	Nil		Nil	Nil	14	1.6	2	Nil
12	Nil	Nil	Nil	Nil	6.2	Nil		1.4	Nil	15.7	3.4	4.2	Nil
13	Nil	Nil	Nil	46.9	15	Nil		Nil	Nil	Nil	Nil	Nil	Nil
14	Nil	Nil	0.6	Nil	Nil	Nil		Nil	2.7	6.7	1.5	Nil	3.6
15	Nil	Nil	Nil	Nil	Nil	Nil		Nil	1	Nil	Nil	Nil	4
16	Nil	Nil	Nil	Nil	Nil	Nil		Nil	1.8	Nil	Nil	Nil	Nil
17	Nil	Nil	5.8	Nil	Nil	Nil		Nil	Nil	Nil	Nil	Nil	Nil
18	Nil	Nil	Nil	Nil	Nil	Nil		Nil	44.6	Nil	Nil	Nil	Nil
19	Nil	Nil	Nil	Nil	Nil	14.9		Nil	1.7	38	Nil	Nil	Nil
20	Nil	Nil	1.6	Nil	Nil	Nil		Nil	Nil	13.5	Nil	Nil	Nil
21	Nil	Nil	21.8	19.3	Nil	Nil		Nil	Nil	Nil	Nil	Nil	5
22	4.8	Nil	Nil	4.8	Nil	Nil		Nil	Nil	3.7	17.6	Nil	Nil
23	Nil	Nil	Nil	0.3	Nil	Nil		4.8	Nil	Nil	4.8	Nil	Nil
24	2.9	Nil	Nil	4.9	Nil	Nil		Nil	Nil	2.2	3	Nil	Nil
25	Nil	Nil	Nil	8.9	Nil	Nil		Nil	Nil	3.2	1.4	Nil	Nil
26	Nil	Nil	Nil	61	11.9	Nil		1	Nil	3.3	3.2	Nil	10.3
27	0.4	Nil	Nil	2.1	Nil	Nil		Nil	8	3.1	Nil	Nil	Nil
28	Nil	Nil	Nil	Nil	Nil	Nil		Nil	Nil	Nil	Nil	Nil	Nil
29	Nil	Nil	Nil	Nil	Nil	Nil		3	Nil	Nil	Nil	Nil	Nil
30	Nil	Nil	Nil	Nil	12.3	Nil		Nil	2	Nil	Nil	Nil	Nil
31	Nil	0.4	0	Nil	0	Nil		5	0	Nil	0	Nil	Nil
Rainy days	**3**	**4**	**6**	**9**	**10**	**1**		**6**	**11**	**11**	**15**	**5**	**6**
Total	**8.1**	**27.4**	**31.7**	**152.8**	**111.6**	**14.9**		**20**	**117.8**	**120.1**	**68.1**	**21.9**	**26**

Table 4.2 Maximum and minimum temperatures (°C) during the cropping season July 2017 to January 2018 at Mwea and Ahero

Months	Mwea		Ahero	
	Mean Max. °C	Mean Min. °C	Mean Max. °C	Mean Min. °C
July 2017	26.0	15.7		
August 2017	27.0	17.0	31.1	16.8
September 2017	27.7	16.0	30.5	17.3
October 2017	30.0	18.0	30.9	17.0
November 2017	30.0	16.0	31.4	16.5
December 2017	29.0	14.6	32.9	16.4
January 2018			32.1	17.1
Mean	**28.2**	**16.2**	**31.5**	**16.9**

4.2 Soils test report

Results of tested soils (Table 4.3a) were based on Mehlichs' method of nutrient classification and pH scale (Table 4.3b) that indicated low total nitrogen at Mwea and Ahero and thus improvement of soils was done by incorporating well decomposed manure (2 tons $acre^{-1}$) during land preparation while low level of zinc in Ahero was amended by broadcasting Zinc sulphate at 12 kg $acre^{-1}$ at sowing. Soil texture classification report (Table 4.3 a) was based on soil texture Bouyoucos hydrometer method (Appendix 23) and indicated considerably higher percentage of sand at Ahero and Mwea which necessitated frequent irrigation events on rain-fed plots at Mwea during crop growth.

Table 4.3 a) Soil samples test results (0-20cm depth) from Ahero and Mwea

Soil characteristics	Mwea rain-fed		Mwea irrigated		Ahero	
	value	class	value	class	value	class
Sand	46	Sandy clay	46	Sandy clay	48	Sandy clay loam
Clay	42		44		34	
silt	12		10		18	
Soil pH	5.78	medium acid	5.12	medium acid	6.30	slight acid
Total Nitrogen %	0.17	low	0.18	low	0.15	Low
Total Org. Carbon %	1.88	moderate	1.89	moderate	1.40	Moderate
Phosphorus ppm	290	high	45	adequate	35	Adequate
Potassium me%	1.00	adequate	0.20	low	1.08	Adequate
Calcium me%	10.7	adequate	7.2	adequate	12.0	Adequate
Magnesium me%	4.33	high	3.58	high	3.90	High
Manganese me%	0.53	adequate	1.76	adequate	1.50	Adequate
Copper ppm	3.10	adequate	8.64	adequate	2.78	Adequate
Iron ppm	108	adequate	590	high	345	High
Zinc ppm	6.00	adequate	7.00	adequate	4.08	Low
Sodium me%	0.35	adequate	0.43	adequate	0.87	Adequate

ppm- parts per million; me% - milliequivalent;

Table 4.3 b) Mehlich method of nutrient classification and pH scale

Nutrient	Deficiency	Adequate	Excessive	Remarks
Sodium, me%	seldom	0-2.0	> 2.0	excessive levels in sodic soils
Potassium, me%	< 0.24	0.24-1.5	> 1.5	
Calcium, me%	< 2.0	2.0-15.0	> 15.0	
Magnesium, me%	< 1.0	1.0-3.0	> 3.0	
Phosphorus, ppm	< 30	30-80	> 80	
	< 80			for flowers
Manganese, me%	< 0.11	0.11-2.0	> 2.0	excessive levels in very acid or poorly drained
Total nitrogen & carbon				
Total nitrogen, %	< 0.2	0.2-0.5	> 0.5	
Total organic carbon,	< 1.33	2.66-5.32	> 5.32	1.33-2.65 moderate
Extraction with 0.1 M HCl				
Copper, ppm	< 1.0			
Iron, ppm	< 10			
Zinc, ppm	< 5.0			

ppm- parts per million; me% - milliequivalent;

pH Scale (In 1:1 Soil: Water ratio)

pH	Rating	Comments
Below 4.5	Extremely acid	In soils with pH less than 5.5 exchangeable acidity is measured
4.5 - 4.99	Strongly acid	
5.0 - 5.99	Moderately acid	
6.0 - 6.80	Slightly acid	
6.81 - 6.99	Near neutral	
7.0 - 7.49	Slightly alkaline	In soils with pH 7.0 and above electrical conductivity is measured
7.5 - 8.49	Moderately alkaline	
8.5 - 8.99	Strongly alkaline	
Above 9.0	Extremely alkaline	

4.3 Crop growth and development on rain-fed lowland ecology

4.3.1: Assessment of tiller number, plant height and number of leaves on four rain-fed rice varieties.

Height of plants, number of leaves hill^{-1} and tiller hill^{-1} number were significantly (P<0.05) affected across varieties where MWUR4 had a mean height of 41.3cm while Komboka had lowest mean at 29.5cm compared to NERICA1and NERICA4 (Table 4.4). Komboka had highest mean number of leaves (35) while MWUR4 had least mean at 18 leaves compared to NERICA1 and 4 at 25 and 20 leaves respectively. Higher number of tillers were observed on Komboka (10) with least mean of tillers on MWUR4 at 5 tillers. However, direct seeding and transplanting method of crop establishment had no significant (P>0.05) effect on plant height, number of leaves and tiller number of rain-fed varieties (Table 4.4).

Table 4.4: Plant height, number of leaves and tiller number of rain-fed varieties on direct seeded and transplanting methods of rice establishment

	Plant height (cm)			Number of leaves hill^{-1}			Number of tillers hill^{-1}		
Variety	DS	TP	Mean	DS	TP	Mean	DS	TP	Mean
NERICA1	43.5	38.4	40.9a	28	23	25b	8	6	7b
NERICA4	42.8	38.9	40.8a	22	18	20c	6	6	6c
KOMBOKA	30.0	29.1	29.5b	39	32	35a	11	9	10a
MWUR4	44.9	37.8	41.3a	20	15	18c	6	4	5c
mean	40.3a	36.0a		27a	22a		8a	6a	
P(Est)	0.173ns			0.091ns			0.111ns		
P(v)	0.001***			0.001***			0.001***		
$P_{(Est\ x\ V)}$	0.073ns			0.869ns			0.34ns		
LSD $_{(0.05)}$ (Est)	8.838			7.241			2.872		
LSD $_{(0.05)}$ (V)	2.317			4.296			1.099		
LSD $_{(0.05)}$ (EstxV)	6.874			6.481			2.213		
CV (%)	15.4			36.3			30.5		

DS-Direct seeded, TP- Transplanted: Est -method of crop establishment, V -variety
*** Statistically highly significant at 0.001, ns not significant

Plant height and number of tillers on rain-fed varieties significantly (P<0.05) differed with sites while on the other hand, number of leaves on varieties was not statistically (P>0.05) affected by site (Table 4.5). A general trend indicated higher plants at Ahero with a mean height of 42.5cm compared to Mwea 33.9cm while number of tillers on rain-fed varieties were higher at Ahero (8) compared to 6 tillers at Mwea (Table 4.5).

Table 4.5 Plant height, number of leaves and tiller number of rain-fed varieties in Mwea and Ahero

	Plant height (cm)			Number of leaves hill^{-1}			Number of tillers hill^{-1}		
Variety	Mwea	Ahero	mean	Mwea	Ahero	Mean	Mwea	Ahero	Mean
NERICA1	36.1	45.7	40.9a	26	25	25b	7	7	7b
NERICA4	35.9	45.8	40.8a	21	20	20c	5	7	6c
KOMBOKA	26.5	32.6	29.5b	34	37	35a	9	12	10a
MWUR4	37.0	45.8	41.4a	19	17	18c	5	6	5c
mean	33.9b	42.5a		25a	25a		6b	8a	
P(v)	0.001***			0.001***			0.001***		
P(s)	0.001***			0.971ns			0.001***		
P(VxS)	0.001***			0.301ns			0.006**		
LSD $_{(0.05)}$V	2.317			4.296			1.099		
LSD $_{(0.05)}$S	1.269			1.973			0.486		
LSD$_{(0.05)}$(VxS)	2.839			4.975			1.26		
CV (%)	15.4			36.3			30.5		

V- variety, S- site (Mwea & Ahero)

*** Statistically highly significant at 0.001, ** statistically significant at 0.01, ns not significant

Number of days after sowing, significantly (P<0.05) influenced number of tillers and plant height on direct seeding and transplanting method rice establishment (rain-fed) with higher mean tillers (Figure 4.1a) and higher mean crop height (Figure 4.1b) on direct seeded crop compared to transplanted crop. Nevertheless, results indicated insignificant (P>0.05) effect on number of leaves per hill when crop was either direct seeded or transplanted at maximum leaf production stage which coincided with crop heading stage (Appendix 3)

