EFFECT OF WITHHOLDING IRRIGATION WATER AFTER COMPLETE HEADING ON RICE YIELD AND SEED QUALITY IN MWEA, KIRINYAGA COUNTY-KENYA

BY

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DECLARATION

This thesis is my original work, and has not been presented for a degree in any other University or any other award. Citation which is not my original work has been fully acknowledged.

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DEDICATION

Special dedication to my wife, Salam Tulay Momo and my four children Faliku, Ramie Fatu, Fatie and Jobson A, Momo Jr.

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ABSTRACT

Rice is considered main source of calories and protein especially in many countries of Africa as it constitutes a major part of the diet. It is steadily becoming a major staple food for many households in Kenya as annual consumption has increased by 12 % for rice; compared with 4% for wheat and 1% for maize hence, increasing its productivity is paramount, as eating habits changes especially among the youth. Threat of climate change continues to impede agricultural activities, resulting to droughts and floods. Hence, the research investigated effect of withholding water after complete heading on morphological characters, yield and its components and seed quality attributes of rice at KARI Mwea and MIAD in 2012. Experimental layout was split plots in randomized complete block design (RCBD) where water was supplied intermittently, and withheld 10 days after complete heading, 15 days, and 20 days. Water withholding were the main plots. Four rice varieties which included Nerica-1, Nerica-4, Nerica-10 and Basmati-370 were selected for the study and used as sub plots. All agricultural agronomic practices were applied as recommended. Variables were scored from five mother (tagged) plants on panicle length, number of matured tillers, grain size, filled and unfilled grain per panicle, filled and unfilled grain weight per panicle, grain weight per five hills sample, 1,000 grain weight, filter and sand germination, seedling length and seedling vigor index. ANOVA was done using SAS program version 9.2. Results from the study indicate that there were no significant differences on the yield components when irrigation was withheld. There were significant differences ($p<0.05$) for morphological characters of varieties which indicated that the varieties were distinct from each other probably due to differences in the genotypes. Seed quality attributes were improved by withholding water. The results showed that water can be economized without affecting productivity and that quality of seed is affected when threshold level is interfered.

Keywords: Irrigation, water stress, variety, yield, germination, seedling vigor index

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LIST OF ABBREVIATIONS AND ACRONYMS

Africa Rice	Africa Rice Center, ex-WARDA
AHSG	African Heads of State and Government
ANOVA	Analysis of Variance
AOSA	Association of Official Seed Analysts
ASAL	Arid and Semi-Arid Land
AWD	Alternate Wetting and Drying
CH	Complete Heading
DAS	Days After Sowing
DAE	Days After Emergency
FAO	Food and Agriculture Organization
FARA	Forum for Agricultural Research in Africa
FURP	Fertilizer Use Recommendation Project
GI	Germination Index
IBID	Ibidem (Same citation)
IIMP	Intermittent Irrigation Management Practice
ISTA	International Seed Testing Association
KARI	Kenya Agricultural Research Institute
KEPHIS	Kenya Plant Health Inspectorate Service
LSD	Least Significant Difference
MASL	Meter Above Sea Level
MC	Moisture Content
MIAD	Mwea Irrigation Agricultural Development
MOA	Ministry of Agriculture
NERICA	New Rice for Africa
NIB	National Irrigation Board
NRDS	National Rice Development Strategy
RPWE	Rice Physiological Water Equilibrium

SAS	Statistical Analysis System
SSA	Sub Sahara Africa
SSC	Saturated Soil Culture
SVI	Seedling Vigor Index
TVR	Treatment, Variety and Replicate
UN	United Nations
WARDA	West Africa Rice Development Association

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the study

Asian rice (*Oryza sativa*) and African rice (*Oryza glaberrrima*) from Asia and west Africa respectively (Wopereis *et al*., 2009), is a staple food for a large part of the world's human population and more than half of the population depends on rice as the main source of calories and protein (FAO, 2009; Song, 2003) especially in many countries of Africa as it constitutes a major part of the diet (MOA, 2008; Oteng and Sant'Anna, 1996). The production of rice ranks the second among the food grains (Ferrero and Nguyen 2006). During the past three decades the crop has consistently increased in demand and its growing importance is evident in the strategic food security plan for many countries. African Heads of State and Government (AHSG) on food security summit held in Abuja in December 2006, identified rice, among other crops, as a continental level strategic commodity for food security and poverty reduction in Africa (FARA, 2009). As it has been projected by Ferrero and Nguyen (2006), the world population will increase from 6.13 billion in 2001 to 8.27 billion in 2030 while rice demand is projected to increase from 571.9 to 771.1 million tons in 2011and 2030 respectively. According to the United States census bureau estimates (Goodkind, 2011), the world population was expected to pass 7 billion by 2012. Rice demand exceeds production and large quantity of rice is still being imported to meet supply demand at a high cost in hard currency in many countries of the world (FAO, 1996).

Competition between producers of rice and other food and industrial crops are mounting serious pressure on land and water hence, improvement in productivity, innovation and technology are required to enable rice growers to practice sedentary farming system using contemporary agricultural technology. The interest for greater investment in agricultural innovation in Africa must exist in practical term because vast majority of the population in Africa derive their livelihood from agriculture, a continent where farmers are among the poorest in the world despite a largely unexploited agricultural potential with respect to land and water (Africa Rice, 2010). The growing importance of rice as staple food in Sub-Saharan Africa is mounting pressure on it production in many African countries as it is the number one source of calories intake particularly in West Africa and comes third after maize and cassava for the continent as a whole (Africa Rice, 2010; Diagne *et al*., 2010). The current production of rice is still far short of meeting the population demand which makes the continent depend on importations of up to 40% of its rice consumption (Africa Rice Trends, 2007). According to Africa Rice Trends (2007), 70% of the production increment comes from land expansion and only 30% is attributed to productivity enhancement.

Kenya is one of those countries in Africa that has been greatly affected by water shortage and therefore food shortage is a reality due to overdependence on a narrow range of food crops and unpredictable rains and the higher dependence on natural resources which is a contributing factor to slow economic growth (Sacks and Warner, 1997).

1.1.1 Agriculture and economic growth in Kenya

Kenya has an area of 582, 646 km^2 of which about 1.9% (11,230 km^2) is occupied by water, leaving 571, 416 km^2 of the arid land of which more than two-thirds is either semi desert or desert land (UN-WATER/WWAP, 2006). This figure clearly suggests that between 142,314 and 189, 562 km^2 of land can be used profitably by the country's estimated population that now stands at 40 million (2011). Other areas of farming that are heavily rain dependent are often disappointed when there are no rains hence, production is curtailed, supply is often reduced and food shortage become eminent, leading to high and volatile prices.

Globally, Kenya is classified as a water scare, arising from uneven distribution of water resources in space and time and with the frequency of extreme weather events (UN-WATER/WWAP, 2006). Droughts are endemic and floods occur quite often (UN-WATER/WWAP, 2006). Hence, scarcity of available water for domestic, industrial and agricultural use is eminent, making agents of these institutions to invest more on water resource management and conservation (UN-WATER/WWAP, 2006). Increased population growth is intensifying pressure on natural resources to achieve food production required to cope with the population growth (UN-WATER/WWAP, 2006). One of the many ways to achieve this would be not only through land expansion but by increasing yields per unit area (productivity) through meaningful and intensive technology farming system.

As land and water are getting scarce, food security has now become one of the many challenges of the century. This problem is even aggravated with the effect of climate change due to human interference. Environment which fully supports human civilization is changing faster than imagined especially during the past 20 years period or even 2 years (www.ccdcommission.org). Agricultural activities form part of the problem and part of the solution as well. The composition of the atmosphere is changing today due to some agricultural activities. Some agricultural practices are also contributing negatively to public health care for example, paddy fields serving as breeding sites for mosquitoes thereby increasing health problems such as malaria (Tadesse *et al.*, 2011). Crop yields are affected because of agriculture's direct impacts by exposure to climate change. Change in temperature pattern is serving as impediment on the viability and yields of rice crops. Hence, the vision of many countries today in the world is to plan on how to increase or double agricultural food production. Effect of climate change varies from continent to continent and even within the same continent, it also varies. Global rice production is gradually declining even with the extensive use of high input and high yielding modern varieties. Farmers' yield outputs are not corresponding with breeders' results due to many factors. Many countries of the world have now decided to go along the green revolution technological packages, but many problems are associated with this technology; among them water, soils, pest and diseases. These problems have really complicated many efforts to maintain farmer's dream. More to this, there are other contributing factors behind the low production of rice; farmers using low quality (old generation) seed or even grain as seed, under rate or overdose of chemical fertilizers, and poor cultivation practices including crop protection. Breeders have immensely contributed to promoting food crop yield in the field but much more is expected by agronomists to enhance this effort. Food security is one of Kenya's major priorities as land and water management is among the many constraints in elevating food insecurity. Perhaps because of these reasons, the country does not rely on its local production to bridge the widening gaps that still exist. At present, the country trades with its neighboring countries like Uganda and Tanzania informally in grains such as; maize and rice to structure the existing gaps (Owuor, 2012).

Kenya is no exception in the growing demands of rice as it is the third staple and consumable cereal crop after maize and wheat (NIB, 2008; Okech *et al*., 2008, Kimani *et al*., 2011). However, consumption (410,000 metric tons) has remained higher than production levels (110,000 metric tons) and imports fill the widening gap (73. 2%) between national supply and demand (MOA, 2010). One of the many ways to unlock this barrier would be through the exploitation of idle lands, arid and semi-arid lands with the practice of intermittent irrigations, enabling saved water to expand production areas and thereby increasing production and productivity. Rice is currently the most expensive cereal in the country (Mati, 2012). Its rate of consumption continues to grow very rapidly and it is likely to surpass wheat, in becoming a main food commodity in many Kenyan households. Urbanization and changing food preferences have increased the consumption of rice in both rural and urban households. Current increment in rice production is due to the large scale rice irrigation schemes in Central Mwea, Tebere, Ahero, South West Kano and Bunyala, but water shortages continue to impede production systems in these areas and even beyond (USAID, 2010). More is yet to be done with the water management systems during the off-seasons to be able to cover the 540,000 hectares of potential land that can support irrigated production and a further 1.0 million hectares under rain-fed production (USAID, 2010). With contemporary innovative management technologies, the irrigated areas can be increased by further 800,000 to 1.3 million hectares (MOA, 2010) enabling Kenya to be food secure. This will become a dream reality, as four out of every five Kenyans depend on agriculture for their livelihood (Beddington *et al*., 2012). Since rice was introduced in Kenya in 1907 from Asia (MOA, 2009), its roles in socio-economic development is a point of focus hence, cannot be overlooked.

According to recent publication by Kimani *et al*., (2011), irrigated rice produced in Kenya now count for 95%, while the remaining 5% is produced under rainfed conditions (NIB, 2008). The 95% is produced from five (Central Mwea, Tebere, Ahero, South West Kano and Bunyala) of the seven (7) irrigation schemes under National Irrigation Board management, and Mwea irrigation scheme account for about 80% of total annual national production (MOA, 2010). This result clearly signified that rainfall is not helping to overcome independency in rice. One of the dominant problems faced by rice farmers is the shortage of water during the off season rice cultivation as they heavily depend on irrigation schemes established by government to meet demand target (MOA, 2008; NRDS, 2008-2018).

As shortage of water continuous to hit the rice production regions of Kenya especially around the Mwea region, so as the rice production will continuous to decline due to water stress. Quality seed is another cardinal issue for rice growers in Kenya and Mwea region in particular. Quality seeds are important in improving rice yields. This is so because they carry the genetic characteristics of the mother plant for successful crop production. It is certain that clean and healthy seeds can be used to enhance farmer's productivity. Shenoy *et al*., (1988) reported that deterioration in seedling vigor due to poor quality seeds in rice crop accounted for 20% of the yield losses. Quality seed has always played a crucial role in agricultural development since man domesticated the first crop. In contemporary agriculture, seed is the power house that generates yield potential. Therefore seed quality is a sum of multiple components (Species, cultivars, purity, germination, vigor, health, temperature and moisture). Good and healthy seed marks a giant start to nursery establishment for transplanting field, and uniform field establishment for direct planted field, all serving as a driving force to yield augmentation. Transplanted rice seedlings establishment and their subsequent growth depend not only on the above-growth morphological characteristics that can define seedlings vigor, but also on the growth of the new roots (Hoshikawa and Ishi, 1974) and the amount of irreparable damage caused to the roots by transplanting (Ros *et al*., 2003). Both characteristics (above-ground and below-ground) of rice plants, prior and after transplanting, vary with seedling age (Himeda, 1994), the growing environment (Kordon, 1974) and seedling rate (Sasaki, 2004). Drought due to climate change is increasingly becoming a major factor in crop production system hence, considered the most stressful factor in rice production and other food crops. As the result of this, breeders and agronomist are assiduously working, to making sure that food crop such as rice survive under such threat. A number of morpho-physiological characters are associated with adaptive response of crops to drought (Araus *et al*., 2003, Reynolds *et al*., 2007).