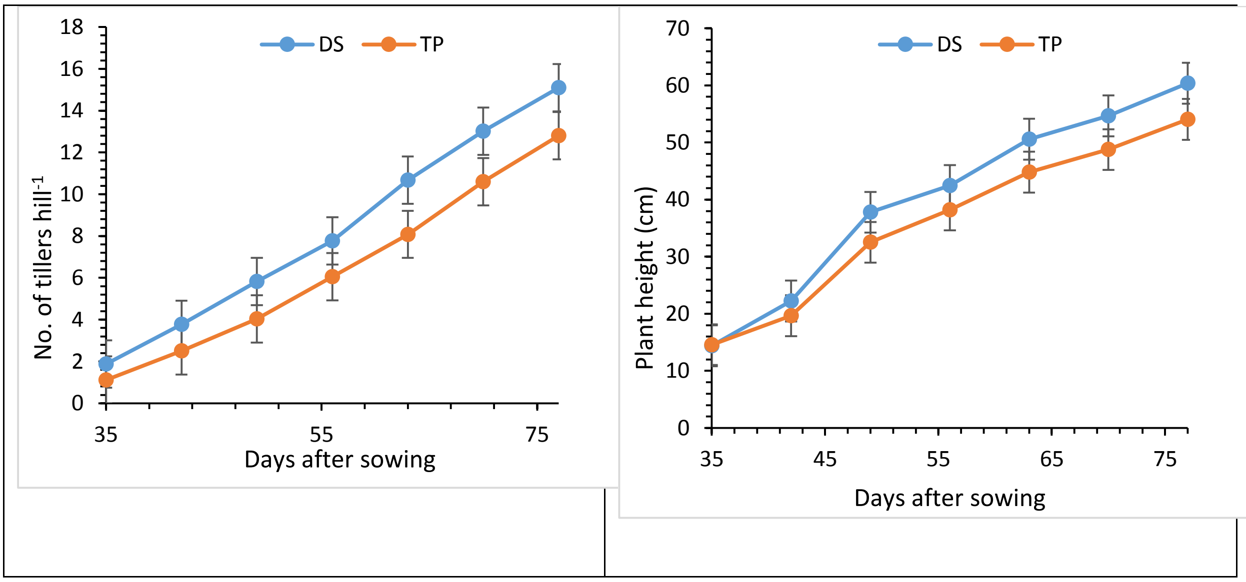


Figure 4.1 (a & b) number of tillers and plant height on different days after sowing on direct seeding(DS) and transplanting(TP) method of crop establishment, rain-fed environment (Bars represent LSD at 0.05 significance level)

Rain-fed varieties revealed a significant ($P<0.05$) progressive increase in number of tillers hill^{-1}, plant height and number of leaves hill^{-1} on varied days after sowing. Komboka posted highest tiller mean by time of maximum tillering at 20 tillers followed by NERICA1 with a tiller mean of 13, while on the other hand, MWUR4 and NERICA4 had means of 10 and 11 tillers respectively (Figure 4.2a). Komboka mean height (46.2cm) differed significantly ($P<0.05$) compared to NERICA1 (60.5cm), NERICA4 (60.8cm) and MWUR4 (61cm) (Figure 4.2b). Similarly, trend on leaf number on rain-fed varieties was significantly ($P<0.05$) affected (Figure 4.2 c) with more leaves on Komboka compared to least leaf means posted by MWUR4 at crops heading stage.

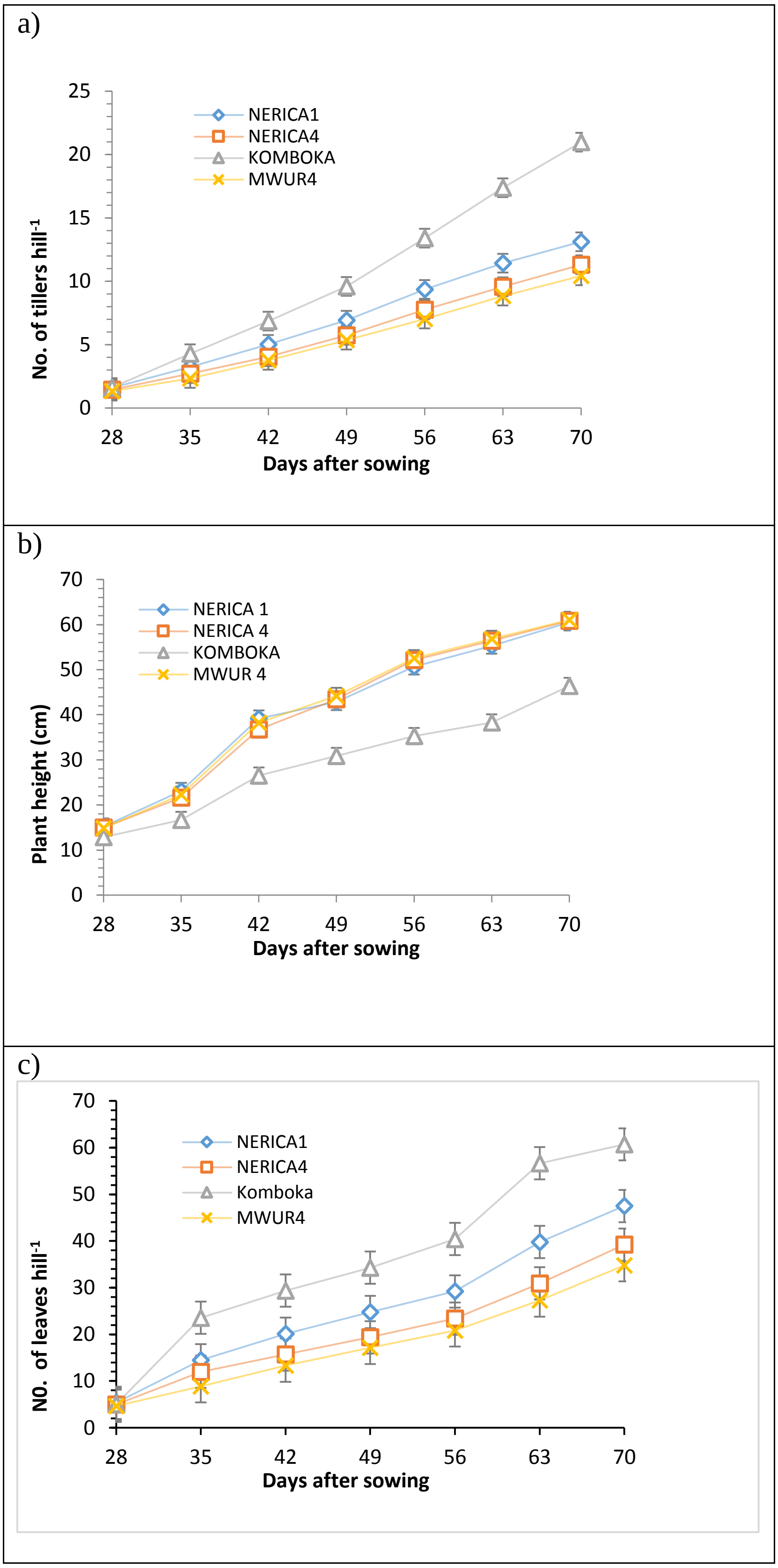


Figure 4.2 (a, b & c) Crop growth and development from sowing to peak tillering, maximum plant height and at stage of highest leaf number on rain fed varieties (Bars represent LSD at 0.05 significance level)

4.4 Crop growth and development on irrigated lowland ecology

4.4.1: Assessment of tiller number, plant height and number of leaves of four irrigated rice varieties.

Results indicated a significant (P<0.05) variation on plant height, number of tillers and number of leaves across the four irrigated rice varieties. Direct seeding and transplanting method of crop establishment did not statistically (P>0.05) affect number of tillers plant height and number of leaves of irrigated rice varieties (Table 4.6). NIBAM11 mean height was highest (42.3cm) compared to MWIR2 with lowest mean at 34.1cm. Number of leaves were higher on MWIR2 with mean of 59 and differed significantly to NIBAM11 (46) while Komboka and SARO5 had same mean at 51 leaves. There were more tillers noted on MWIR2 (17), followed by Komboka (15) whereas NIBAM11 and SARO5 had 13 and 14 tillers respectively (Table 4.6).

Table 4.6: Plant height, number of leaves and tiller number of irrigated varieties on direct seeded and transplanting methods of rice establishment

	Plant height (cm)			Number of leaves hill^{-1}			Number of tillers hill^{-1}		
Variety	DS	TP	Mean	DS	TP	Mean	DS	TP	Mean
SARO5	37.5	34.5	36.0b	59	44	51b	16	12	14b
KOMBOKA	36.6	34.7	35.7b	59	44	51b	17	13	15b
NIBAM11	45.0	39.7	42.3a	54	39	46b	16	10	13b
MWIR2	33.9	34.4	34.1c	68	51	59a	20	14	17a
mean	38.2a	35.8a		60a	44a		17a	12a	
P(Est)	0.171ns			0.054ns			0.06ns		
P(v)	0.001***			0.009**			0.013*		
$P_{(Est\ x\ V)}$	0.005**			0.982			0.891		
LSD $_{(0.05)}$(Est)	5.01			16.289			6.296		
LSD $_{(0.05)}$(V)	1.379			6.613			2.281		
LSD$_{(0.05)}$(EstxV)	3.871			12.69			4.824		
CV (%)	7.4			25.4			21.9		

DS-Direct seeded, TP- Transplanted, Est- method of crop establishment: V- variety
*** Statistically highly significant at 0.001, ** statistically significant at 0.01, * statistically significant at 0.05, ns not significant

.

Irrigated varieties displayed significant (P<0.05) variations on plant height, number of leaves and tiller number in Mwea and Ahero site (Table 4.7). Plant height mean at Ahero was higher (37.6cm) compared to Mwea (36.4cm). Highest variety mean height was on NIBAM11with 42.3cm while MWIR2 had least mean of 34.1cm. More leaves were noted at Ahero (57) compared to Mwea (46) with highest leaf number on MWIR2 (59) followed SARO5 and Komboka at same leaf number (51) and lowest mean was noted on NIBAM11 with 46 leaves (Table 4.7). Equally, number of tillers were significantly more at Ahero (16) when compared to those noted in Mwea (14). MWIR2 led with a higher tiller mean of 17 and least mean was noted on NIBAM11 with 13 tillers.

Table 4.7 Plant height, number of leaves and tillers of irrigated varieties in Mwea and Ahero

	Plant height (cm)			Number of leaves hill^{-1}			Number of tillers hill^{-1}		
Variety	Mwea	Ahero	mean	Mwea	Ahero	Mean	Mwea	Ahero	Mean
SARO5	36.1	36.0	36.0b	45	57	51b	13	15	14b
KOMBOKA	35.1	36.2	35.6b	43	59	51b	13	17	15b
NIBAM11	40.4	44.3	42.3a	46	47	46b	13	13	13b
MWIR2	34.3	34.0	34.1c	53	65	59a	16	18	17a
mean	36.4b	37.6a		46b	57a		14b	16a	
P(v)	0.001***			0.009**			0.013*		
P(s)	0.001***			0.001***			0.001***		
P(VxS)	0.001***			0.002**			0.001***		
LSD $_{(0.05)}$V	1.379			6.673			2.281		
LSD $_{(0.05)}$S	0.597			2.895			0.717		
LSD $_{(0.05)}$ (VxS)	1.572			7.611			2.445		
CV (%)	7.4			25.4			21.9		

V- variety: S-site

*** Statistically highly significant at 0.001, ** statistically significant at 0.01, * statistically significant at 0.05, ns not significant.