The acute shortage of available water in and around rice growing areas particularly in Mwea has made many farmers to seek alternative technologies. Such technologies include the System of Rice Intensification (SRI) that has attracted most Mwea farmers. This system enables them to grow young seedling with healthy roots under limited water supply by applying good management practices. A number of reports indicate that SRI practices increase tillers and yield as compared to continuously flooded conditions (Ceesay *et al*., 2006; Kabir and Uphoff, (2007; Sato and Uphoff, 2007 and Sinha and Talati, 2007) . Good agricultural practices such as perfect water management systems will help to transform and stabilize food security by translating field successes into both quantitative and qualitative validation.

1.2 Problem Statement

Climate upon which civilization is based is changing faster than ever imagined. These changes especially on temperature patterns are having major impacts on the viability and yield potential in crop production. Studies on rice productivities under global warming also suggest that productivity of rice and other tropical crops will decrease as global temperature increases (Nguyen, 2004). Humidity and wind speed are accelerating these changes. Across Africa today, the unfavorable weather conditions continue to threaten rice production both in the lowland and upland ecologies (Africa Rice Trends, ex-WARDA, 2007). The environment for agricultural activities in Sub-Sahara Africa is vulnerable due to erratic rainfall patterns. The inducing variations in the climate patterns such as increasing incidence of drought, extreme temperatures and flooding, and increasing levels of salt stress are expected to aggravate these constraints, thereby affecting rice production. These constraints have direct effect on the five rice production systems (rainfed upland, rainfed lowland and lowland, mangrove swamp and deep water) recognized in Sub-Sahara Africa and Kenya in particular, leading to food and nutritional insecurity. The economy of Kenya is agricultural-based, yet over 80 % of the country is classified as arid and semiarid land (ASAL) which is typically characterized by low and erratic rainfall, high evapotranspiration rates and generally fragile ecosystems (Bank *et al*., 2002). Water shortage in the country continues to increase due to competition among water users leading to scarcity and unreliability that is now the major constraints for agriculture development. Rice is a unique food crop and therefore value for production throughout the year under good water management practices. Today around the globe, varieties such as the NERICAs have high yield potential and short growth cycle ranging from 90 days upwards (http://www.warda.org). What remains crucial now in this contest (rice production industry) is the scaling down of inefficient use of water during the plant growth period as the excess water could significantly be used to expand the rice growing areas. It is against this backdrop that the research was undertaken to contribute to some solutions of the existing problems that are undermining food crop production. Results from the studies will significantly help the country to realize the vision 2030 agric-business objectives to feed a rising population of Kenya as it helps quickly address major constraints hindering the growth of agriculture, beginning with water management strategy - the wise way in using water for crop use.

1.2.1 Climate and rainfall in rice production

Due to climate change, farmers are faced with many challenges (low rainfall and high temperature) in all rice producing regions of the world today. Some rice growing ecologies are constrained with high or low temperature, leading to plant sterility or death, while others are constrained with erratic rainfall leading to flood and complete destruction of the entire crop growing field. Yield fluctuation is caused by both water limitations and floods.

Among the food crop of the world, rice plant is adapted to a wide range of hydrological conditions beginning with rainfed upland, rainfed lowland, irrigated lowland, deep water or floating and mangrove swamp. This adaptation makes the crop very unique and peculiar among many other food crops. Both cultivated species are water loving (not in idle term) hence, semi-aquatic crop and its cultivation is at the ecological limits of the species and in this term the climate, particularly rainfall, is a critical determinant for its productivity (Gupta and O'Toole, 1986). Other factors such as the solar radiation and temperature strongly influence growth and yield.

1.3 Justification

Rice is the most consumed cereal crop of the world's population today, yet farmers are not capable of meeting the demand. In 2004, rice was the staple food for about 3.23 billion people, wheat 1.55 billion and maize 2.88 billion. Optimization of yield for commercial grain products alone cannot help us realize global food security but we must also considered seed yield and quality components.

In Kenya, rice is speedily becoming the major staple food but production is far below consumption level as farmers cannot fill the widening gap between the two parameters (production and consumption) because environment for agricultural activities are vulnerable to drought. The technology of water-saving regimes that will require saturated soil culture (SSC), intermittent irrigation (II) and alternate wetting and drying (AWD) methods will contribute in enhancing both commercial grain and seed yields productivity.

The purpose of this research is to contribute knowledge on how to maintain or increase rice yield through scaling down of irrigation water supply and increasing production area under rice irrigation through appropriate water management strategy. The change in eating habits of many Kenyan has now led to an annual increase in consumption which stands at 12% for rice as compared to 4% for wheat and 1% maize respectively (MOA, 2008; NRDS, 2009). Despite the increased demand of rice not only in Kenya but the world at large, agriculture's vulnerability to climate change will put millions of people in developing countries at greater risk of poverty, hunger and malnutrition (Nelson *et al*., 2009). Although there are many biotic and abiotic factors affecting rice production in Kenya, drought due to climate change is one of the major constraint. Food shortage in Kenya is a reality due to overdependence on unpredictable rains. Due to the fact that rice production would be managed throughout the year under good water management system, the results of this experiment will be used by farmers and researchers as an instrumental tool in the proper use of available water during the growth performance of the most powerful consumable cereal and other related food crops.

The possibility of expanding the area under rice-based systems remain limited as the competition for land in Kenya is very intensive due to expansion of urban and industrial sectors. The expansion of total rice harvested area through rice cropping intensification especially in the lowland ecologies may also be limited in the future. Hence, technology generated (one seedling per hill and calculated transplanting depth) will help farmers to increase production not only by expansion but most importantly per unit area as one seedling per hill can profusely tiller to compensate the wider space.

The study will unravel the lower and upper limit of irrigation supply after complete heading during which yield and seed quality is attained without compromise.

The study will also generate empirical information that can be used to examine the varietal performances of some genotype lines under different soil water tables while looking at those attributes that can immensely contribute to either increasing or stabilizing the rice yield and seed quality under AWD irrigation at the field levels during different phonological (growth) phases of rice. The study will critically examine other contributing factors that can enhance yield augmentation under good water management practices. The expansion of cultivated rice areas will enable the government to provide employment and income opportunities to a majority of rural dwellers. For an example, in Liberia, rice production activities have employed at least 200-240 manday ha^{-1} (vegetation dependent)

The technology will allow at least 20 to 30 % water saved, allowing for the saved water to be used to expand production area as water scarcity is currently affecting most rice growing schemes in the country and elsewhere in the world. Moreover, scaling down of seed rate per hectare will be an economic boost for our resource poor farmers

The practice of Intermittent Irrigation (II), otherwise known as Alternate Wetting and Drying (AWD) may further help to reduce many environmental problems associated with flooded rice production, health and environmental benefits such as reduction of mosquito breeding sites (Walker, 2002; Tadesse *et al.,* 2011), and minimization of schistosomiasis in standing water. Standing water is commonly found in farmer’s paddy field that still practice traditional way of cultivating rice under the lowland ecology. To a larger extend, the practice of water conservation which result to drying up paddy field could probably help to reduce toxicity of both organic and inorganic toxins that accumulate from the decomposition of organic materials at the beginning of cropping season (Haden, 2009). The study has further established précis seed requirement (quantity) per variety based on seed size and planting distance, and, method of transplanting depth. These two achievements will now help famers to lower cost on the purchase of seeds from larger quantity to smaller quantity per hectare and, avoid transplanting too deep that will eventually lead to low tillering under field establishment. This idea will enable farmers to save seed and money as reported by Kipkorir *et al*., (2011). Help farmers to save cost from extravagant water-use to skillful water-use. The study have helped established additional details on rice physiological water equilibrium (RPWE), using perforated PVC pipe to indicate water threshold level below the soil surface. The idea of using simple tool (PVC pipe) was developed by group of scientists at International Rice Research Institute (Tuong *et al*., 2009). The simple tool can now help Mwea farmers to monitor the water level below soil surface and make decisions on when to irrigate. The hi-tech intervention of saving water is a welcome initiative to increasing productivity.

1.4 Objectives and hypotheses

1.4.1 General objective

To contribute towards expansion of acreage under paddy rice production using saved water to increase productivity in order to alleviate food insecurity.

1.4.2 Specific objectives

1. To determine the effect of withholding irrigation waters on the morphological characters of rice.
2. To determine the effect of withholding irrigation water after complete heading on yield and seed quality components

1.4.3 Hypotheses adopted

1. Withholding irrigation water after complete heading has no significant effect on morphological characters of rice.
2. Withholding irrigation water after complete heading has no significant effect on the yield components and seedling quality components

1.5 Conceptual frame work

This section is more diagrammatic, set to properly argue and defend ideas that prompted the study and explain a phenomenon specifying variables and the laws that relate the variables to each other synchronously. It is the schematic presentation of the entire work. Two complementing sound effects; one primary, dealing with water management through withholding irrigation that contribute to rice growing area (acreage) and one secondary involving rice genotype that can possibly contribute in an increase of productivity (yield)- coupled with good agronomic practices will lead to an increased in production and serve as good driving force to income generation and food security. The two parameters (land and productivity) are concomitantly constant in realizing food security. Diagram (Figure 1) below clearly shows that the interaction will establish trend to food security due to the positive changes in the underlying variables.

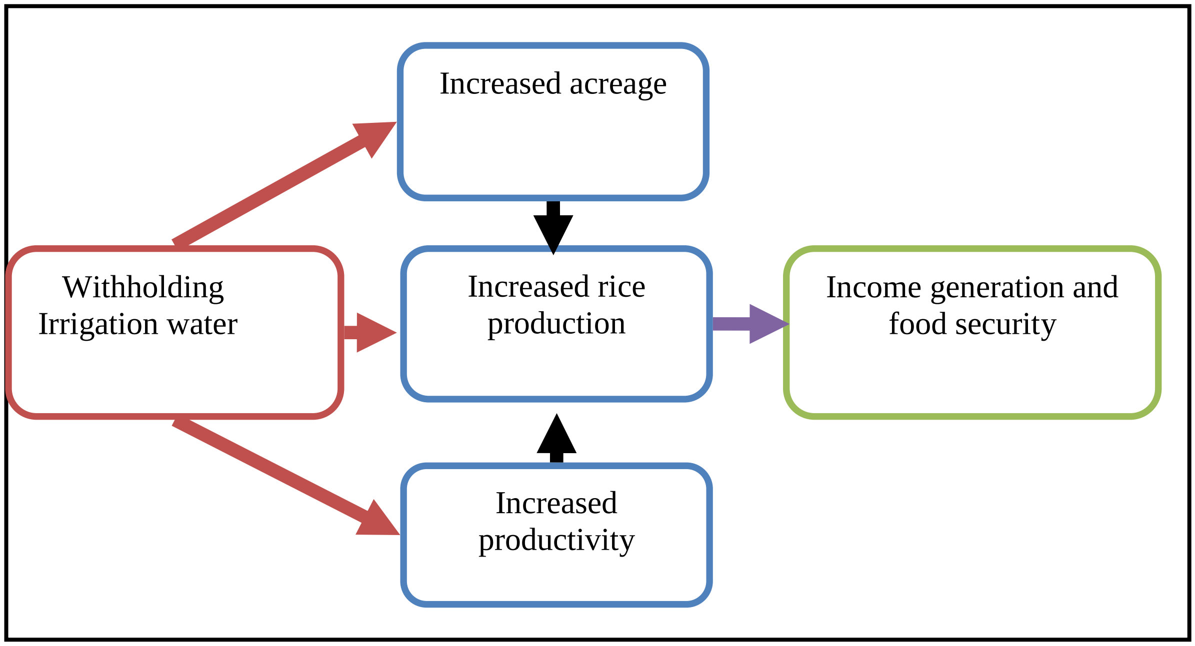


Figure 1: Conceptual framework

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Rice taxonomy and its origin (*Oryza sativa* L and *Oryza glaberrima* steud).

Rice is a plant that belongs to the family of gramineae (poaceae), tribe Oryzeae. The genus *Oryza* contains 25 recognized species, of which 23 are wild species and two (*O. sativa L*, the Asian rice and *O. glaberrima Steud*, the African Rice) are domesticated/cultivated species (Morishima, 1984; Vaughan, 1994; Brar and Khush, 2003; Tripathi *et al*., 2011). *O.sativa* is the most popular species among the two, and grown worldwide while *O.glaberrima* is solely grown in West African Countries. The *O. sativa* is further divided into two species, making it three distinct cultivated species in the world. These species include, *O. sativa japonica* type which originally came from Japan and Korea (Temperate and Subtropical Asia) and *O. sativa indica* types emanating from India (Tropical Asia), usually characterized by their distinct morphological structures (Langer and Hill, 1991). African rice (*Oryza glaberrima)* originated from the inland of Niger River to Senegal (West Africa) is distinct from its counterpart in many qualitative and quantitative traits (Sarla and Swamy, 2005; Vaughan *et al*. 2008). The two species are cultivated for their unique characteristics. However; the Asian species is cultivated far more than the African species mainly because of its higher yield potential. African varieties have many unique and useful traits among them are; weed competitiveness, tolerance to most abiotic stresses (acidity, salinity and drought) and resistance to diseases/pests (Linares, 2002; Sarla and Swamy, 2005). The two species of cultivated rice evolved from a pool of wide *Oryza* species (Chang, 1976a, 1976b). *Oryza sativa* was domesticated in tropical and subtropical Asia but the center of domestication is a matter of contention (Chang, 1976c). One school of thought assumes its simultaneous domestication in various centers extending from the plains below the eastern foothills of the Himalayas, through Burma, northern Thailand, Laos, and northern Vietnam to southwest and West China (Chang, 1976d, 1976e; Chang, 2003).