Results indicated that direct seeding and transplanting method of establishment had a significant (P<0.05) effect on tiller number and number of leaves of irrigated varieties' in relation to days after sowing. Direct seeded crop had more leaves (Figure 4.3 a) compared to transplanted crop within the development stages, with a similar observation on number of tillers (Figure 4.3 b). However, there was no significant effect on plant height within crop development stages when the crop was either direct seeded or transplanted (Appendix 5).

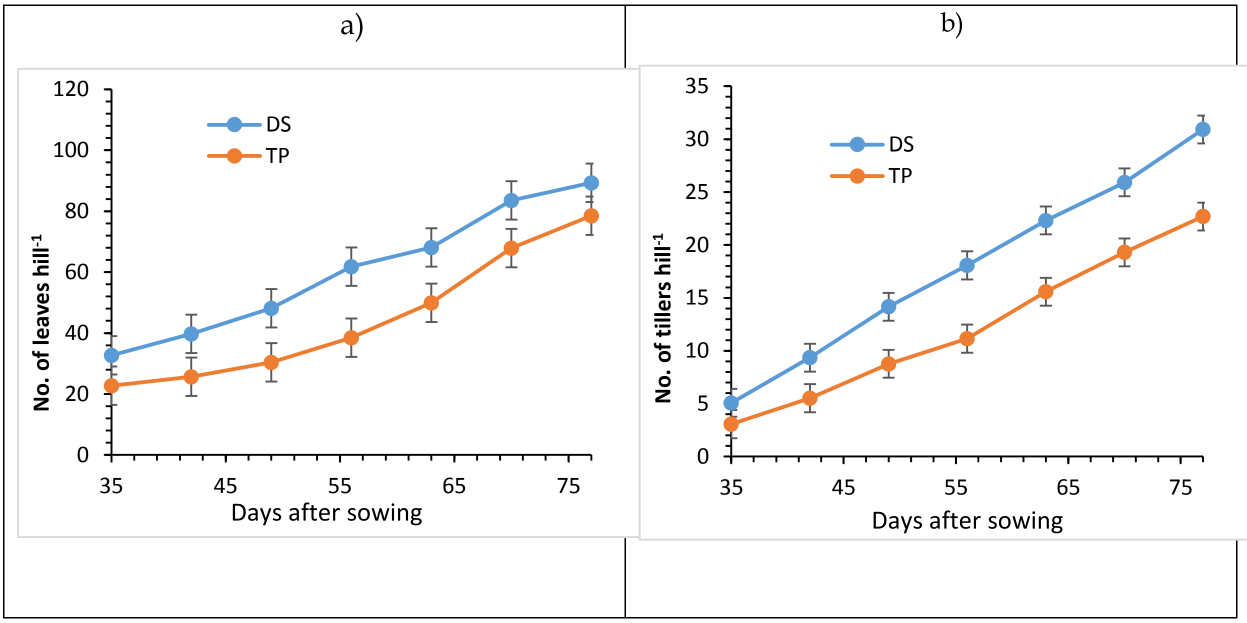


Figure 4.3 (a and b) number of leaves and tillers on different days after sowing on direct seeding(DS) and transplanting (TP) method of crop establishment, irrigated environment (Bars represent LSD at 0.05 significance level)

Selected irrigated rice varieties had a significant (P<0.05) progressive increase in number of tillers, plant height and leaf number on varied days after sowing date where MWIR2 posted highest tiller mean by time of maximum tillering (31) while NIBAM11 indicated a general trend of low tiller counts (Figure 4.4 a). Number of leaves exhibited an increasing trend from planting along growth phases with varieties recording mean values from high to low as V4>V3>V1>V2 with a significant (P<0.05) effect on leaf number at heading stage.(Figure 4.4 b). NIBAM11 showed highest mean on height and significantly (P<0.05) differed with height means of SARO5, Komboka and MWIR2 at crop heading stage (Figure 4.4 c).

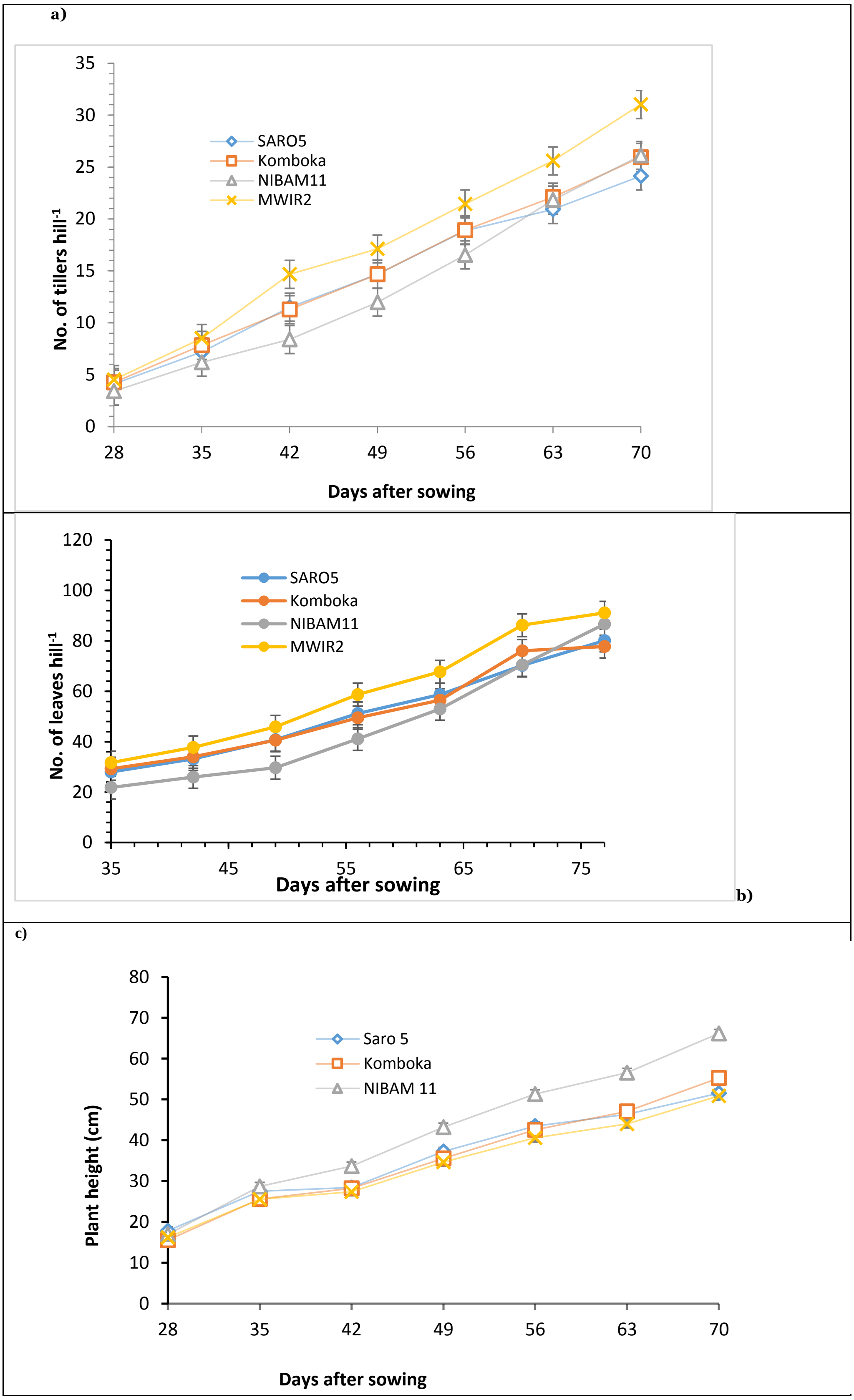


Figure 4.4 (a, b & c) Crop growth and development from sowing to peak tillering, maximum plant height and at stage of highest leaf number on irrigated rice varieties (Bars represent LSD at 0.05 significance level)

4.5 Days to flowering of direct seeded and transplanted rain-fed rice varieties at Mwea and Ahero sites

Results revealed that number of days to flowering onset was not significantly (P>0.05)) influenced by method of crop establishment. However, direct seeding significantly reduced duration to flowering by seven days to 50% and five days to 100% (Table 4.8). Significant effect was noted across varieties with NERICA1 attaining flower onset within least (77) number of days and Komboka was last to attain flower onset covering a duration of 101 days. NERICA4 and MWUR4 did not differ statistically in attaining flower onset with means of 81 and 82 days respectively

It was also observed that method of crop establishment across Mwea and Ahero sites significantly affected rain-fed varieties at 100 % flowering (Appendix 9) which could be due to prevailing environmental factors. Equally, a general trend was that the crop at Ahero site attained flower onset, 50% flowering and 100% flowering earlier compared to Mwea (Table 4.9) with difference in means at 6 ,7 and 5 days respectively

Table 4.8 Days to flowering of direct seeded and transplanted rain-fed varieties

	Onset flowering			50% flowering			100% flowering		
Variety	DS	TP	mean	DS	TP	Mean	DS	TP	Mean
NERICA1	71	83	77c	85	95	90b	97	103	100b
NERICA4	76	86	81b	86	96	91b	96	103	99b
KOMBOKA	103	99	101a	109	108	108a	115	114	114a
MWUR4	78	86	82b	86	95	90b	94	101	97b
mean	82a	88a		91b	98a		100b	105a	
P(Est)	0.12ns			0.004**			0.025*		
P(v)	0.001***			0.001***			0.001**		
P (Est x V)	0.002**			0.069ns			0.368ns		
LSD $_{(0.05)}$(Est)	10.74			1.897			3.42		
LSD $_{(0.05)}$(V)	3.677			4.81			5.67		
LSD$_{(0.05)}$(EstxV)	8.204			5.937			7.084		
CV (%)	4.8			5.4			3.8		

DS-Direct seeded, TP- Transplanted: Est- method of crop establishment: V- variety
*** Statistically highly significant at 0.001, ** statistically significant at 0.01, * statistically significant at 0.05, ns not significant.