2.1.1 Rice origin, evolution and dispersal

Both species *Oryza sativa* (Asian origin) and *Oryza glaberrima* (African origin) seem like they developed from annual progenitors: in the case of *O. sativa* resembling *O. nivara*, and in the case of *O. glaberrima* resembling *O. barthii*. The former is widely cultivated than the latter and is rapidly replacing it in Africa. The morphological and agronomic characteristics are summarized by Purseglove (1972). The 'sativa complex', all of which are diploid (2n = 24), includes *O. sativa* and its wild relatives (*O. rufipogon* and *O. nivara*) and, *O. glaberrima* and its wild relatives (*O. barthii* and *O. longistaminata* (Norman *et al*., 1984).

2.1.2 *Oryza sativa* L.

In China, the remains of *Oryza sativa* L have been dated to 6500 BC; the earliest archaeological evidence from India goes back to 2500 BC (Brink and Belay, 2006). This variety was brought from Asia into tropical Africa along different routes. It was introduced to Madagascar by seamen-farmers sailing from Indonesia, to another part of Africa at the dawn of the Christian era through the trade route from Sri Lanka and India via Oman to Somalia and the Zanzibar and Kilwa off the coast of Tanzania. Most probably, it migrated to Egypt, where it was introduced about 800-900 AD, to West Africa.

2.1.3 *Oryza glaberrima* steud.

O. glaberrima Steud originated from West Africa hence referred to as. African rice or red rice. *Oryza glaberrima* was derived from the wild annual *Oryza barthii* A.Chev. (synonym; *Oryza breviligulata* A.Chev. & Roehr.) *O. barthii* grew abundantly in lakes that existed in what is now the Sahara from 8000-4000 BC and it was harvested as a wild cereal. When the climate became drier, *O.glaberrima* which was gradually developed from *O. barthii* (probably around 1500 BC or later) was grown as a rainfed home garden crop in oases (Norman *et al*., 1984). *Oryza glaberrima* was later transformed into the current floating rice crop during the time population took refuge in the interior delta of the Niger river (around 1500 BC). The African rice is now grown widely in a zone extending from the delta of the River Senegal in the west to Lake Chad in the east (Norman *et al*., 1984). The intensive areas of cultivation are the floodplains of northern Nigeria, the inland delta of the Niger river in Mali, parts of Sierra Leone and the hills on the Ghana-Togo border (Norman *et al*., 1984).

2.1.4 Development of NERICA varieties.

The term NERICA stands for NEw RICe for Africa, varieties developed at the Africa Rice Center formerly WARDA by a team of rice breeders led by Dr. Monty Jones in the early 1990s. Hence, NERICA varieties were developed from crosses between the African species (*O.glaberrima*) and the Asian species (*O.sativa*) using conventional biotechnology to overcome the sterility barrier between the two giant species. Therefore, NERICA is an inter-specific variety but not genetically modified. Out of those NERICAs currently developed by Africa Rice Center, 18 varieties are suited for upland systems (NERICA 1 to NERICA 18) and 60 varieties are suited for lowland systems coded as NERICA-L (NERICA-L1 to NERICA-L60).

2.1.5 Basmati-370

Basmati-370 is one of the many traditional rice varieties originated from Pakistan (Kadam and Patanker, 1938). The variety is widely consumed all over the world due to its aromatic flavor and palatability. In Kenya, it is one of the leading growing variety preferred by rice growers due to it profuse tillering ability. For consumers, its aromatic flavor and grain quality (slender) plays an important role among the other Basmati varieties like Basmati-217. The aroma is due to presence of large number of compounds in endosperm in specific proportion (Kadam and Patanker, 1938).

2.1.6 Production constraints in Kenya

Rice is normally grown as an annual plant but can also survive as a perennial crop in most tropical countries of the world through its unique ratooning system for about 1-3 years. The plant grows to a height of 90-180cm tall, occasionally more depending on the cultivar and soil fertility. The unhusked grain, as well as the growing crop, is known as a paddy. Rice grown predominantly in the upland ecology is referred to as upland rice and the type grown predominantly in the lowland ecology is referred to as lowland rice. The multiple problems rice producers faced today are shortage of cultivating land, increasing scarcity of water and an increasing demand of rice (seed and grain). Rice is a heavy consumer of water among the cereal crops hence, water stress due to scarcity is considered as one of the major impediments for productivity.

Rice is a unique food crop and therefore value for production throughout the year under good water management practices. These practices are better realized when quality seed inputs are used. Many research results (Davies, 1987; Brenners and Cheikh, 1995) revealed that plant hormones are considered key regulators for seed development. Other reports including Karssen (1982), Davies, (1987); Hassen and Grossmann (2000) reported that auxins, glaberrellins (GAs) and abscisic acid (ABA) are involved in regulation of grain development. Subjecting two rice cultivars to water treatments (well-watered and water stressed) under two levels of applied nitrogen (normal or high) at heading, showed that water stressed (WS) on rice increased partitioning of fixed $^{14}CO_2$ into grains. It accelerated grain filling rate but shortened grain filling period, whereas the nitrogen at heading did the opposite (Yang *et al.*, 2001). Gibberellins (GAs; $G_1 + G_4$) in the grain were high at early grain filling but sodium (NH) enhanced, whereas WS substantially reduced it accumulation. Abscisic acid (ABA) was low at early grain filling but WS remarkably enhanced its accumulation. Wang *et al.* (1998) and Yang *et al.* (1999) suggested that poor grains filling was associated with low indole-3-acetic acid (IAA) and ABA contents in the rice grains. Early work done by Yang *et al.*, (2000, 2001) showed that water stress imposed during grains filling of wheat (*Triticum aestivum*) could enhance the remobilization of pre-stored carbon reserves to the grains and grain filling rate. Yang *et al.* (2001) results suggested that an altered hormonal balance in rice grains by water stress during grain filling, decrease in GAs and an increase in ABA, enhances the remobilization of pre-stored carbon to the grains and accelerates the grain filling rate (Yang *et al.* 2001).

Producing quality seeds that represent the genetic potential of a cultivar signals a good beginning to enhancing food security as it is the nucleus and power house for agricultural development. The summation of all factors that contribute to seed performance is termed as quality seed. Farmers are interested in planting high quality seeds as it is a contributing factor to yield increase through better seedling emergence and vigorous plant growth. As seedling emergence is enormous due to quality seeds, optimum plant population density could certainly be achieved under wide range of environment. In summary, quality seeds can therefore be defined as seeds that have the most economic planting rate (kg/ha), seeds emergence (Germination %), minimum of replanting (replacement), vigorous seedling establishment (growth speed) and uniform plant stand. Such seed has faster growth rate, greater resistance to stress, diseases and uniformity in ripening. As reported by Udaykumar (2005), better seed quality parameters were recorded under SRI method like higher germination percent (95.56), root length (5.44 cm) and shoot length (5.49 cm) higher values of speed germination (31.11) and vigor index (991) compared to that under normal method. Harrington (1972) reported that maximum seed quality is achieved at the end of grain filling period; this was previously termed as physiological maturity (Shaw and Loomis, 1950). After this period, seed begins to age, losing viability and vigor. In contrast, many reports on various crops by Pieta Filho and Ellis (1991), Ellis and Pieta Filho (1992), Demir and Ellis (1992, 1993), Sanhewe *et al*., (1996) suggested that maximum quality of seed were attained sometime after the end of grain filling. Hence, Ellis and Pieta Filho (1992) suggested that the term physiological maturity is therefore misleading to the seed physiologists to describe the end of grain filling period and that the term mass maturity is preferable. Varietal performance under water stress varies, some variety are susceptible at vegetative stage and other at flowering and grain filling period (Pantuwan *et al*., 2002). Different cultivars might have different responses to the same drought stress timing and intensity as reported by Bourman and Tuong (2001). Wopereis *et al*., (1996) reported that if water stress occurs at tillering stage, this will cause reduced number of reproductive tillers and panicles per hill.

Hence, the study cross examined the effect of withholding irrigation water at different levels after complete heading on rice yield and seed quality. As rice is considered the most suitable food security crop due to its short growth duration, prolific multiplier and highest nutritional value attached, more is yet to be done in overcoming theses alarming biotic and abiotic constraints in the production and productivity of this major food crop in Kenya and Africa at large.

2.1.7 Rice development pattern

Rice is a unique consumable cereal crop that shows a wide range of variation in development pattern through its adaptation to the climatic factors of temperature, depth of flooding and day-length. Its temperature adaptation is illustrated by the importance of the crop in the wet, wet-and-dry and cool tropics (Huke, 1976). In the lowland or irrigated conditions, rice is planted directly (seeded) or transplanted (seedling). Under the transplanting method, it is either done using traditional (conventional) or modern method. The traditional method of transplanting rice is characterized by putting more than 3 seedlings per clump (Karki, 2009). This practice provides assurance to farmers that if one or two plant died, the other will substitute the others in order to avoid or lower percentage of missing hills. The modern method on the other hand is characterized by transplanting 1 seedling per hill now termed as System of Rice Intensification (SRI) practice (Association Tefy Saina, 1992). According to Joelibarison; (1998) and reported by Karki, (2009), research done in 1998 revealed that a single plant per hill could express its tillering potential better than number of plants per hill

2.1.8 Growth phases of rice plant

Growth of the rice plant can be divided into three agronomic phases (vegetative, reproductive and ripening) figure 2. Two of these phases (reproductive and ripening) are relatively constant. However; variation in temperature (low or high) can either prolong or shorten their duration. If the low temperatures interfere with the ripening phase of the cultivar, this may certainly lead to a prolonged period of harvesting. According to Vergara and Chang (1985), it is the vegetative phase whose duration generally varies greatly and which largely determines the growth duration of a cultivar. Theses growth phases can influence the three yield components; number of panicle per unit land area, average number of grain produced by panicle and average weight of the individual grains (Moldenhauer and Slaton, 1985). Vergara and Chang (1985) further divided vegetative phase into two namely; the basic vegetative phase (BVP) and the photoperiod-sensitive phase (PSP). They referred to the later as the juvenile growth stage of the plant, which is not affected by photoperiod (Figure 3). It is after the BVP has been completed that the plants now respond to the photoperiodic stimulus for flowering known as PSP of the plant. The PSP period is varietal dependent. According to their report, these two phases are controlled by different genes.

1. Vegetative phase. This period runs from germination to panicle initiation. The period which begins with germination include three stages (seedling, tillering and stem elongation).

2. Reproductive phase. This is the second phase of the rice growth that starts from panicle initiation to flowering stage. This phase involved three stages (panicle initiation to booting, heading and flowering)

3. Ripening phase. This period starts from flowering to full development of grain. The last phase involves three stages (milk grain, dough grain and mature grain).