Table 4.9 Days to flowering of rain-fed varieties in Mwea and Ahero

	Onset flowering			50% flowering			100% flowering		
Variety	Mwea	Ahero	mean	Mwea	Ahero	Mean	Mwea	Ahero	Mean
NERICA1	81	72	77c	95	85	90b	103	97	100b
NERICA4	85	77	81b	93	88	91b	99	99	99b
KOMBOKA	104	99	101a	110	106	108a	116	112	114a
MWUR4	86	78	82b	94	87	90b	100	94	97b
mean	89a	81b		98a	91b		104a	101b	
P(v)	0.001**			0.001**			0.001**		
P(s)	0.001**			0.001**			0.005*		
P(VxS)	0.625ns			0.62			0.293ns		
LSD $_{(0.05)}$V	3.677			4.81			5.67		
LSD $_{(0.05)}$S	2.529			3.148			2.414		
LSD $_{(0.05)}$(VxS)	4.893			6.252			6.371		
CV (%)	4.8			5.4			3.8		

V- variety: S-site

** Statistically significant at 0.01, * statistically significant at 0.05, ns not significant.

4.6 Days to flowering of direct seeded and transplanted irrigated rice varieties at Mwea and Ahero sites

Duration of days to flowering onset was significant ($P<0.05$) across irrigated varieties with a trend of more days on transplanted crop compared to direct seeded crop. Varietal means indicated that MWIR2 had longest means of 106 days, 102 for SARO5 while least number of days to flowering was noted on Komboka (96) and NIBAM11 (95) (Table 4.10). Method of crop establishment had a significant influence on flowering onset with a reduced three days on direct seeded crop to flower onset (Table 4.10). Similarly onset to flowering at Mwea and Ahero differed significantly with varieties at Mwea attaining flower onset earlier than crop at Ahero (Table 4.11) with tested varieties attaining flower onset at mean of 98 days at Mwea compared to 102 days at Ahero. Similarly, days to 50% and 100% flowering were significantly less at Mwea compared to number of days at Ahero site (Table 4.11)

Table 4.10 Days to flowering of direct seeded and transplanted irrigated varieties

	Onset flowering			50% flowering			100% flowering		
Variety	DS	TP	mean	DS	TP	Mean	DS	TP	Mean
SARO5	102	103	102b	108	110	109b	114	117	115b
KOMBOKA	95	98	96c	101	104	103c	110	110	110c
NIBAM11	93	97	95c	100	103	101d	106	108	107d
MWIR2	105	107	106a	114	114	114a	118	118	118a
mean	99b	101a		106a	108a		112a	113a	
P(Est)	0.009**			0.34ns			0.174ns		
P(v)	0.001***			0.001***			0.001***		
$P_{(Est\ x\ V)}$	0.371ns			0.105ns			0.193ns		
$LSD_{(0.05)}$(Est)	0.949			1.729			2.677		
$LSD_{(0.05)}$(V)	2			1.087			1.179		
$LSD_{(0.05)}$(EstxV)	2.478			1.599			2.121		
CV (%)	1.9			1.5			1.6		

DS-Direct seeded, TP- Transplanted: Est- method of crop establishment: V- variety,

*** Statistically highly significant at 0.001, ** statistically significant at 0.01, ns not significant.

Table 4.11 Days to flowering of irrigated varieties in Mwea and Ahero)

	Onset flowering			50% flowering			100% flowering		
Variety	Mwea	Ahero	mean	Mwea	Ahero	Mean	Mwea	Ahero	Mean
SARO5	104	100	102b	111	107	109b	115	116	115b
KOMBOKA	95	98	96c	100	105	103c	106	114	110c
NIBAM11	88	102	95c	94	109	101d	98	116	107d
MWIR2	105	107	106a	114	113	114a	118	118	118a
mean	98b	102a		104b	108a		109b	116a	
P(v)	0.001***			0.001***			0.001***		
P(s)	0.001***			0.001***			0.001***		
P(VxS)	0.001***			0.001***			0.001***		
$LSD_{(0.05)}$V	2			1.087			1.179		
$LSD_{(0.05)}$S	1.168			0.995			1.114		
$LSD_{(0.05)}$(VxS)	2.477			1.703			1.885		
CV (%)	1.9			1.5			1.6		

V- variety: S-site

*** Statistically highly significant at 0.001

4.7 Yield factors on direct seeded and transplanted rain-fed varieties

Results revealed significant (P<0.05) varietal differences on number of productive tillers per hill of rain-fed varieties (Table 4.12). Komboka registered significantly higher number of productive tillers at 13 compared to NERICA1 and MWUR4 each at 10 tillers while NERICA4 had the lowest means at 8 tillers (Table 4.12). Direct seeding and transplanting method of rice establishment did not statistically (P>0.05) influence production of productive tillers on tested rain-fed varieties. On the other hand, there was a significant (P<0.05) increase in number of productive tillers in Ahero compared to Mwea site (Table 4.13).

Number of unfilled grains per hill was significant (P<0.05)) among the four rain-fed varieties, though insignificantly (P>0.05) affected by direct seeding and transplanting method of crop establishment (4.12). The highest number of unfilled grains was recorded by Komboka compared to the other three varieties. Site of trial also significantly (P<0.05) influenced occurrence of unfilled grains per hill as confirmed by higher numbers at Ahero compared to Mwea site. A significant (P<0.05) interaction was noted between variety and site in regard to production of unfilled grains per hill of rain-fed varieties.

Direct seeding and transplanting method of rice establishment had insignificant (P>0.05) effect on weight of thousand seeds and similarly non-significance among the four rain-fed varieties (Table 4.12). Equally no significant variation was registered on thousand seed weight across Mwea and Ahero site (Table 4.13).

Grain yield was not statistically affected among four rain-fed varieties on either direct seeding or transplanting method of crop establishment. Similarly, grain yield was not influenced by site location. Nevertheless, transplanted mean was higher (5.1 t h^{-1}) compared to direct seeded (4.7 t h^{-1}) on rain-fed varieties. On the other hand direct seeding registered grain yields of 5.5 t h^{-1} on NERICA1 and 4.9 t h^{-1} for Komboka (Table 4.12). On the other hand, results indicated grain yield mean of 4.4 and 5.2 t h^{-1} at Ahero and Mwea respectively while on individual varieties, Komboka performed better with highest mean on grain yield of 5.3 t h^{-1}, compared to lowest mean at 4.6 t h^{-1} on MWUR4 variety (Table 4.13).

Table 4.12 Yield components on direct seeded and transplanted rain-fed varieties

Variety	No. of productive tillers/hill			Number of unfilled grains/hill			1000 seed weight (g)			Grain yield (t h^{-1})		
	DS	TP	Mean	DS	TP	Mean	DS	TP	Mean	DS	TP	Mean
NERICA1	11	10	10b	96	70	83b	23.8	23.0	23.4a	5.5	4.5	5.0a
NERICA4	8	9	8c	81	77	79b	21.9	22.1	22.0a	4.3	5.4	4.9a
KOMBOKA	12	14	13a	116	188	152a	25.1	22.3	23.7a	4.9	5.6	5.3a
MWUR4	10	11	10b	71	68	69b	23.3	24.4	23.8a	4.3	4.8	4.6a
Mean	10a	11a		91a	100a		23.5a	22.9a		4.7a	5.1a	
P(Est)	0.248ns			0.55ns			0.404ns			0.503ns		
P(V)	0.001**			0.001**			0.422ns			0.489ns		
P(EstxV)	0.521ns			0.05*			0.422ns			0.735ns		
$LSD_{(0.05)}$ (Est)	2.735			59.28			2.373			3.009		
$LSD_{(0.05)}$ (V)	1.696			34.89			2.564			1.085		
$LSD_{(0.05)}$ (EstxV)	2.509			52.83			3.31			2.305		
CV (%)	24.4			33.2			12.8			33.8		

Est- method of crop establishment: V- variety

** Statistically significant at 0.01, * statistically significant at 0.05, ns not significant.

Table 4.13 Yield components of rain-fed varieties at Mwea and Ahero sites

Variety	No. of productive tillers/hill			Number of unfilled grains/hill			1000 seed weight (g)			Grain yield (t h^{-1})		
	Mwea	Ahero	Mean	Mwea	Ahero	Mean	Mwea	Ahero	Mean	Mwea	Ahero	Mean
NERICA1	9	11	10b	59	107	83b	23.1	23.7	23.4a	5.3	3.8	4.6a
NERICA4	7	9	8c	57	100	79b	21.6	22.4	22.0a	5.6	4.2	4.9a
KOMBOKA	11	14	13a	175	129	152a	24.8	22.5	23.7a	5.0	5.5	5.3a
MWUR4	6	14	10b	35	103	69b	23.3	24.4	23.8a	4.8	4.2	4.5a
Mean	8b	12a		81b	110a		23.2a	23.2a		5.2a	4.4a	
P(S)	0.001***			0.007**			0.966ns			0.129ns		
P(V)	0.001***			0.001***			0.422ns			0.489ns		
P(SxV)	0.11ns			0.002**			0.499ns			0.421ns		
$LSD_{(0.05)}$ (S)	1.576			19.52			1.819			0.998		
$LSD_{(0.05)}$ (V)	1.696			34.89			2.564			1.085		
$LSD_{(0.05)}$ (SxV)	2.682			42.51			3.464			1.705		
CV (%)	24.4			33.2			12.8			33.8		

V- variety: S-site

*** Statistically highly significant at 0.001, ** statistically significant at 0.01, ns not significant.

4.8 Yield factors on direct seeded and transplanted irrigated varieties

Results indicted significant ($P<0.05$) varietal differences on number of productive tillers hill^{-1} of irrigated varieties (Table 4.14). NIBAM11 and MWIR2 statistically differed from SARO5 and Komboka (Table 4.14). Direct seeding and transplanting had no significant ($P>0.05$) effect on number of productive tillers on irrigated varieties, though more tillers were revealed when direct seeding was adopted (20 tillers) compared to transplanting (18tillers) (Table 4.14). In addition, number of productive tillers were statistically ($P<0.05$) influenced by the site with Ahero registering high mean of 22 compared to Mwea with 17 (Table 4.15).

Number of unfilled grains hill^{-1} was not significantly (P>0.05) different among the four tested irrigated varieties and similarly not affected by either direct seeding or transplanting method of crop establishment (4.14). Results indicated that location of site significantly (P<0.05) influenced occurrence of unfilled grains as confirmed by higher numbers at Ahero compared to Mwea site (4.15). MWIR2 had highest number of unfilled grains at both Ahero and Mwea while least number of unfilled grains was noted on NIBAM11 at Mwea (Table 4.15). Weight of thousand seeds (g) was not significantly (P>0.05) influenced by either direct seeding or transplanting of irrigated rice varieties. Varietal means ranged between highest at 23.6g (SARO5) to the lowest 22.3g (MWIR2). Similarly, variation in weight (g) of 1000 seeds was insignificant across Mwea and Ahero site whose means were 22.9g and 22.4g respectively (Table 4.15).

Method of crop establishment did not significantly (P>0.05) affect grain yield (t h^{-1}) (Table 4.14) and also no significant (P>0.05) varietal grain yield differences was revealed. Under direct seeded crop, Komboka and MWIR2 registered the highest grain yield each at d at 5.8 t h^{-1} each. Under transplanting method of crop establishment, MWIR2 posted a high of 6.8 t h^{-1} compared to Komboka at 5.6 t h^{-1}. SARO5 and NIBAM11 had similar levels of grain yield on both direct seeding and transplanting at 5.7 t h^{-1} for SARO5 and 4.8 t h^{-1} for NIBAM11. Also, grain yield was not statistically affected by site location (Mwea and Ahero), though MWIR2 posted highest 8.0 t h^{-1} and NIBAM11 at 5.3 t h^{-1}as least grain yield at Ahero (Table 4.15). SARO5 (4.8 t h^{-1}) had the highest means on grain yield at Mwea and the least was NIBAM11 (4.3 t h^{-1}).