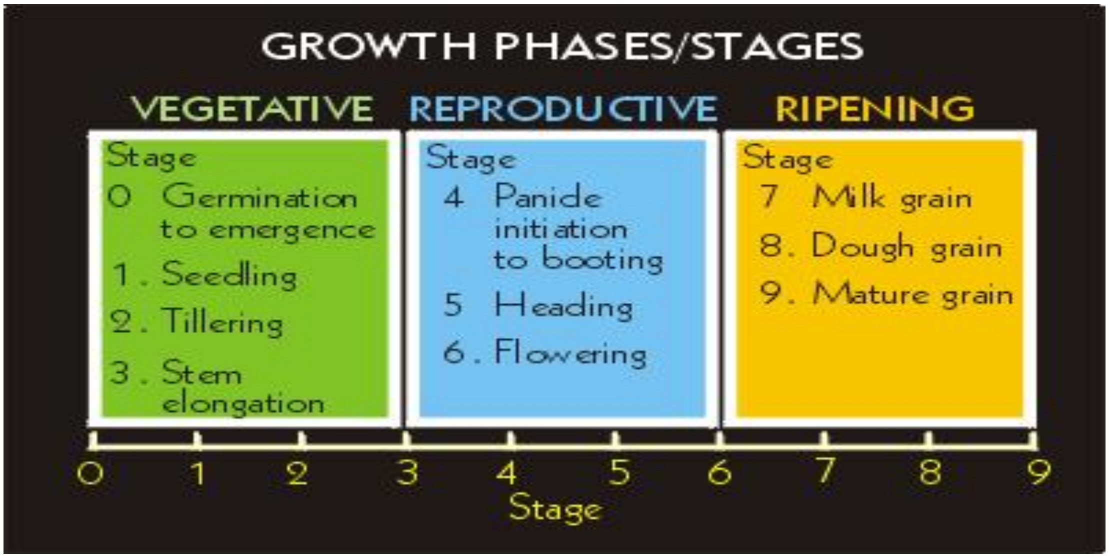


Figure 2: Growth stages/phases (Courtesy of IRRI – Philippines)

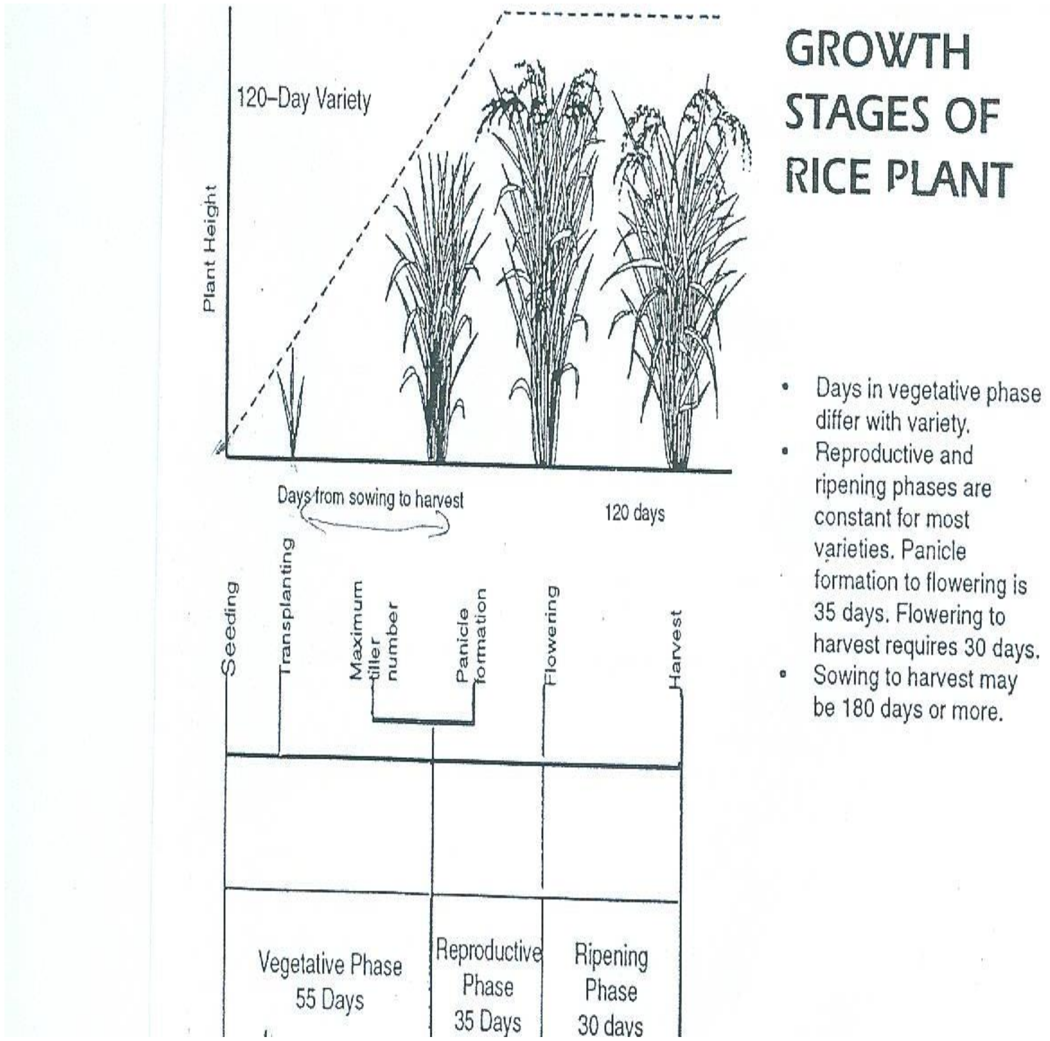


Figure 3: Growth stages of rice (Courtesy of IRRI – Philippines)

2.1.9 Definition of seed

Seed is a living product of a plant that is used for regeneration as it is termed as a post fertilized ovule (Asea *et al*., 2010). It represents the end of flowering process and the beginning of a new plant in seedling form. The difference between seed and grain in the case of rice is that ‘grain’ is used for human or perhaps livestock consumption while ‘seed’ is used for further multiplication (Asea *et al*., 2010). The agronomic practice of rice seed and rice grain are quite distinct in many ways. From the outer appearance deep into the inner parts, both appear the same. Structurally, the seed has the hull, bran coat called aleurone, endosperm and the embryo. The endosperm is the larger part of rice seed containing starch. Seed has an intellectual property right and therefore legally sold with high commercial value attached. Considering the post harvest handling, 14 % moisture content or less is safe for grain storage, while 12 % or less is safe for seed storage (http://www.knowledgebank.irri.org).

Seed is one of the most critical inputs in agricultural production, in that it has the greatest potential of increasing grower productivity and further enhancing food security. In agriculture, seed is delivered as an agronomic starting point and product having the economic value. For yield potential to be realized, good quality seed therefore must be sown as this act can increase yields by 5-20%. This increment is therefore directly proportional to the quality of the seed that is been sown. Hence, seed quality can be considered as the summation of all factors that contribute to seed performance. Seed quality production is a unique consideration that must not be taken for granted, as farmer's success or failure begins from the seed that is planted. However, the benefit of quality seed does not stop at crop growth but goes a very long way to grain quality and yield.

2.1.10 Rice seed Dormancy

Steady, rapid and full germination of seeds is considered as an essential first step towards effective utilization of any germplasm that can be multiply through seed. Dormancy in any seed refers to a condition that temporarily suspends visible growth of meristem, hence, considered as a prime factor that can hamper germination. However, dormancy by nature can be an advantage for some species, as it put seed in a good maintenance phase. Rice seed dormancy is a good agronomic trait as it relates to pre-harvest sprouting, Dormancy period in rice seed is varietal dependent. Rice seed may be sown or planted under favorable (soil and atmospheric) conditions but failed to germinate, said seed is either dormant or dead. Seed become dormant when it enters it maintenance phase. Dormancy renders resistance to pre-harvest sprouting and prevents germination until favorable conditions for plant development prevail (Das, 1989). Said situation become problematic and even unbearable for farmers and research scientist when time frame is budgeted especially due to threat of climate change. Dormancy period of each variety depends on the trait of the seed. Rice seed may take 2-3 weeks or even 2-3 months before it break dormancy. Rice variety that breaks dormancy within the first 14 days from harvest is considered slightly dormant, 15-60 days as moderate and 60-90 days as highly dormant. Duration on dormancy period is either due to domestication of crop plants or breeding work that led to the reduction or elimination of seed dormancy to suit cropping period.

2.1.11 Variation in rice seed dormancy

Germination test on the four experimented varieties was conducted within 55-60 days from harvest. However, all but one (Basmati-370) variety failed to germinate within this period. As earlier stated above, dormancy period in rice is varietal dependent. Wild or traditional varieties have much higher degrees of dormancy than modern varieties. Basmati-370 happens to be one of those traditional varieties failed to break dormancy along the same period of the NERICAs (1, 4 & 10). However, said seeds were subjected to green house temperature of minimum 20 ^{0}C and maximum 50 ^{0}C for ten days period, after which dormancy was broken. Though Basmati is one of the many popular rice varieties commonly grown in Mwea region, some farmers normally used old generation (6-12 months old) seeds for their cropping cycle for fear of field failure. Further investigation is required to ascertain the exact period of dormancy in Basmati-370, which will enable farmers to minimize cost associated with period of storage.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of sites

The field experiment activities were done in one growing season but two established sites, different soil types but a similar climatic condition that is; Kenya Agricultural Research Institute (KARI) located in Kimbimbi-Mwea and Mwea Irrigation Agricultural Development (MIAD) located within National irrigation Board (NIB). The two categories of rice, Nerica 1, 4, and 10 (dual purpose) and Basmati 370 (predominantly lowland line) were grown under irrigated condition.

Mwea is in the central region of Kenya – Kirinyaga County. Kirinyaga borders Nyeri County to the west, Meru to the north, Embu to the north-east, and Murang'a to the south west. The county main features are rice farming and their main economic activities are rice farming in Mwea, tea, coffee farming and horticulture. As rice farming continuous to gain momentum among the populace, the crop has become major source of income and job creation for the inhabitants. Mwea host one of the research satellite stations of Kenya Agricultural Research Institute (KARI) and it is located 21 km South-West of Embu town and about 112 km North-East of Nairobi City. The selection of Mwea was based upon the region involvement in the growth and development of rice and rice research industry in Kenya. Furthermore, KARI-Mwea has good and updated irrigation facilities that facilitated the trials. It lies on Latitude 0^0 37' S Longitude 37^0 20' E at an elevation of 1159 m above sea level (ASL). The rainfall is characterized by uneven distribution. The temperature ranges from 15.6 ^{0}C to 28.6 ^{0}C with a mean of 22^0 C (FURP, 1987; Jaetzoid *et al*., 2005). KARI-Mwea has the soil type classified as red, and has the properties of 0.119 % N, 107.0 % P (ppm) and 0.085 % K me/140g with pH of 6.18

The Mwea Irrigation Agricultural Development (MIAD) Center is about 26 km from KARI-Mwea, 16 km from Mwea town and 6 kilometers from the Nairobi – Embu Highway. MIAD is situated near Kandongu Village, fragmented compound which is surrounded by model farms. The Institution main research is on rice, though there are other crops (tomatoes and onions) which are under research. It is located latitude of 0^0 39’ S and longitude 37^0 17’ E at an attitude of 1195M above sea level (ASL). MIAD works in collaboration with other institutions such as National Irrigation Board (NIB), Kenya Agricultural Research Institute (KARI) and Universities. The sole responsibility of NIB is to supply water resources to all food and horticultural crops. The selection of MIAD was based on the correlated idea on the topic of research. Two soil samples were collected from MIAD (experiment site) and labeled as sample 1 and sample 2. MIAD has black cotton soil with properties of 0.112 % N, 12.0 % P and 0.170 % K me/140g with pH of 7.53 at time of transplanting. According to FAO classification, black cotton soils are grouped under Vertisols. Vertisol soils are dark montmorillonite-rich and poorly drained cracking clays of the top and bottomlands. Black cotton soils often have high level of cracking clay (Jaetzoid *et al*., 2005). Both sites are located in Kirinyaga County (Figure 4).

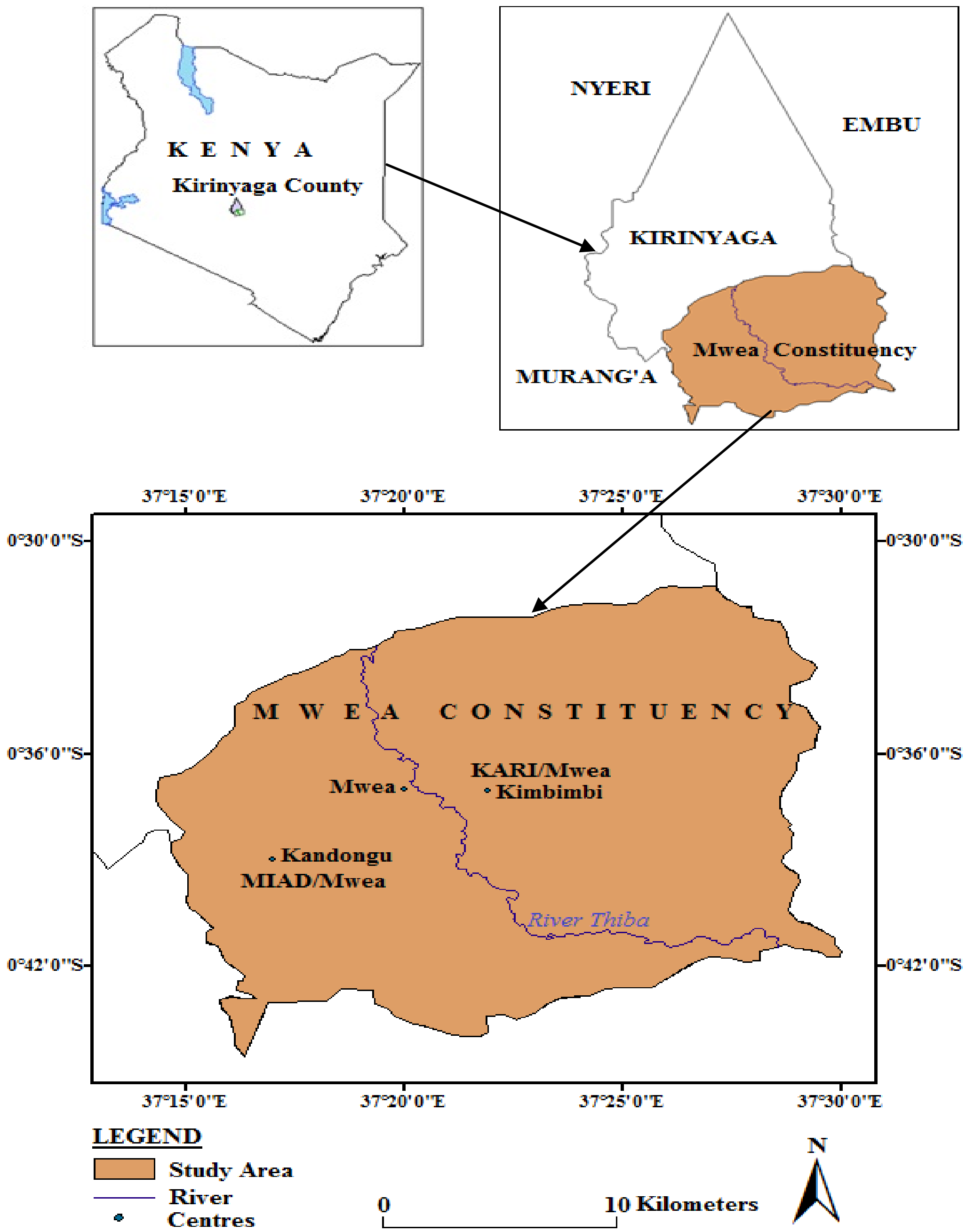


Figure 4: Map of Kenya describing the study site (shaded and shown by arrow)

3.1.1 Research Design

The experiment was designed for both field and laboratory work. Two factors (water regimes and varieties) were investigated. Water regimes were the main plot while the varieties were the sub plots. The water regimes (factor A) were (i) Intermittent flooding (ii) Withholding of water 10 days after complete heading (iii) Withholding of water 15 days after complete heading (iv) Withholding of water 20 days after complete heading. The varieties (factor B) used were (i) Nerica-1 (ii) Nerica-4 (iii) Nerica-10 (iv) Basmati-370. Both factors (A and B) were tailored in split plot arrangements in Randomized Complete Block Design (RCBD) with three replicates. Varieties and water regimes were randomly selected.

3.1.2 Description of the design and variety coding

The experiment was conducted in a natural environment of 34 X 17m (578m^2) land size, bounded with a drainage of 50cm deep well developed levee high 20cm to minimize any foreign water from getting direct contact with experimental plot. Experimental layout was tailored in a split plot (4_t x 4_v) using randomized complete block design (RCBD). Every water regime plot (treatment) of 8.8m × 1.6m (14.08m^2) had distance isolation of 1m and fortified with plastic sheet (buried 35cm deep and 20 cm high above soil surface), reinforced with sub soils serving as a bund/levee. The buried plastic sheet and levee served as hindrance to entry and exit of water from one main plot to the other. Varieties (3 NERICAs and

1 Basmati-370) were coded as N-1, N-4, N-10 and BS-370 - popularly grown by farmers in Mwea. Varieties placed in sub plots were subjected to different levels of water stress (0, 10, 15 and 20 days) after complete heading (CH). Rice seeds of the four varieties were soaked in plain water for 48 hrs, water drained and incubated (kept under moist) for 48 hrs to spark and accelerate germination.

3.2 Experimental Procedures 1:

3.2.1 Seed Selections, Germination Tests and Seed Quality

Rice seeds selected for the experiment were sourced from KARI-Mwea, from the category of foundation/pre-basic seed.

Germination test was conducted on selected seeds for the experiment to determine germination percentage. 400 hundred seeds from each variety (Nerica-1, Nerica-4, Nerica-10 and Basmati-370) were randomly selected and replicated 3 times. Filter paper placed in petri-dish was used to conduct the test. Seed quality components such as descriptive, hygiene and potential performances were used as guiding tools (ISTA, 1999).

Quality seed has the potential to germinate and develop into a healthy plant either in a smooth or harsh environment with contributing effort of it been viable (fully fertilized), germinate (fully matured), and attained vigor (under controlled moisture and temperature) during harvest and drying period. Human plays a contributing key role in achieving and maintaining these qualities.

3.2.2 Determining rice Seed rate per hectare for transplanting

Is a process that determines the quantity of seeds required for a giving area, taking into consideration the class of seed and germination percentage. Seed size, planting distance, seed or seedling per hill and tillering ability are the main determining factors in quantity requirement. Seed size varies from variety to variety as it determined the quantity in kilogram per hectare. The study found it clear that with quality seed attributes, 7.7 kg of NERICA-1, 6.3 kg of NERICA-4, 7.5 kg of NERICA-10, and 5.4 kg of BASMATI-370 can plant one hectare. The formula was used to arrive at the quantity requirement, consideration agronomic details (planting spacing 20 x 20 cm and 1 seedling per hill and material replacement/gaping (Table 1, 2). Table (2) and figure (5) provided results on the four varieties used during the experiment.

Table 1: Seed rate and calculations for transplanting

Class of seeds	**Germination % (range 80-100)**	**Results (Seed counted)**	**Requirements**
Foundation/Pre-basic	10 – 1,000 ÷ 10	1 to 100	11 to 1,100
	10,000 to 100,000 ÷ 10	1,000 to 10,000	11,000 to 110,000
Registered /Basic seed	10 – 1,000 ÷ 10	1 to 100	11 to 1,100
	10,000 to 100,000 ÷ 10	1,000 to 10,000	11,000 to 110,000
Quality declared seed	8 to 1,000 ÷ 8	1 to 125	9 to 1,125
	10,000 to 100,000 ÷ 8	1,250 to 12,500	11,250 to 112,500
Farmer’s deed	4 to 1,000 ÷ 4	1 to 250	5 to 1,250
	10,000 to 100,000 ÷ 8	2,500 to 25,000	12,500 to 125,000

Table 2: Varietal descriptions and seed weight, % germination and rate per hectare

Variety	50g seeds	Mean (g)	100g seeds	Mean (g)	% germination	Kg/ha
Nerica – 1	1,700 1,800	1,750	3,500 3,600	3,550	100	7.7
Nerica – 4	2,100 2,200	2,150	4,300 4,400	4,350	100	6.3
Nerica – 10	1,800 1,900	1,850	3,600 3,700	3,650	100	7.5
Basmati– 370	2,500 2,600	2,550	5,100 5,200	5,150	100	5.3

Requirement tools for seed calculation:

a) Class of seed (foundation seed)

b) Percent germination (considering 100 %)

c) Quantity of seed per 100g (Table 2)

d) Planting distance (20 cm × 20 cm = 250,000 hills/ha)

e) Gap filling (25,000 seeds is required for gap filling following (Table 1) calculation)

Calculation:

4.0g of foundation seeds are required to t/plant 5.12m^2 areas of land.

Therefore, 1hectare area of land will require -

$$\frac{\%\ \text{germination} \times \text{rate/area (pd + gf)}}{\text{Quantity/100g}} = 100 \times 275{,}000 \div 3{,}550 = 7{,}746\text{g (7.7kg)}$$

NOTE: 250,000 seeds are required to plant a hectare at the distance of 20 cm × 20 cm hence, 25,000 seeds were required for gapping.

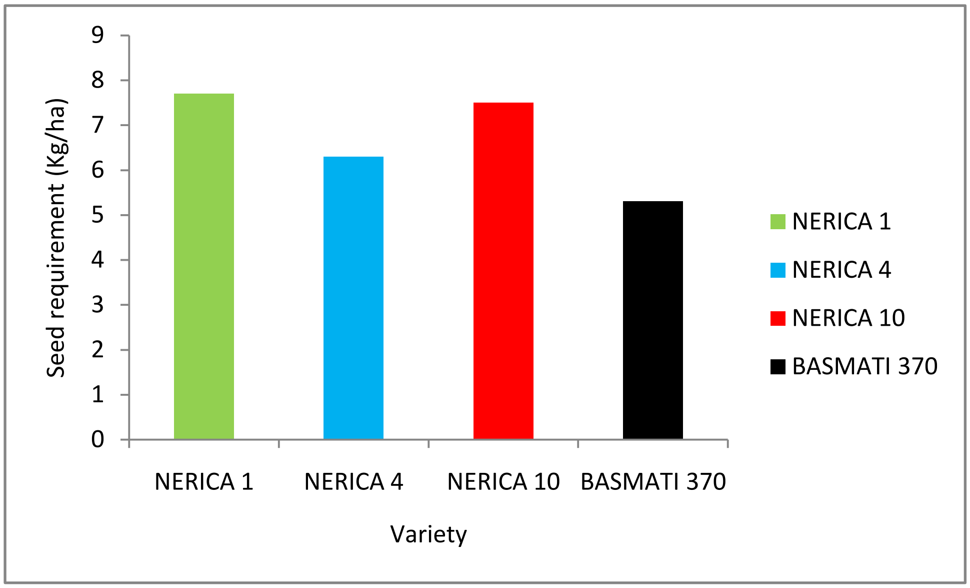


Figure 5: Graph showing seed rates per ha for different rice varieties

Nursery was prepared in trays size of 189.75cm^2 (16.5 x 11.5 cm), and sown using broadcasting method after 48hrs of soaked and 48hrs of incubation, in a sandy loam soils.

3.3 Experiment 2:

3.3.1 Determining soil conditions prior to transplanting

Soil samples were collected from the two experimental sites and analyzed in the MIAD soil laboratory, located within MIAD research stations (Table 3). One sample was collected from KARI/Mwea and two samples from MIAD as details in the table (3).

Table 3: Soil sample results of two sites

Sample No	% N	P (ppm)	K me/140g	pH
MIAD	0.112	12.0	0.170	7.53
MIAD	0.113	17.0	0.127	7.31
KARI/MWEA	0.119	107.0	0.085	6.18

Ploughing of land and layout were mechanically done. There were three (3) replicates, the main plot was water regimes and sub plot was rice varieties (Appendix 1 & 2).

The main factors of the experiment were: water regimes (0 day, 10 days, 15 days and 20 days irrigation intervals after CH), placed in the main plots and varieties (Coded as N-1, N-4, N-10 and BS-370) placed in the sub plots hence, providing four treatments and four varieties, replicated three times, all under blanket fertilizer treatment. Varieties were subjected to one cropping pattern; from land preparation, planting, harvest and post harvest practices.

Seedlings were transplanted 22 days after emergence (Table 6).

Table 4: Day of sowing to day of transplanting

	GROWTH STAGE	DAYS
1	Sowing date	0
2	Germination	3-5
3	Emergence	6-8
4	Seedling	12-18
5	Date of transplanting	22

3.3.2 Seedling height measurement to calculate transplanting depth

Under the one seedling per hill planting method, the planting depth was calculated based on the average height (above ground surface) of each of the four varieties (Figure 6 & Table 6). Fourteen out of one hundred forty-one seedlings from nursery plate were randomly sampled to determine the average height of plant from above ground surface aged-22 days after emergence. The heights were divided by the seedling age and multiply by 4. At the end of the exercise, 2.0 cm to 2.3 cm of transplanting depth was reached. It was observed during the experiment that planting depth of seedling solely depend on the age and vigor.

Figure 6: Measurement of seedling length

Table 5: Seedling height (cm) on nursery prior to transplanting

PLATE #	BASMATIC-370	NERICA-10	NERICA-4	NERICA-1
01	9.0	10.0	11.0	12.0
02	10.5	9.0	11.0	12.0
03	10.2	12.0	11.0	12.0
04	12.6	12.0	11.0	13.0
05	10.7	10.8	10.0	12.5
06	10.2	10.5	11.0	9.6
07	10.5	10.8	11.0	13.0
08	10.0	10.5	10.5	13.5
09	10.0	11.0	11.0	14.0
10	8.0	11.0	11.5	12.7
11	11.0	8.0	11.0	12.0
12	10.5	13.2	10.2	13.0
13	11.0	11.0	11.5	13.0
14	11.0	10.3	8.5	11.0
Total Height (cm)	**145.2**	**150.1**	**150.2**	**173.3**
Average height (cm)	**10.4**	**10.7**	**10.7**	**12.4**

3.3.3 Method of transplanting

Seedlings were manually transplanted to both trial sites using rope to line every hill. From the date of sowing, seedlings were transplanted at 22 days and one seedling per hill, with an average height of 12.4 cm for N-1, 10.7cm for N-4, 10.7 cm N-10 and 10.4 cm for BS-370. Seedlings were transplanted at the average depth of 2.0-2.3 cm. Plots were puddled under fully saturated conditions and drained a day before transplanting. Transplanting spacing was 20 x 20 cm which culminated to 250,000 plants population per hectare.

3.3.4 Method of irrigation

Out of the many ways of irrigating paddy field (continuous flooding, continuous shallow flooding, soil saturated culture and alternate wetting and drying), field prepared for transplanting was kept under saturated condition for twelve (12) days, followed by alternate wetting and drying after fourteen (14) days of transplanting. Plots were irrigated at 7-8 cm of water depth, and water added for 5-6 days after surface water disappearance approximately 15 cm below soil surface. Hence, 15 cm below soil surface was marked as the water threshold level which is called "save AWD" as suggested by Bouman and Lampayan (IRRI, 2009).

Irrigation was done after every 2-3 days for the first two weeks of transplanting. The 5-6 days Alternate Wetting and Drying (AWD) practice started 5-6 days period after the first top dressing of fertilizer.