Table 4.14: Yield response on direct seeded and transplanted irrigated varieties

Variety	No. of productive tillers/hill			Number of unfilled grains/hill			1000 seed weight (g)			Grain yield (t h^{-1})		
	DS	TP	Mean	DS	TP	Mean	DS	TP	Mean	DS	TP	Mean
SARO5	20	15	17b	114	125	120a	22.9	24.2	23.6a	5.7	5.7	5.7a
KOMBOKA	16	17	17b	95	158	127a	21.8	23.6	22.7a	5.8	5.6	5.7a
NIBAM11	21	22	22a	113	139	126a	22.7	21.1	21.9a	4.8	4.8	4.8a
MWIR2	25	18	21a	179	131	155a	21.6	23.0	22.3a	5.8	6.8	6.3a
Mean	20a	18b		125a	138a		22.2a	23.0a		5.5a	5.7a	
P(Est)	0.019*			0.343ns			0.196ns			0.796ns		
P(V)	0.007**			0.34ns			0.359ns			0.266ns		
P(EstxV)	0.041*			0.98ns			0.299ns			0.831ns		
$LSD_{(0.05)}$ (Est)	1.597			45.21			1.652			2.868		
$LSD_{(0.05)}$ (V)	3.203			43.9			2.071			1.576		
$LSD_{(0.05)}$ (EstxV)	3.975			57.53			2.633			2.468		
CV (%)	24.3			45.7			13.7			38.3		

DS-Direct seeded, TP- Transplanted: Est- method of crop establishment: V-variety

** Statistically significant at 0.01, * statistically significant at 0.05, ns not significant

Table 4.15: Yield response of irrigated rice varieties at Mwea and Ahero sites

Variety	No. of productive tillers/hill			Number of unfilled grains/hill			1000 seed weight (g)			Grain yield (t h^{-1})		
	Mwea	Ahero	Mean	Mwea	Ahero	Mean	Mwea	Ahero	Mean	Mwea	Ahero	Mean
SARO5	15	19	17b	73	167	120a	24.7	22.4	23.6a	4.8	6.7	5.7a
KOMBOKA	14	17	17b	68	185	127a	22.7	22.7	22.7a	4.4	7.0	5.7a
NIBAM11	19	24	22a	56	196	126a	22.0	21.7	21.9a	4.3	5.3	4.8a
MWIR2	19	24	21a	112	199	155a	22.0	22.6	22.3a	4.6	8.0	6.3a
Mean	17b	22a		77b	187a		22.9a	22.4a		4.5b	6.7a	
P(S)	0.002**			0.001***			0.572ns			0.003**		
P(V)	0.007**			0.34ns			0.359ns			0.266ns		
P(SxV)	0.991ns			0.712ns			0.693ns			0.619ns		
$LSD_{(0.05)}$ (S)	2.921			36.99			1.899			1.331		
$LSD_{(0.05)}$ (V)	3.203			43.9			2.071			1.576		
$LSD_{(0.05)}$ (SxV)	5.005			65.27			3.247			2.346		
CV (%)	24.3			45.7			13.7			38.3		

V-variety: S-site

*** Statistically highly significant at 0.001, ** statistically significant at 0.01, ns not significant

4.9 Filled grains ratio of direct seeded and transplanted rain-fed rice varieties.

Number of unfilled grains in relation to filled grains per hill on rain-fed varieties were statistically (P<0.05) affected by method of crop establishment. Komboka posted higher ratio (0.3) on transplanting compared to direct seeding (0.17). MWUR4 had the least filled grain ratios of 0.09 and 0.12 on transplanting and direct seeding respectively (Figure 4.5)

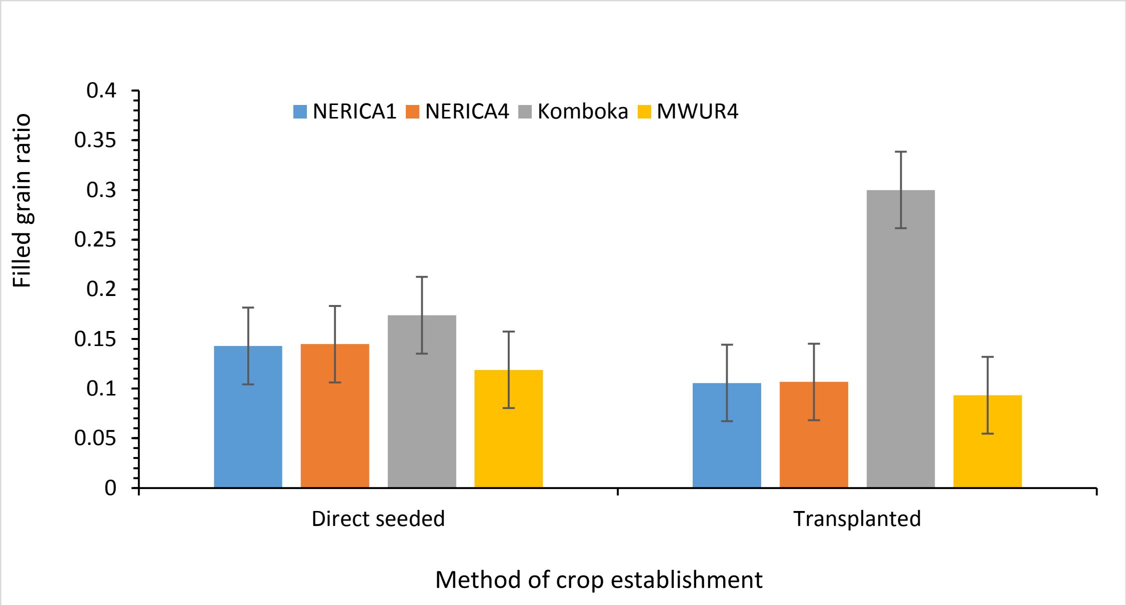


Figure 4.5: Effect of establishment method on filled grain ratio of four rain-fed varieties. *(*Bars represent LSD at 0.05 significance level.)

4.10 Gross margin analysis under direct seeding and transplanting methods of rice establishments

Variable costs were higher on transplanted (KES 84 850) compared to direct seeded crop (KES 60 300) specifically on land puddling, nursery management practices, transplanting operations and bird scaring (Table 4.16). Gross margin and gross income were higher on transplanted MWIR2 than direct seeded Komboka (Table 4.16). Demand for weeding labour was spread over a long period under direct seeding (Kumar and Ladha, 2011) where four weeding operations were carried out to reduce competition thus keeping crop weed free for a longer period and ensuring higher yields, and probably a higher gross margin (Getachew *et al*, 2017). Results of this study indicated that, direct seeded rain-fed varieties attained flowering onset earlier than transplanted irrigated varieties and also matured 7-10 days earlier thus decreased labour cost on bird scaring activity compared to transplanted irrigated rice that exhibited delayed maturity.

Table 4.16 Gross margin analysis of direct seeded rain-fed (Komboka) and transplanted irrigated (MWIR2) rice varieties

Item Category	**KES acre^{-1}**	
Land preparation	Transplanted (MWIR2)	Direct seeded (Komboka)
Plough, Rotavation levelling	10,000	N/A
Plough, Harrow	N/A	6,000
Bunds& canal repair/	2,000	N/A
Paddocking	N/A	5 000
Manure	5,000	5 000
Nursery management (10m^2)		
Bed preparation, Seeds, fertilizer	2 250	N/A
(Seeding, Bird scare, weeding, Irrigation)	11 400	N/A
Labour requirements		
Transplanting/ Seeding/gapping	10 000	5 350
Fertilizer + pesticide +application	10 650	10 850
Pesticides	300	500
Management aspect		
Weed control	4 000	9 600
Bird scaring	11 250	9 500
Irrigation management	12 000	2 500
Harvesting	6 000	6 000
Total variable costs	**84 850**	**60 300**
Yield (kg acre^{-1})	**2 760**	**1 960**
Price (KES kg^{-1})	**150**	**150**
Gross income	**414 000**	**294 000**
Gross margin	**329 150**	**233 700**

CHAPTER FIVE: DISCUSSION, CONCLUSION AND RECOMMENDATION

5.1 DISCUSSION

Certainly, demand for rice as food commodity continues to grow as a result of increasing human population as well as change in feeding behavior. Objective of this research was to assess growth and yield response by use of direct seeding and transplanting method of crop establishment on rain-fed and irrigated rice varieties within the lowlands of Kenya. Direct seeding and transplanting of rain-fed rice is rarely practiced amongst farmers in rice growing areas of Kenya. Direct seeding of irrigated rice is also a rare cultivation practice in Kenya compared to the conventional system where farmers transplant seedlings raised in nursery for three-four weeks.

In the present research, direct seeded crop had more tillers and increased height compared to transplanted crop during growth and development on both rain-fed and irrigated varieties. Among the four rain-fed varieties under trial, DS- MWUR4 was taller compared to TP-MWUR4 with a similar trend observed on Komboka, NERICA1 and 4. A higher number of tillers and leaves were displayed by Komboka which might have contributed to the higher grain yield among the four tested rain-fed varieties. Increased number of tillers on direct seeded crop could be as a result of absence of transplanting shock caused by root damage during uprooting and transplanting operation and hence delayed tillering. These results are in line with Dingkuhn, (1990) that there was 15 days delay on tillering thus a reduction on tiller number on young seedlings that suffer transplanting shock.

Results on irrigated rice varieties showed increased number of leaves and tillers on directed seeded crop compared to transplanted crop. Similarly, varieties indicated significant height differences with NIBAM11 as tallest (42.3cm) compared to shortest MWIR2 (36.1cm). However, MWIR2 had more tillers and leaf number compared to NIBAM11 which indicated lowest of numbers among the tested irrigated varieties probably due to inherent attributes. The continuous increase in height on both rain-fed and irrigated varieties was a sign that the crop changed from rapid vegetative to reproductive phase along the crops' growth phases (Krishnan *et al*., 2011).The varietal differences in tiller production may be an attribute of individual variety inherent traits (Chandrashekhar *et al*., 2001) with similar results on significant differences in vegetative growth (height and leaf number) as a result of individual variety character, and agrees with Mannan *et al*., (2009), Garba *et al*., (2013) and Gagandeep and Gandhi, (2015) who emphasized that vegetative growth of rice is significantly subjective to specific variety.

Results of this study indicated a significant site difference on vegetative growth of height and number of tillers on rain-fed and irrigated varieties with Ahero displaying taller crops and more tillers compared to shorter crop compared to Mwea location. Temperatures at Ahero and Mwea were within optimum and conducive range (25-35^oC) and perceived not to have any effect on growth characters (Ali *et al*, 2006). However, Ahero was hot and humid for most of days within the growing season and yet favoured by conventional type of rains owing to site proximity to lake Victoria water body, as opposed to Mwea that experienced hot and dry weather in most of the days within the crop season and this could have led to the higher number of tillers and height differences compared to Mwea site. These findings were in agreement to results by Ashrafwzzaman *et al*., (2009) and Hailu, (2010) that, growth characters of rice are dependent on environmental factors apart from their genetic composition. Soils from both sites indicated adequate levels of required nutrients for rice growth while low total nitrogen was corrected accordingly thus the crop growth and development potential was demonstrated.

Days to flowering on rain-fed crop was not significantly affected by method of crop establishment. However, days to 50% and 100% flowering were significantly reduced on direct seeded crop compared to transplanted crop by 7 days and 5 days respectively.