As per practice of MIAD and KARI-Mwea, two types of fertilizer were applied: (1) Basal dressing was done with Di-ammonium phosphate (DAP) of 64g per sub plot on the day of transplanting, considering 50kg/acre. (2) Ammonium sulphate (SA) for top dressing at 22g per sub plot in two split applications (12 days and 40 days after transplanting), considering 17kg/acre. Although water escaped from the paddy field during rice growth, the study managed to fully contain over-bund flow and seepages. Percolation was rear but evaporation was minimized after plant full establishment. Meanwhile, transpiration was high due to increased temperature during trials.

Weeding was done thrice, using traditional method (hand): first weeding was done twelve days after transplanting, second weeding during maximum tillering, and third weeding prior to booting stage as agronomic practice (AWD) encourages purification of weeds. Tillering started within two to three weeks period after transplanting.

3.3.5 Water Threshold level during crop development

Water threshold (WTH) level below the soil surface was estimated at 15 cm. The cracked width in both soil types (red sandy-clay and black cotton soils) at the WTH level was marked at 0.5-2.0 cm. The threshold was determined using technique developed by International Rice Research Institute (IRRI) with input from Tuong, Bouman and Lampayan (Figure 7).

Figure 7: Water threshold level gauge (15 cm below soil surface)

The sample area (M^2) was taken using quadrat drill calibrated in 1m x 1m (M^2). Quadrat drill is one of the many sampling tools commonly used to collect scientific data in the field. It helps restrict the exercise within the quadrat and plants used for sampling were randomly selected. Variable from the field were scored from five (5) tagged mother plants (Figure 8).

Figure 8: Panicle tagged for data collection

3.3.6 Crop duration (from date of transplanting to date of harvest)

Maturity of rice plant depends on the variety, growth condition and also location. NERICAs are fast grown varieties that are ready for harvest within 100 to 120 days period, earlier than Basmati-370 that takes about 135-150 days to maturity. Nerica-10 matured at 100-105 days much earlier than Nerica-1 and 4 that matured within 110-115 days period (Table 6). Basmati-370 matured within 120-125 days later than the NERICAs. Maturity was recognized when field turned 80-90 % golden brown in color and harvested done when grain moisture content was between 18-20 %.

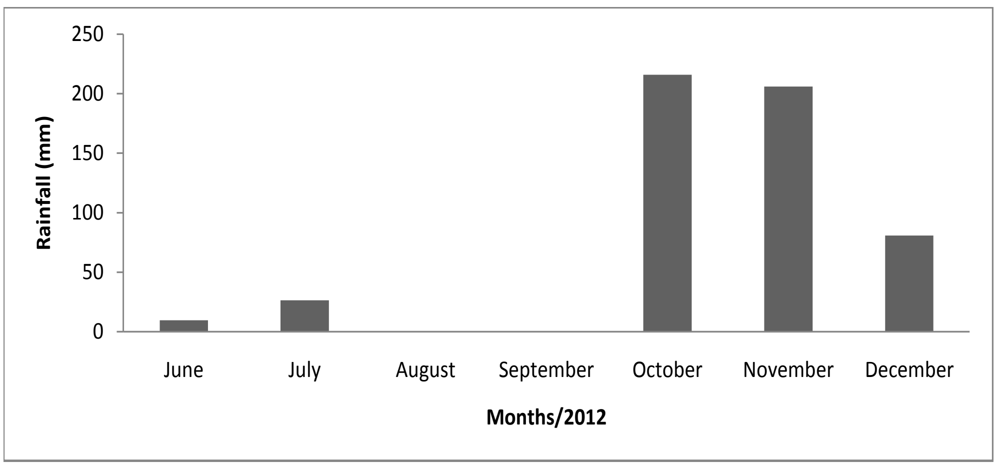
Table 6: Growth stages of the rice plant

	GROWTH STAGE	DAYS
6	Date of transplanted	**22**
7	Tillering	21-30
8	Stem elongation	28-40
9	Panicle initiation	45-55
10	Heading	55-67
11	Flowering	5-7 days after heading
9	Milk stage	72-80
10	Dough stage	80-90
11	Mature grains	91-100
12	Harvesting	100-115 (NERICAs) 120-125 (Basmati-370)

Seed harvesting is marked as an appropriate stage in achieving seed quality **(**Copeland and McDonald, 1995). According to Seetanum and De Datta (1970), the optimum time for harvesting has been considered to be 30-42 days after heading in the wet season and 28-34 days after heading in the dry season in rice. Even though rice is one of those cereal crops that profusely tiller especially under the AWD cultural practice method, it can also be term as one of the dissipated cereal crops during harvesting, threshing and drying period. The pre and post harvest lost in rice is often enormous to affect yield output with subsequent contributions to farmer's yield failure. Meanwhile, collective measure in curtailing yield lost during this period is considered positive and giant step in real term.

3.3.7 Meteorological data during production period

The research experiments coincided with the short raining period hence, average rain water in both trial sites from June to December, 2012 ranged from 9.6 to 215.9mm from both site (Figure 9), which is far less than normal water requirement for rice growth period that is around 1,240-3,000 mm (Yoshida, 1981).



MIAD Weather

Figure 9: MIAD meteorological data

3.3.8 Determining germination rate in the laboratory

Laboratory experiments were conducted in Kenyatta University to determine germination percentage and test for field emergence. Two substrata were used to determine results. The first substratum used filter paper in a Petri-dish to determine the germination percentage and the second substratum used pure sand in a narrow dish plate to determine both germination percentage (normal and abnormal) and rate of field emergence. Dried seeds at 11 % moisture content (average) were used for experimental purposes

Under filter paper germination test conducted, coleorhiza was visible in Nerica 1, 4 and 10 within 24 to 48 hours of imbibitions. Germination in the petri-dish (Figure 10) started with the appearance of coleorhiza within two to three days period in Nerica-1, Nerica-4 and Nerica-10 and, five to six days in Basmati-370 from date of sowing, two days after that the radical appear through the covering. The coleoptile emerges within three to six days period and followed by the appearance of primary leaf.

Figure 10: Germination test using filter paper in petri-dish

Two days after sowing using sand stratum, the coleorhiza appears, followed by the coleoptiles within three days period. Seed sown directly in the sand at about 1.0 -

1.25cm dept (Table 7) took four to five days for the appearance of coleoptiles above the soil surface (Figure 11). The mesocotyl is the basal portion of the coleoptiles that elongate when rice seed germinates. It pushes the coleoptiles above the soil surface. The appearance of seedling above the soil surface depends on the variety and depth of planting. Following ISTA rules, final germination count was made on the sixth days after sowing. Results are presented in table 8.

Table 7: Sowing method, spacing, rate per plate and sowing depth

Sowing method	**Space between roll (cm)**	**Seed rate/plate**	**Sowing depth (cm)**
Drill	3.2	100	1.0 – 1.25

Table 8: Germination results from the laboratory

variety	Germination % (Using filter paper)		Germination % (Using sand)	
	KARI	MIAD	KARI	MIAD
NERICA-1	94.33	98.58	81.92	81.92
NERICA-4	98.92	98.83	91.67	91.67
NERICA-10	98.17	99.58	94.20	94.20
BASMATI-370	80.10	89.20	-	-

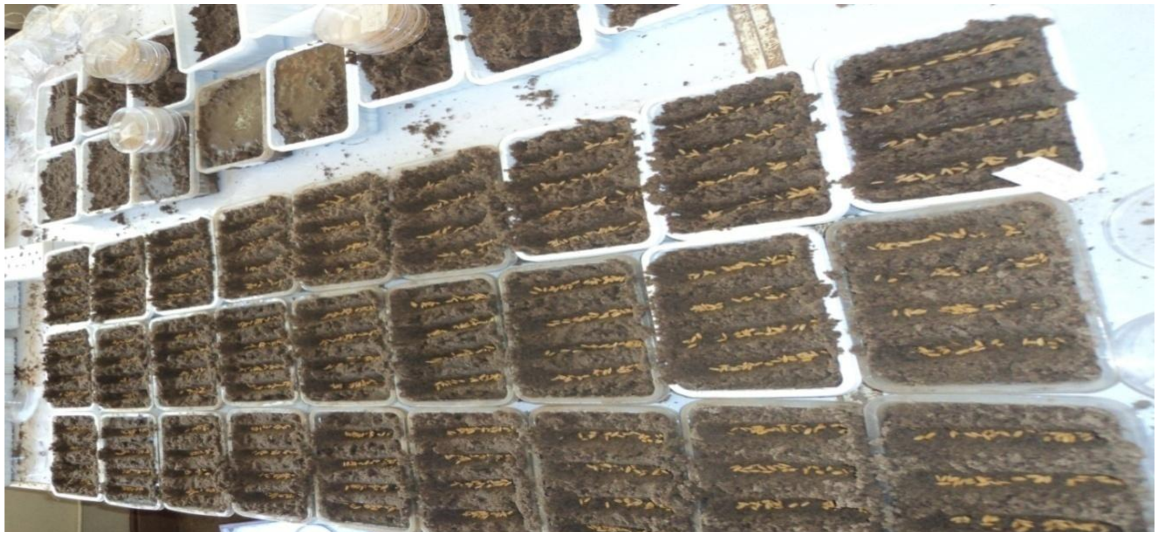


Figure 11: Germination test using sterilized sand (seed drilled)

3.3.9 Determining rice seed purity

As it relate to the presence of other materials or dockage other than paddy, which includes chaff, stones, weed seeds, soil, rice straw, stalks and other impurities that come from the field or drying floor affect the physical properties of rice seed. These impurities serve as a host and carrier of diseases and pest that further help to reduce the quality of the paddy. These quality results (genetic, physiological and sanitary characteristics) were expressed and field determined using sterilized soil medium in natural environment. The physiological parameters of seed quality comprise of viability and vigor; where the viability refers to the capability of seed to germinate and produce normal healthy seedlings and vigor comprises those properties which determine the potential for rapid, uniform emergence, and subsequent development of normal seedling under wide range of field conditions (AOSA, 1983). Other components of seed quality can be grouped into three categories: (1) Description – This deal with the species and cultivar purity; analytical purity; uniformity; and seed weight. (2) Hygiene – Deals with the noxious weed contamination; seed health; storage fungi contamination; insect and mite contamination. (3) Potential performance – It's about germination; vigor; moisture content; field emergence and uniformity; and storability (Coolbear and Hill, 1988; Hampton, 2002). High seeds quality should be able to produce normal seedlings, expected field emergence and uniformity.

3.3.10 Purpose of conducting germination test

Germination test conducted in the laboratory was not done to determine field performance, it was primarily done to result only the germination capacity of produced seeds. However, following the latter, field emergence test were carried out to clearly determine the development of seedlings under natural and harsh environment.

The term (germination) is defined as "emergence" and development of seedling from the seed embryo of those essential structures (embryo, endosperm and seed coat), which indicate its ability to satisfactorily produce normal plant under favorable conditions (ISTA, 2004). Embryo in due course gives rise to the new plant, endosperm (storage tissues) nourish the embryo during development and seed coat gives protective covering which shields the embryo and endosperm and further control factors (moisture and gaseous exchange) that initiate germination. Germination occurs when the seed coat has imbibed adequate water becoming soft and elastic. The coleorhiza (shealth covering the radical) elongates slightly, emerging through the seed coat and the radical breaks through the coleorhiza becomes anchored in the soil. Under dry-seeded or aerobic conditions, the radical (young root) emerges before the coleoptiles. This may be the opposite (coleoptile may emerge before the radical) under water-seeded (anaerobic) conditions (Figure 12).

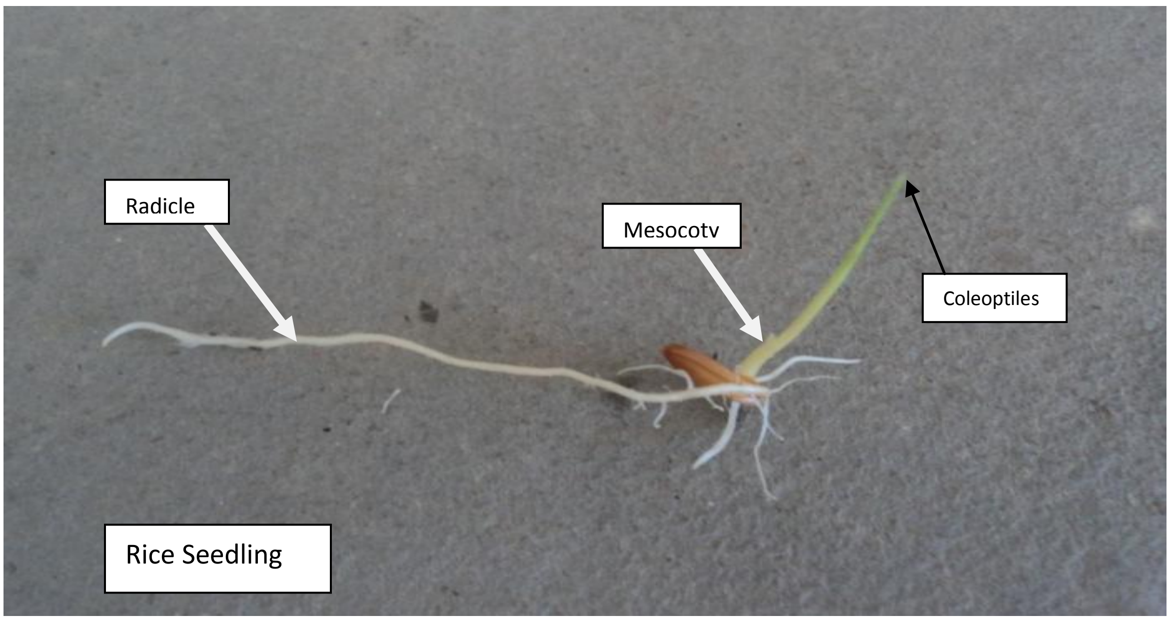


Figure 12: Rice seedling (anaerobic)

3.3.11 Purpose of conducting vigor test

Germination test conducted using sand medium was done to determine seedling vigor index as this method further classified the seedlings into "strong" and "weak". These classifications further provide information about seedlings free from deficiencies. Though there are many ways (medium) to determine seed viability, germination test is incomplete whereto, without using soil either under smooth or rough environment. Seed may germinate using different types of germination method but the germinant may fail to perform it normal duties as it grows into a full plant in farmer's field, as it is in the case of rice seed. Quality seed is determined by number of genetic (genetic make-up, seed size and bulk density) and physiological (injury during harvest, processing, planting and establishment, growing condition during seed development, physical damage during storage by either human, machine or pest and, moisture and temperature during storage and age and maturity of seed) characteristics.

Both tests were conducted to determine the germination percentage and seedling vigor of various seeds produced under different irrigation regimes period. Following ISTA rules of 1977 as reported by Gupta (n.d), one of the two criteria (relationship between vigor test and results of seedling emergence in field soil) employed by ISTA seed vigor committee was adapted to evaluate the germination percentage and seed performance under field conditions. Vigor test provides estimate value of the potential field performance, leading to farmers planting value.

3.3.12 Determining germination percentage

Percentage of germination clearly expresses the proportion of the total number of seed that are alive. This determination is justified through controlled tests and actual counts of the number of seed that germinate. As it is in the case of this study, seed that failed to germinate within 3 to 6 days period was either considered dead seed or seed that germinate but considered abnormal seedling due to it abnormality to satisfactorily perform it genetic potential as stated under ISTA rule. This process clearly indicates the genetic potential and nutritional quality (physiological and biochemical) of seed to germinate and perform it normal function. Germination percentage allow seed growers to determine the level of quality associated with the seed before planting, which further determine field rate, field emergence and crop uniformity. However, percentage germination test conducted in the laboratory only gives an idea of the performance of a category of seeds in the field. This cannot be 100% considered for calculation seed rate per hectare because said test (laboratory) is often conducted in an optimum condition specific to different species. Forty-eight petri-dishes ($4_t \times 4_v \times 3_r$) were used to conduct the germination test, placing hundred seeds per petri-dish in three replications.

Percentage was computed using below formula:

$$\textbf{GP} = \frac{\text{Number of germinated seed}}{\text{Total number of seed tested}} \times 100$$

3.3.13 Purpose of determining germination rate

The process rate the number of seed that germinate on daily bases from day zero to last day of complete germination. The process quantifies seedlings into normal, abnormal and dead seeds, and expressed into percentage. Meanwhile, speed of germination varies from one cultivar to another. This process is facilitated through imbibing of water within 24 to 48 hours period to be able to produce a radical (root) and the first leaf (Plumule) within 3 to 6 days. At this point, said seed is considered fully germinated and, continue until establish. Following the definition, calculation was done using this formula (Abdul-Baki and Anderson, 1973):

RGI = n =Number of germinated seeds
d Number of germination days

Where: 'n' is the number of seedlings emerging on day and 'd' representing the days after sowing. As sampled below (Figures 13-16), the same process was followed for all the four varieties as graphed below.

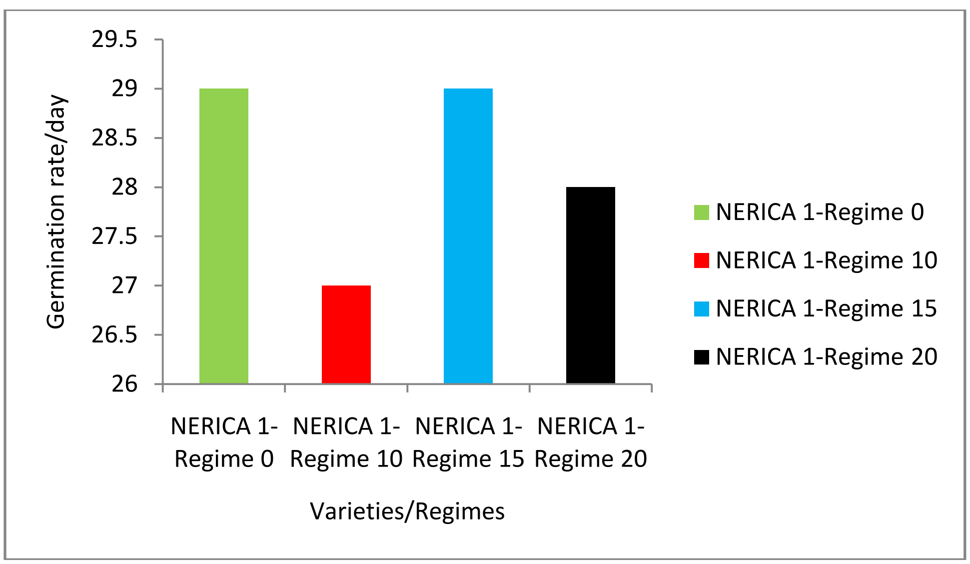


Figure 13: Germination rate for NERICA 1 (Filter paper germination)

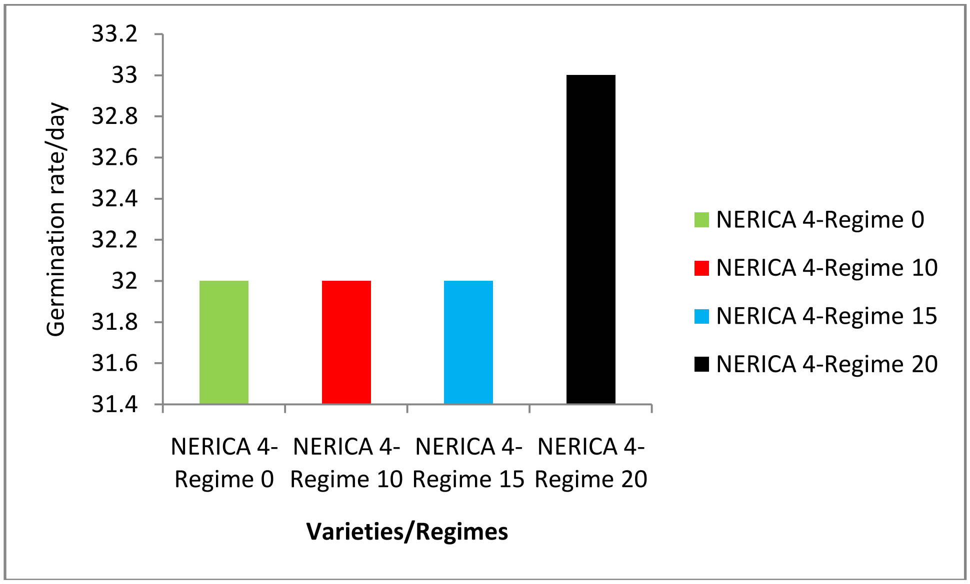


Figure 14: Germination rate for NERICA 4 Filter paper

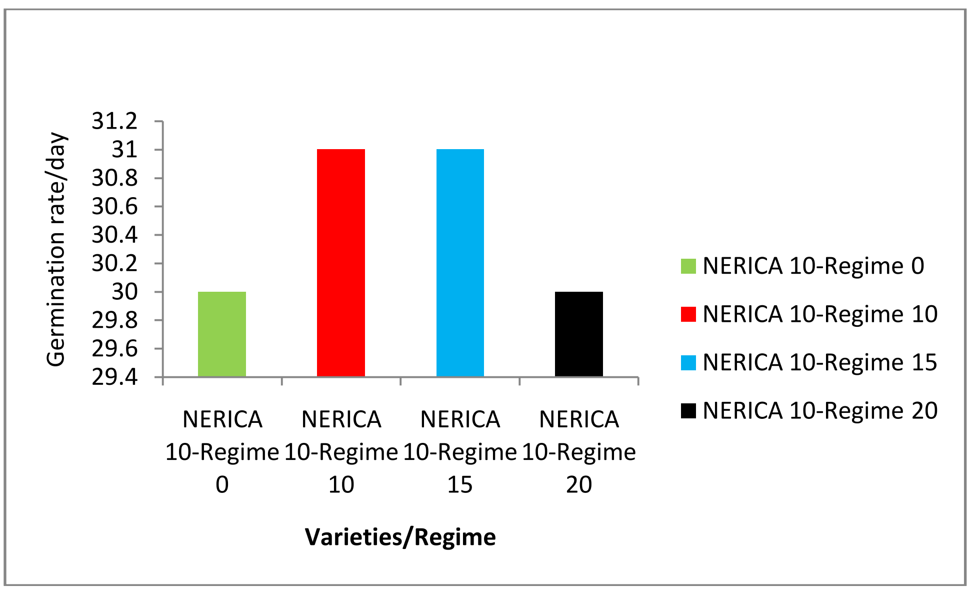


Figure 15: Germination rate for NERICA 10 Filter paper

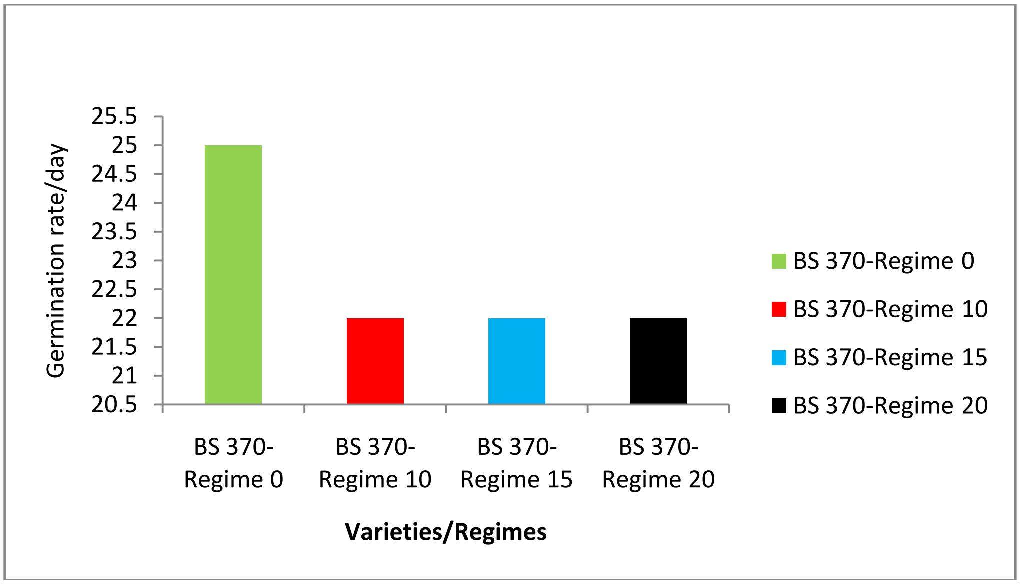


Figure 16: Germination rate of BASMATI 370 Filter paper

3.3.14 Purpose of conducting seedling vigor test

Though differences in physiological attributes of seed can be demonstrated in the laboratory, it had been recommended that the term should be used to describe the performance of seeds when sown in the field (Perry, 1984), therefore, vigor test was conducted in a natural environment using sand and nursery plate size 189.75cm (16.5 × 11.5) to determine seedling performance and seedling vigor index (SVI). On the day of the final count, five seedlings out of the hundred seeds sown in each plate (as per plot) were randomly selected, carefully uprooted and roots washed in plain water to determine growth performance and vigor index**.**

It provides an estimate of seed potential field performance that can be related to field planting value. The process indorsed using formula of Abdul-Baki and

Anderson (1973), multiplying germination percentage × seedling length (root length + shoot length). Under this method, normal, abnormal and dead seedlings were evaluated at the time of final count.

Formula

SVI = sl (r + s) x % germination

Where 'sl' represent the seedling length (r=root and s=shoot) and % g represents the germination percentage.

3.3.15 Evaluation of seedling:

Seeds produced under different regimes were tested under same conditions and substrata. Germination rate was conducted under room temperature, while germination speed and seedling vigor index was tested under natural environment. Six days after germination, seedlings were transferred and grown under natural environment for eight days. Mulching was done for seven days to lower the rate of transpiration and watered once after every 24 hours. Counting of germinated seedlings and measuring of seedling length (root and shoot) was done on the fourteenth days after sown. Under the speed tests and vigor tests, seedlings were categorized and recorded under normal, abnormal and dead seeds under germination rate.