Flowering time of a rice variety is a necessary agronomic trait besides yield and plant height (Xue *et al*., 2008) and forms an important criteria in varietal selection. Varieties that attains flowering earliest are likely to mature earlier and therefore will make use of available moisture in rain-fed lowland when rainfall is inadequate. Farmers are also able to plan for a second crop within a year thus a reliable source of grain for household consumption. Among the tested, varieties NERICA1 attained flower onset earlier (77days) compared to Komboka with longest (101) duration in days which could probably be a varietal trait for rain-fed varieties. NERICA1, 4 and MWUR4 significantly reduced number of days to 50% and 100% flowering when compared to Komboka which took more days and at the same time a variety, suitable on both irrigated and rain-fed environments. Results findings showed that days to flower onset and 50% were statistically reduced at Ahero compared to Mwea by 8 and 7 days respectively and probably favoured by the environmental factors at the site during early crop growth.

On the contrary, irrigated varieties significantly reduced days to flower onset, 50% and 100% at Mwea compared to irrigated varieties at Ahero. This could probably be as a result of environmental factors at the site during crop growth that hastened the crop physiological processes. These results are in conformity with Xue *et al*., (2008) findings that environmental factors during crop growth have an effect on days to flowering besides genetic and farm practices on spacing, irrigation regimes and weeding. Similar results of significantly reduced number of days to flowering onset was shown on direct seeded rain-fed varieties. Direct seeding of rice protects the crop from damage caused to roots during transplanting process which causes the shock to young seedlings before the plant regenerates new roots. Among the tested irrigated varieties, MWIR2 took the longest time to attain flower onset, 50% flowering as well as 100% while NIBAM11 had fairly less number of days to flower onset (96 days), 50% (101 days) and 100% at 107 days. These findings most likely had a bearing on variety's genetic traits.

Trial results confirmed that direct seeding and transplanting method of crop establishment had non-significant effect on number productive tillers hill^{-1} and number of unfilled grains hill^{-1} of rain-fed varieties. However there were significant differences on productive tillers and unfilled grains due to site location as well as significant influence in number of productive tillers and unfilled grains produced across the tested varieties. These results are in line with Krishnan *et al*., (2011) who reported that number of panicle bearing tillers per unit area largely influence grain yield besides other yield components. Komboka posted highest mean of productive tillers hill^{-1} as well as high number of unfilled grains. Rain-fed crop at Ahero had more unfilled grains than in Mwea which may have been attributed to more tillers produced at Ahero that caused competition thus more unfilled grains. These results differs with Islam *et al*., (2009) who stated that varieties with more productive tillers per unit area were likely to yield more grain compared to those with few tillers.

Number of productive tillers hill^{-1} on irrigated varieties were significantly affected by direct seeding and transplanting while number of unfilled grains were not significantly influenced by crop establishment method. There were significantly more tillers on direct seeded crop than transplanted crop probably because the crop was not subjected to transplanting shock (Dingkuhn, 1990) thus no negative influence on tillering behavior (Pasuquin *et al*., 2008). Ahero had a higher mean on number of productive tiller on irrigated varieties compared to Mwea site which could be attributed to enough moisture within the growing season at Ahero compared to Mwea site where the field required frequent replenishing with water due to drought within the crop growing season.

Grain yield (t ha^{-1}) and thousand seed weight (g) of rain-fed and irrigated rice varieties were not significantly affected by direct seeding or transplanting method of crop establishment. Similarly, there was no significant variation across tested rain-fed and irrigated varieties on 1000 seed weight and grain yield. These results confirms Hailu, (2010) sentiments that weight of thousand seeds was a varietal inherent yield component least affected by environmental factors and contrary to results by Mondal *et al*. (2005) who revealed differences in thousand grain weight on seventeen tested varieties.

However, grain yield of irrigated varieties was significantly different across sites with Ahero registering higher grain yield means compared to Mwea which probably could have a bearing to more rainfall events at Ahero coupled with lower clay percentage in soils that enhanced water and nutrients uptake by the crop during early crop growth. Although grain yield of rain-fed varieties was statistically similar under direct seeding and transplanting, Komboka had highest (5.3 t ha^{-1}) on rain-fed varieties while MWIR2 was highest (6.3 t ha^{-1}) among irrigated varieties.

These results are in line with Kukal and Aggrawal (2002) who confirmed that yields of direct seeded and transplanted rice on sandy loam conditions, (similar to rain-fed conditions at Mwea and Ahero) are likely to be similar as was the case with our results on rain-fed varieties. However, there is great possibility of increased yields on rain-fed rice at both Mwea and Ahero sites compared to what was realized owing to the prevailing dry weather and uneven distributed rains within the crop growing season that most likely affected consequent grain filling processes. On the other hand, grain yield on rain-fed varieties surpassed FAO, (2003) estimates for East Africa at 2.3 t ha^{-1}. In this study, NERICA4 attained 5.5 t ha^{-1} (transplanted) compared to 4.4 t ha^{-1} (direct seeded) which confirms Seyuom (2011) report that, under ideal conditions NERICA have grain yield potential of over 5.4 t ha^{-1}.

During this experiment, demand for weeding labour was spread over a longer period on direct seeded crop compared to transplanted rice so as to reduce weed competition thus, additional cost on production. These results concurs with Kumar and Ladha, (2011) whose results indicated that labour requirement for weeding were higher on direct seeded rice and hence higher labour costs in weeding. The weeds in transplanted crop were managed by flooding field with water while occasional hand pulling of volunteer weed species was important after the initial weeding operation. Variable costs were higher on transplanted (KES 84 850) crop compared to direct seeded (KES 60 300) specifically on land puddling, nursery-bed practices, transplanting and bird scaring. Direct seeding excluded rising of seedlings in the nursery, uprooting and transplanting and therefore reduced variable costs in this trial, with similar results by Kabir *et al*, (2009). Direct seeding of rain-fed rice reduced labour costs in bird scaring activity since the crop attained flower onset earlier compared to transplanted irrigated crop thus a reduction in bird scaring labour cost.

5.2 Conclusion and recommendation

Great potential exists towards yield improvement if only improved rain-fed and irrigated rice varieties could be exploited through appropriate cultivation practices within Kenyan lowlands. Direct seeding has shown an improvement on crop growth factors of plant height and number of tillers on both irrigated and rain-fed varieties. These growth factors form an important basis for increased yields on these varieties. The level of grain productivity generated by this trial may not be near the expected frontier to meet demand for rice in Kenya due to increasing demand for rice grains. Though grain yield on direct seeded crop were statistically similar to yields on transplanted crop on both rain-fed and irrigated varieties, the results on grain yield indicate substantial improvement with reference to previous report by FAO that East African small holders' barely produce beyond 2.3 t ha^{-1} on rain-fed varieties. Among the tested varieties, direct seeded and transplanted Komboka on rain-fed lowlands indicated better growth and yields factors while MWIR2 revealed greater potential on growth and yield factors on direct seeded and transplanted irrigated lowlands which makes them better choices for Mwea and Ahero lowland. Also, direct seeded NERICA1 and 4 attained flowering onset and subsequently matured earlier presenting a great potential towards food security even when there is water scarcity. There were less variable costs on direct seeding compared to transplanting method of crop establishment which reduces the farmers' expenditure on cost of production and thus a sustainable method among the small holders.

Further research would be appropriate targeting more rain-fed and irrigated rice varieties under direct seeding method of rice establishment within other suitable rice growing areas, as an expansion strategy on increasing areas under rice cultivation in Kenya.

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APPENDICES

Appendix 1 Summary ANOVA table for number of tillers on direct seeded and transplanted rain-fed rice varieties at different days after sowing in Mwea and Ahero rain-fed lowland ecology

Source of variation	d.f.	s.s.	m.s.	F	P	
Block	2	69.627	34.813	0.93		
EST	1	283.434	283.434	7.57	0.111	
Residual	2	74.861	37.43	3.5		
Variety	3	1278.674	426.225	39.89	<.001	***
EST x Variety	3	39.561	13.187	1.23	0.34	
Residual	12	128.217	10.685	5.38		
DAS	6	6031.853	1005.309	506.34	<.001	***
EST.DAS	6	31.148	5.191	2.61	0.022	*
Variety x DAS	18	616.094	34.227	17.24	<.001	***
EST x Variety x DAS	18	16.606	0.923	0.46	0.967	
Residual	96	190.602	1.985	0.39		
Site	1	173.434	173.434	34.3	<.001	***
EST x Site	1	27.087	27.087	5.36	0.022	*
Variety x Site	3	67.152	22.384	4.43	0.006	**
DAS x Site	6	269.855	44.976	8.89	<.001	***
EST x Variety x Site	3	21.067	7.022	1.39	0.25	
EST x DAS x Site	6	4.336	0.723	0.14	0.99	
Variety x DAS x Site	18	110.562	6.142	1.21	0.262	
EST x Variety x DAS x Site	18	8.167	0.454	0.09	1.000	
Residual	112	566.32	5.056			
Total	335	10008.66				

Appendix 2 Summary ANOVA table for plant height (cm) on direct seeded and transplanted rain-fed rice varieties at different days after sowing in Mwea and Ahero rain-fed lowland ecology

Source of variation	d.f.	s.s.	m.s.	F	P	
Block	2	1224.91	612.45	1.73		
EST	1	1528.32	1528.32	4.31	0.173	
Residual	2	708.87	354.44	7.46		
Variety	3	8400	2800	58.95	<.001	***
EST x Variety	3	425.8	141.93	2.99	0.073	
Residual	12	569.97	47.5	3.21		
DAS	6	72396.76	12066.13	814.9	<.001	***
EST x DAS	6	395.67	65.95	4.45	<.001	***
Variety x DAS	18	1856.97	103.16	6.97	<.001	***
EST x Variety x DAS	18	141.55	7.86	0.53	0.937	
Residual	96	1421.46	14.81	0.43		
Site	1	6228.13	6228.13	180.82	<.001	***
EST x Site	1	418.53	418.53	12.15	<.001	***
Variety x Site	3	190.22	63.41	1.84	0.144	
DAS x Site	6	4823.82	803.97	23.34	<.001	***
EST x Variety x Site	3	693.96	231.32	6.72	<.001	***
EST x DAS x Site	6	242.35	40.39	1.17	0.326	
Variety x DAS x Site	18	434.86	24.16	0.7	0.803	
EST x Variety x DAS x Site	18	180.91	10.05	0.29	0.998	
Residual	112	3857.8	34.44			
Total	335	106140.9				

Appendix 3 Summary ANOVA table for number of leaves on direct seeded and transplanted rain-fed rice varieties at different days after sowing in Mwea and Ahero rain-fed lowland ecology

Source of variation	d.f.	s.s.	m.s.	F	P	
Block	2	834.68	417.34	1.75		
EST	1	2249.57	2249.57	9.45	0.091	
Residual	2	475.86	237.93	1.46		
Variety	3	15145.78	5048.59	30.91	<.001	***
EST x Variety	3	116.1	38.7	0.24	0.869	
Residual	12	1959.77	163.31	2.86		
DAS	6	55509.04	9251.51	162.2	<.001	***
EST.DAS	6	368.11	61.35	1.08	0.383	
Variety x DAS	18	3750.11	208.34	3.65	<.001	***
EST x Variety x DAS	18	390.85	21.71	0.38	0.989	
Residual	96	5475.51	57.04	0.68		
Site	1	0.11	0.11	0.00132	0.971	
EST x Site	1	1.41	1.41	0.02	0.897	
Variety x Site	3	308.43	102.81	1.23	0.301	
DAS x Site	6	8566.49	1427.75	17.14	<.001	***
EST x Variety x Site	3	519.73	173.24	2.08	0.107	
EST x DAS x Site	6	219.15	36.53	0.44	0.852	
Variety x DAS x Site	18	4819.62	267.76	3.21	<.001	***
EST x Variety x DAS x Site	18	497.26	27.63	0.33	0.995	
Residual	112	9330.08	83.3			
Total	335	110537.7				

Appendix 4 Summary ANOVA table for number of tillers on direct seeded and transplanted irrigated rice varieties at different days after sowing in Mwea and Ahero irrigated lowland ecology

Source of variation	d.f.	s.s.	m.s.	F	P	
Block	2	375.12	187.56	1.04		
EST	1	2709.81	2709.81	15.06	0.06	
Residual	2	359.77	179.88	3.91		
Variety	3	754.13	251.38	5.46	0.013	*
EST x Variety	3	28.23	9.41	0.2	0.891	
Residual	12	552.19	46.02	10.2		
DAS	6	19294.75	3215.79	712.81	<.001	***
EST x DAS	6	323.63	53.94	11.96	<.001	***
Variety x DAS	18	292.65	16.26	3.6	<.001	***
EST x Variety x DAS	18	103.4	5.74	1.27	0.223	
Residual	96	433.1	4.51	0.41		
Site	1	321.36	321.36	29.24	<.001	***
EST x Site	1	167.17	167.17	15.21	<.001	***
Variety x Site	3	224.16	74.72	6.8	<.001	***
DAS x Site	6	1429.51	238.25	21.68	<.001	***
EST x Variety x Site	3	112.16	37.39	3.4	0.02	*
EST x DAS x Site	6	108.15	18.02	1.64	0.143	
Variety x DAS x Site	18	268.45	14.91	1.36	0.168	
EST x Variety x DAS x Site	18	94.09	5.23	0.48	0.964	
Residual	112	1231.05	10.99			
Total	335	29182.87				

Appendix 5 Summary ANOVA table for plant height (cm) of direct seeded and transplanted irrigated rice varieties at different days after sowing in Mwea and Ahero irrigated lowland ecology

Source of variation	d.f.	s.s.	m.s.	F	P	
Block	2	11.355	5.677	0.05		
EST	1	499.81	499.81	4.39	0.171	
Residual	2	227.748	113.874	6.77		
Variety	3	3317.401	1105.8	65.75	<.001	***
EST x Variety	3	356.587	118.862	7.07	0.005	**
Residual	12	201.808	16.817	4.06		
DAS	6	53827.33	8971.222	2166.84	<.001	***
EST.DAS	6	8.02	1.337	0.32	0.924	
Variety x DAS	18	1346.25	74.792	18.06	<.001	***
EST x Variety x DAS	18	114.027	6.335	1.53	0.096	
Residual	96	397.463	4.14	0.54		
Site	1	114.567	114.567	15.03	<.001	***
EST x Site	1	52.646	52.646	6.91	0.01	**
Variety x Site	3	238.91	79.637	10.45	<.001	***
DAS x Site	6	7136.526	1189.421	156.07	<.001	***
EST x Variety x Site	3	270.2	90.067	11.82	<.001	***
EST x DAS x Site	6	12.017	2.003	0.26	0.953	
Variety x DAS x .Site	18	461.988	25.666	3.37	<.001	*
EST x Variety x DAS. x Site	18	44.26	2.459	0.32	0.996	
Residual	112	853.547	7.621			
Total	335	69492.46				

Appendix 6 Summary ANOVA table for number of leaves on direct seeded and transplanted irrigated rice varieties at different days after sowing in Mwea and Ahero irrigated lowland ecology

Source of variation	d.f.	s.s.	m.s.	F	P	
Block	2	1820.6	910.3	0.76		
EST	1	20634.6	20634.6	17.14	0.054	
Residual	2	2407.7	1203.9	3.06		
Variety	3	7221.4	2407.1	6.11	0.009	**
EST x Variety	3	65	21.7	0.06	0.982	
Residual	12	4728.1	394	5.16		
DAS	6	132325.6	22054.3	288.78	<.001	***
EST x DAS	6	1526.1	254.3	3.33	0.005	**
Variety x DAS	18	2625.3	145.9	1.91	0.024	*
EST x Variety x DAS	18	920	51.1	0.67	0.833	
Residual	96	7331.7	76.4	0.43		
Site	1	8547.6	8547.6	47.67	<.001	***
EST x Site	1	32.4	32.4	0.18	0.672	
Variety x Site	3	2772.9	924.3	5.15	0.002	**
DAS x Site	6	56588.1	9431.4	52.6	<.001	***
EST x Variety x Site	3	3425.4	1141.8	6.37	<.001	***
EST x DAS x Site	6	1514.5	252.4	1.41	0.218	
Variety x DAS x Site	18	2720.5	151.1	0.84	0.647	
EST x Variety x DAS x Site	18	965.2	53.6	0.3	0.997	
Residual	112	20082.4	179.3			
Total	335	278255.1				

Appendix 7 Summary ANOVA table for days to flowering onset on direct seeded and transplanted rain-fed rice varieties in Mwea and Ahero

Source of variation	d.f.	s.s.	m.s.	F	P	
BLOCK	2	81.38	40.69	0.54		
EST	1	513.52	513.52	6.87	0.12	
Residual	2	149.54	74.77	4.38		
Variety	3	4306.23	1435.41	83.99	<.001	***
EST x Variety	3	487.06	162.35	9.5	0.002	**
Residual	12	205.08	17.09	1		
Site	1	682.52	682.52	39.95	<.001	***
EST x Site	1	336.02	336.02	19.67	<.001	***
Variety x Site	3	30.73	10.24	0.6	0.625	
EST x Variety x Site	3	312.9	104.3	6.11	0.006	**
Residual	16	273.33	17.08			
Total	47	7378.31				

Appendix 8 Summary ANOVA table for days to 50% flowering on direct seeded and transplanted rain-fed rice varieties in Mwea and Ahero

Source of variation	d.f.	s.s.	m.s.	F	P	
BLOCK	2	262.5	131.25	56.25		
EST	1	581.02	581.02	249.01	0.004	**
Residual	2	4.67	2.33	0.08		
Variety	3	2875.56	958.52	32.79	<.001	***
EST x Variety	3	269.23	89.74	3.07	0.069	
Residual	12	350.83	29.24	1.1		
Site	1	526.69	526.69	19.91	<.001	***
EST x Site	1	858.52	858.52	32.45	<.001	***
Variety x Site	3	48.23	16.08	0.61	0.62	
EST x Variety x Site	3	498.73	166.24	6.28	0.005	**
Residual	16	423.33	26.46			
Total	47	6699.31				

Appendix 9 Summary ANOVA table for days to100% flowering on direct seeded and transplanted rain-fed rice varieties in Mwea and Ahero

Source of variation	d.f.	s.s.	m.s.	F	P	
BLOCK	2	261.5	130.75	17.24		
EST	1	290.08	290.08	38.25	0.025	*
Residual	2	15.17	7.58	0.19		
Variety	3	2157.17	719.06	17.69	<.001	***
EST x Variety	3	140.42	46.81	1.15	0.368	
Residual	12	487.67	40.64	2.61		
Site	1	168.75	168.75	10.84	0.005	**
EST x Site	1	481.33	481.33	30.93	<.001	***
Variety x Site	3	63.08	21.03	1.35	0.293	
EST x Variety x Site	3	283.83	94.61	6.08	0.006	**
Residual	16	249	15.56			
Total	47	4598				

Appendix 10 Summary ANOVA table for days to flowering onset on direct seeded and transplanted irrigated rice varieties in Mwea and Ahero

Source of variation	d.f.	s.s.	m.s.	F	P	
Block	2	7.167	3.583	6.14		
EST	1	65.333	65.333	112	0.009	**
Residual	2	1.167	0.583	0.12		
Variety	3	954.25	318.083	62.92	<.001	***
EST x Variety	3	17.333	5.778	1.14	0.371	
Residual	12	60.667	5.056	1.39		
Site	1	168.75	168.75	46.29	<.001	***
EST x Site	1	5.333	5.333	1.46	0.244	
Variety x Site	3	506.25	168.75	46.29	<.001	***
EST x Variety x Site	3	29.333	9.778	2.68	0.082	
Residual	16	58.333	3.646			
Total	47	1873.917				

Appendix 11 Summary ANOVA table for days to 50% flowering on direct seeded and transplanted irrigated rice varieties in Mwea and Ahero

Source of variation	d.f.	s.s.	m.s.	F	P	
Block	2	3.875	1.938	1		
EST	1	54.188	54.188	27.97	0.034	*
Residual	2	3.875	1.938	1.3		
Variety	3	1244.562	414.854	277.86	<.001	***
EST x Variety	3	11.396	3.799	2.54	0.105	
Residual	12	17.917	1.493	0.56		
Site	1	172.521	172.521	65.2	<.001	***
EST x Site	1	3.521	3.521	1.33	0.266	
Variety x Site	3	597.396	199.132	75.26	<.001	***
EST x Variety x Site	3	33.729	11.243	4.25	0.022	*
Residual	16	42.333	2.646			
Total	47	2185.312				

Appendix 12 Summary ANOVA table for days to100% flowering on direct seeded and transplanted irrigated rice varieties in Mwea and Ahero

Source of variation	d.f.	s.s.	m.s.	F	P	
Block	2	4.625	2.312	0.5		
EST	1	20.021	20.021	4.31	0.174	
Residual	2	9.292	4.646	2.64		
Variety	3	864.562	288.188	164.03	<.001	***
EST x Variety	3	9.729	3.243	1.85	0.193	
Residual	12	21.083	1.757	0.53		
Site	1	567.188	567.188	171.23	<.001	***
EST x Site	1	2.521	2.521	0.76	0.396	
Variety x Site	3	636.896	212.299	64.09	<.001	***
EST x Variety x Site	3	45.896	15.299	4.62	0.016	*
Residual	16	53	3.313			
Total	47	2234.812				

Appendix 13 Summary ANOVA table for thousand seed weight (g) of direct seeded and transplanted rain-fed rice varieties in Mwea and Ahero

Source of variation	d.f.	s.s.	m.s.	F	P
Rep	2	13.015	6.508	1.78	
EST	1	4.025	4.025	1.1	0.404
Residual	2	7.3	3.65	0.44	
Variety	3	25.187	8.396	1.01	0.422
EST x Variety	3	25.171	8.39	1.01	0.422
Residual	12	99.681	8.307	0.94	
Site	1	0.017	0.017	0.0019	0.966
EST x Site	1	25.085	25.085	2.84	0.111
Variety x Site	3	21.849	7.283	0.82	0.499
EST x Variety x Site	3	18.734	6.245	0.71	0.562
Residual	16	141.33	8.833		
Total	47	381.395			

Appendix 14 Summary ANOVA table for thousand seed weight (g) of direct seeded and transplanted irrigated rice varieties in Mwea and Ahero

Source of variation	d.f.	s.s.	m.s.	F	P
Rep	2	1.788	0.894	0.51	
EST	1	6.453	6.453	3.65	0.196
Residual	2	3.538	1.769	0.33	
Variety	3	19.145	6.382	1.18	0.359
EST x Variety	3	22.272	7.424	1.37	0.299
Residual	12	65.061	5.422	0.56	
Site	1	3.203	3.203	0.33	0.572
EST x Site	1	6.75	6.75	0.7	0.415
Variety x Site	3	14.192	4.731	0.49	0.693
EST x Variety x Site	3	28.822	9.607	1	0.419
Residual	16	154.033	9.627		
Total	47	325.257			

Appendix 15 Summary ANOVA table for number of productive tillers on direct seeded and transplanted rain-fed rice varieties in Mwea and Ahero

Source of variation	d.f.	s.s.	m.s.	F	P
Block	2	23.795	11.897	2.45	
EST	1	12.607	12.607	2.6	0.248
Residual	2	9.695	4.848	1.33	
Variety	3	124.229	41.41	11.39	<.001
EST x Variety	3	8.649	2.883	0.79	0.521
Residual	12	43.617	3.635	0.55	
Site	1	177.101	177.101	26.72	<.001
EST x Site	1	4.441	4.441	0.67	0.425
Variety x Site	3	47.009	15.67	2.36	0.11
EST x Variety x Site	3	6.442	2.147	0.32	0.808
Residual	16	106.067	6.629		
Total	47	563.652			

Appendix 16 Summary ANOVA table for number of unfilled grains of direct seeded and transplanted rain-fed rice varieties in Mwea and Ahero

Source of variation	d.f.	s.s.	m.s.	F	P
Block	2	6596	3298	1.45	
EST	1	1158	1158	0.51	0.55
Residual	2	4556	2278	1.48	
Variety	3	51608	17203	11.18	<.001
EST.Variety	3	16050	5350	3.48	0.05
Residual	12	18462	1538	1.51	
Site	1	9673	9673	9.51	0.007
EST.Site	1	8	8	0.01	0.933
Variety.Site	3	23351	7784	7.65	0.002
EST.Variety.Site	3	67	22	0.02	0.995
Residual	16	16281	1018		
Total	47	147809			

Appendix 17 Summary ANOVA table for total grain yield (t h^{-1}) on direct seeded and transplanted rain-fed rice varieties in Mwea and Ahero

Source of variation	d.f.	s.s.	m.s.	F	P
Block	2	0.029	0.014	0.002	
EST	1	3.856	3.856	0.66	0.503
Residual	2	11.74	5.87	3.)95	
Variety	3	3.826	1.275	0.86	0.489
EST x Variety	3	1.918	0.639	0.43	0.735
Residual	12	17.85	1.487	0.56	
Site	1	6.838	6.838	2.57	0.129
EST x Site	1	3.262	3.262	1.23	0.285
Variety x Site	3	7.935	2.645	0.99	0.421
EST x Variety x Site	3	0.42	0.14	0.05	0.984
Residual	16	42.595	2.662		
Total	47	100.268			

Appendix 18 Summary ANOVA table for number of productive tillers on direct seeded and transplanted irrigated rice varieties in Mwea and Ahero

Source of variation	d.f.	s.s.	m.s.	F	P
Block	2	15.93	7.96	4.82	
EST	1	83.21	83.21	50.33	0.019
Residual	2	3.31	1.65	0.13	
Variety	3	259.86	86.62	6.68	0.007
EST x Variety	3	145.81	48.6	3.75	0.041
Residual	12	155.63	12.97	0.57	
Site	1	312.12	312.12	13.7	0.002
EST x Site	1	0.48	0.48	0.02	0.886
Variety x Site	3	2.39	0.8	0.04	0.991
EST x Variety x Site	3	30.98	10.33	0.45	0.719
Residual	16	364.63	22.79		
Total	47	1374.35			

Appendix 19 Summary ANOVA table for number of unfilled grains on direct seeded and transplanted irrigated rice varieties in Mwea and Ahero

Source of variation	d.f.	s.s.	m.s.	F	P
Block	2	6606	3303	2.49	
EST	1	2009	2009	1.52	0.343
Residual	2	2649	1325	0.54	
Variety	3	9029	3010	1.24	0.34
EST.Variety	3	19191	6397	2.63	0.098
Residual	12	29225	2435	0.67	
Site	1	144075	144075	39.43	<.001
EST.Site	1	18258	18258	5	0.04
Variety.Site	3	5077	1692	0.46	0.712
EST.Variety.Site	3	11558	3853	1.05	0.396
Residual	16	58464	3654		
Total	47	306141			

Appendix 20 Summary ANOVA table for total grain yield (t h^{-1}) on direct seeded and transplanted irrigated rice varieties in Mwea and Ahero

Source of variation	d.f.	s.s.	m.s.	F	P
Block	2	9.106	4.553	0.85	
EST	1	0.463	0.463	0.09	0.796
Residual	2	10.667	5.333	1.7	
Variety	3	14.069	4.69	1.49	0.266
EST x Variety	3	2.745	0.915	0.29	0.831
Residual	12	37.678	3.14	0.66	
Site	1	60.232	60.232	12.74	0.003
EST x Site	1	0.012	0.012	0	0.961
Variety x Site	3	8.643	2.881	0.61	0.619
EST x Variety x Site	3	9.311	3.104	0.66	0.591
Residual	16	75.652	4.728		
Total	47	228.579			

Appendix 21 Summary ANOVA table for filled grain ratio on direct seeded and transplanted irrigated rice varieties in Mwea and Ahero

Source of variation	d.f.	s.s.	m.s.	F	P
Block	2	0.013802	0.006901	5.48	
EST	1	0.011748	0.011748	9.32	0.093
Residual	2	0.00252	0.00126	0.28	
Variety	3	0.008753	0.002918	0.65	0.595
EST x Variety	3	0.032385	0.010795	2.42	0.117
Residual	12	0.053505	0.004459	0.64	
Site	1	0.364265	0.364265	52.52	<.001
EST x Site	1	0.04361	0.04361	6.29	0.023
Variety x Site	3	0.015433	0.005144	0.74	0.543
EST x Variety x Site	3	0.018183	0.006061	0.87	0.475
Residual	16	0.11097	0.006936		
Total	47	0.675174			

Appendix 22 Summary of soil analysis methods procedures

Mehlich double acid method for available nutrient elements (P, K, Na, Ca, Mg and Mn):
The oven - dry at 40^0 C soil samples (< 2 mm) are extracted in a 1:5 ratio (w/v) with a mixture of 0.1 N HCl and 0.025 N H_2SO_4. Elements such as Na, Ca and K are determined with a flame photometer and P, Mg and Mn – spectrophotometrically.

Ref: Mehlich, A., Pinkerton, A., Robertson, W. and Kepton, R. (1962). Mass analysis methods for soil fertility evaluation. Cyclostyled Paper, National Agric. Laboratories, Nairobi.

Kjeldahl method for Total nitrogen:
Oven - dry at 40^0 C soil samples (< 0.5 mm) digested with concentrated sulphuric acid containing potassium sulphate, selenium and copper sulphate hydrated at approximately 350^0 C. Total N is determined by distillation followed by titration with diluted standardized H_2SO_4.

Ref: Page, A. L., Miller, R. H. and Keeney, D. R. (eds.) (1982). Methods of soil analysis. Part 2. Second edition. Amer. Soc. of Agron., Madison, Winconsin, USA. pp 595-622.

Calorimetric method for Total organic carbon
All organic carbon in the oven - dry at 40^0 C soil sample (< 0.5 mm) is oxidized by acidified dichromate at 150^0 C for 30 minutes to ensure complete oxidation. Barium chloride is added to the cool digests. After mixing thoroughly digests are allowed to stand overnight. The carbon concentration is determined on the spectrophotometer at 600 nm.

Ref: Anderson, J.M. and J.S.I. Ingram. (1993). Tropical soil biology and fertility: A handbook of methods. CAB International, Wallingford, Oxon, UK

Soil pH – water
Soil pH is determined in a 1:1 (w/v) soil – water suspension with pH – meter.

Ref: Mehlich, A., Pinkerton, A., Robertson, W. and Kepton, R. (1962). Mass analysis methods for soil fertility evaluation. Cyclostyled Paper, National Agric. Laboratories, Nairobi.

Extraction with 0.1 M HCl for available trace elements (Fe, Zn & Cu):
The oven - dry at 40^0 C soil samples (< 2 mm) are extracted in a 1:10 ratio (w/v) with 0.1 M HCl. Elements are determined with AAS (Atomic Absorption Spectrophotometer).

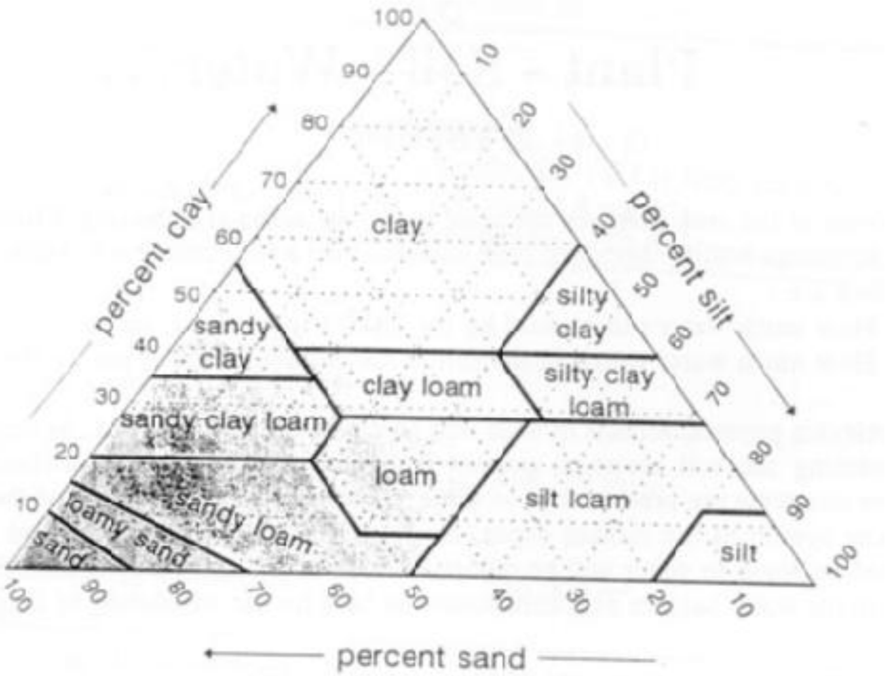
Ref: Mehlich, A., Pinkerton, A., Robertson, W. and Kepton, R. (1962). Mass analysis methods for soil fertility evaluation. Cyclostyled Paper, National Agric. Laboratories, Nairobi.

Appendix 23 Soil texture Bouyoucos hydrometer method

Procedure;

50g of oven-dry at 40^0 C soil sample (< 2 mm) was weighed and transferred into a 500-ml plastic shaking bottle. 300 ml of distilled water and 50 ml of dispersion agent (calgon) then added and shaken overnight. After shaking the soil suspension was transferred into to sedimentation cylinder and toped up to the 1 L mark. It was then mixed thoroughly with a plunger to bring the soil particles into suspension. The temperature of the suspension was observed and recorded.

A hydrometer was lowered into the solution and a reading taken and recorded 40 seconds after stirring ceased. After 2 hours a second reading was taken. The first hydrometer reading gave percentage for silt and clay. The second reading gave the density of clay particles. After getting the percentage sand, silt and clay, a textural classification chart (see below) was used to classify the soil.



Reference:

1. A. Klute (Ed.), (1986). Physical and mineralogical methods. Second Edition. The American Society of Agronomy, USA.