Normal seedling poses all the essential structures and capable to grow into a normal plant under favorable conditions. Such seedling must possess healthy stem and fabulous rooting systems.

Abnormal seedling that does not show capacity for continues development into normal plant even when grown in a quality soils (free from all soil borne diseases and foreign seeds) and favorable environment (water, temperature and light). Abnormal seedlings are often weak, have unbalanced development of essential structures such as poor rooting systems, twisted plumules or stunted.

Seed must be able to germinate either under smooth or harsh environments. However, when said seed failed to perform it genetic potential in all substrata, it is considered a dead seed.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Results of yield and yield components for different rice varieties and water regimes across sites

Results revealed that flag leaf length, number of matured tillers per hill, panicle length, single panicle weight, filled grain per panicle and filled grain weight per panicle were significantly different ($p<0.05$) across sites. Number of unfilled grain per panicle, unfilled grain weight per panicle, grain weight per hill, grain size, 1,000 grain weight, straw weight and percent moisture content were not significant ($p<0.05$).

Results revealed that there was no significant difference ($p<0.05$) on all the variables scored for water regimes. Results revealed that withholding water after complete heading has no effect on components of yield (Tillers per hill, panicle length, filled grain per panicle and 1,000 grain weight).

Results revealed that there were significant differences ($p<0.05$) between flag leaf length, number of matured tillers per hill, panicle length, single panicle weight, number of filled grain per panicle, filled grain weight per panicle, number of unfilled grain per panicle, grain size, 1000 grain weight and straw weight for the variables. Unfilled grain weight per panicle, grain weight per hills and percent moisture content were not significantly different ($p<0.05$). Significant differences between varieties occurred as the result of genetic factor.

Flag leaf lengths ranged from 21.83 cm to 25.91 cm, number of matured tillers per hill ranged from 6.8 to 9.1, panicle lengths ranged from 20.40 cm to 22.04 cm and were higher at KARI (Table 9). Single panicle weight ranged from 2.95 g to 3.44 g, number of filled grain per panicle ranged from 112.40 to 122.92 and filled grain weight per panicle ranged from 2.74 g to 3.24 g and was higher at MIAD.

Flag leaf length, tillers per hill, panicle length, Single panicle weight, number of filled grain per panicle and filled grain weight per panicle for all treatments were significantly different. Unfilled grain per panicle, unfilled grain weight per panicle, grain weight per hill, grain size, 1,000 grain weight, straw weight per hill and percent moisture content were not significantly different ($p<0.05$). Site x variety interaction were significant for panicle length and percent moisture content (Appendix 3).

Water regimes were not significantly different ($p<0.05$) across sites (Table 10). Withholding of water after complete heading did not have any effect on the components of yield (matured tillers per hill, panicle length and filled grain per panicle and 1,000 grain weight /grain size) as evidenced (Figure 17). Similar results were reported by Sadeghi and Danesh, (2011).

Many researchers have reported that rice plant perform to water deficit differently at every growth stage during every phase. According to De Datta (1973); Singh and Misra (1974); IRRI (1976, 1978) as reported by Tantawi and Ghanem (1999), significant reductions in tillers and panicles numbers as well as height and grain yield were rear when water stress was imposed at tillering stage. Krupp *et al*. (1971); De Datta (1973) concluded that vegetative and reproductive phases reduced numbers of panicles per plant; percentage filled grains and 1,000 grain weight. Grain yield was pronounced when plants were exposed to water stress at panicle initiation stage, while the moisture stress at the dough stage had significant effects on grain yield (Singh and Misra 1974). RRTC Annual Report (1999) established that withholding irrigation water at certain time of the growth stages of rice plant can save some of irrigation water without much effect on yield component. Report from this study is in agreement with RRTC Annual Report (1999). However, such sensitive stage(s) have to be well determined before water regime applications. Further study at the RRTC (2001), data indicated that continuous saturation throughout the growing period without any standing water could help save water about 23 % with minimum reduction in crop yield and high water use efficiency. In a situation where many farmers are clustered and water for irrigation is eminent such as the case of Mwea, field located at the beginning of the irrigation canals rationalized their water use, the other farmers at the terminals will certainly find some water and on time.

Figure 17: Paddy field under regime period after complete heading

Flag leaf length ranged from 20.81 cm to 25.92 cm for Basmati-370 and Nerica-4 respectively (Table 11). Numbers of tillers per hill ranged from 6.30 to 12.42 for Nerica-1 and Basmati-370, respectively. Panicle length ranged from 20.10 cm to 23.50 cm for Nerica-1 and Basmati-370. Single panicle weight ranged from 2.20 g to 3.83 g for Basmati-370 and Nerica-4, respectively. Number of filled grain per panicle ranged from 99.20 g to 134.71 g for Basmati-370 and Nerica-4, respectively. Filled grain weight per panicle ranged from 2.01 g to 3.60 g for Basmati-370 and Nreica-4 respectively. Unfilled grain number per panicle ranged from 10.00 g to 13.99 g for Basmati-370 and Nerica-1 respectively. Grain size ranged from 19.50 mm to 26.60 mm for Basmati-370 and Nerica-1, while 1,000 grain weight ranged from 18.30 g to 24.70 g for Basmati-370 and Nerica-1, respectively. Straw weight per hill ranged from 66.70 g to 104.10 g for Nerica-1 and Basmati-370, respectively

Flag leaf length for Nerica-4 (25.92 cm) and Nerica-10 (25.35 cm) were significantly different ($p<0.05$) from Nerica-1 (23.41 cm) and Basmati-370 (20.81cm). Numbers of tillers per hill for Basmati-370 (12.42) were significantly different from Nerica-10 (7.20), Nerica-4 (6.42) and Nerica-1 (6.30). Panicle length for Basmati-370 (23.50 cm) was significantly different from Nerica-4 (20.99 cm), Nerica-10 (20.30 cm) and Nerica-1 (20.10 cm). Single panicle weight for Nerica-4 (3.83 g) was significantly different from Nerica-1 (3.50 g), Nerica-10 (3.33 g) and Basmati-370 (2.20 g). Number of filled grain per panicle for Nerica-4 (134.71) was significantly different from Nerica-1 (114.50), Nerica-10 (122.23) and Basmati-370 (99.20). Filled grain weight per panicle for Nerica-4 (3.60 g) was significantly different from Nerica-1 (3.30 g), Nerica-10 (3.12 g) and Basmati-370 (2.01 g). Unfilled grain number per panicle for Nerica-1 (13.99), Nerica-10 and Nerica-4 were significantly different from Basmati-370 (10.00). There was no significant difference between the Nerica varieties. Grain size for Nerica-1 (26.60 mm) was significantly different from Nerica-4 (25.31 mm), Nerica-10 (24.50 mm) and Basmati-370 (19.50 mm). Differences also occurred between Nerica-4, Nerica-10 and Basmati-370. Similarly, 1,000 grain weight for Nerica-1 (24.70 g) was significantly different from Nerica-4 (22.90 g), Nerica-10 (21.99 g) and Basmati-370 (18.30 g). Straw weight per hill for Basmati-370 (104.10 g) was significantly different from Nerica-4 (75.13 g), Nerica-10 (69.80 g) and Nerica-1 (66.70 g). There was no significant difference between the Nerica varieties. These differences occurred as the results of genetic factor. Sadeghi and Danesh, (2011) reported similar results on the effect of varieties for unfilled grain per panicle under 5% probability level while Roshan *et al*. (2013) reported the effect of variety on traits such as grain yield, straw yield, harvest index, panicle length, number of grain per panicle, number of bearer tillers, percentage of unfilled grain per panicle, 1,000 grain weight and plant height at 1 % significant level. According to Kipkorir *et al*. (2011), Basmatic-370 which is tall popular variety and commonly associated with lodging due to heavy winds under traditional continuous flooding was not affected under SRI practice. This report is also in agreement with findings from this research.

Rice tiller is counted as principal contributing parameter in rice production when considering yield components. When tillering ability of any variety is increased, said variety is bound to attain yield increase. Alternate wetting and drying irrigation system promoted the tillering ability of all the varieties tested. After subjecting the plant to regime treatments, results revealed that there was no significant different on mature panicle harvested however, water regimes 15 and 20 numerically recorded the highest with the least recorded in water regime 10. Varietal-wise, there was significant different between Basmati-370 and the NERICAs (N-1, 4 and 10). Basmati-370 recorded the highest, followed by Nerica-1, 10 and 4 respectively as evidenced (Figure 18 & 19). However, there was no significant different between the NERICAs. Rice among other crops is very sensitive to water deficit. As reported by Amiri *et al*. (2009); De Datta *et al*. (1973); Krupp, (1971), moisture stress at milk ripe or dough stage had significant effects on grain yield. However, this was not experienced when crops were subjected to treatments 10 days after complete heading

Figure 18: Basmati-370 under AWD irrigation system at KARI-Mwea

Figure 19: NERICA-1 under AWD irrigation system at MIAD-Mwea

Table 9: Yield and yield components across sites

Site	Flag leaf length, (cm)	tillers per hill (No.)	panicle length (CM)	single panicle weight (g)	number of filled grain per panicle, (No.)	filled grain weight per panicle (g)	unfilled grain per panicle (No.)	unfilled grain weight per panicle (g)	grain weight per hill (g)	grain size (mm)	1,000 grain weight (g)	straw weight per hill (g)	Moisture content %
KARI	25.91a	9.15a	22.04a	2.95b	112.40b	2.74b	12.74a	0.10a	15.70a	23.70a	21.84a	75.90a	11.25a
MIAD	21.83b	6.80b	20.40b	3.44a	122.92a	3.24a	11.83a	0.10a	14.50a	24.23a	22.10a	81.94a	11.40a

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Table 10: Yield and yield components for water regimes across sites

Regime	Flag leaf length, (cm)	tillers per hill (No.)	panicle length (CM)	single panicle weight (g)	number of filled grain per panicle, (No.)	filled grain weight per panicle (g)	unfilled grain per panicle (No.)	unfilled grain weight per panicle (g)	grain weight per hill (g)	grain size (mm)	1,000 grain weight (g)	straw weight per hill (g)	Moisture content %
0	23.13a	7.71a	21.03a	3.10a	111.90a	2.90a	11.51a	0.13a	15.10a	24.10a	21.99a	7390a	11.30a
10	23.70a	7.63a	21.23a	3.20a	122.42a	3.03a	11.21a	0.10a	14.60a	24.10a	21.80a	73.54a	11.21a
15	23.90a	8.42a	21.70a	3.24a	117.40a	3.03a	13.70a	0.10a	17.12a	24.00a	22.40a	86.13a	11.30a
20	24.90a	8.50a	20.90a	3.30a	118.93a	3.01a	12.70a	0.10a	13.60a	23.70a	21.65a	82.13a	11.43a

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Table 11: Yield and yield components for varieties across sites

Variety	Flag leaf length, (cm)	tillers per hill (No.)	panicle length (CM)	single panicle weight (g)	number of filled grain per panicle, (No.)	filled grain weight per panicle (g)	unfilled grain per panicle (No.)	unfilled grain weight per panicle (g)	grain weight per hill (g)	grain size (mm)	1,000 grain weight (g)	straw weight per hill (g)	Moisture content %
N-1	23.41b	6.30b	20.10c	3.50b	114.50b	3.30b	13.99a	0.14a	16.02a	26.60a	24.70a	66.70b	11.33a
N-4	25.92a	6.42b	20.99b	3.83a	134.71a	3.60a	12.32a	0.10a	14.50a	25.31b	22.90b	75.13b	11.40a
N-10	25.35a	7.20b	20.30bc	3.33b	122.23b	3.12b	12.84a	0.10a	13.72a	24.50c	21.99c	69.80b	11.20a
BS-370	20.81c	12.42a	23.50a	2.20c	99.20c	2.01c	10.00b	0.10a	16.10a	19.50d	18.30d	104.10a	11.33a

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

4.2 Results of seed quality attributes of different rice varieties and water regimes across sites

Results revealed that filter paper germination percent, sand germination percent, abnormal seedling, seedling length and seedling vigor index were significantly different (p<0.05) across sites.

Results revealed that sand germination and abnormal seedling were significantly different (p<0.05) for water regimes. Percent filter paper germination, seedling length and seedling vigor index were not significantly different (p<0.05).

Results revealed that filter paper germination percent, sand germination percent and abnormal seedling were significant different (p<0.05) for varieties. Seedling length and seedling vigor index were not significantly different (p<0.05).

Filter paper germination percent ranged from 93.04 to 96.54 and was highest at KARI (Table 12). Sand germination percent ranged from 89.30 to 93.92 and was highest at KARI. Abnormal seedling number ranged from 1.83 to 4.40 and was highest at MIAD**.** Seedling length ranged from 5.85 cm to 12.30 cm and was highest at KARI. Seedling vigor index ranged from 520.40 to 1155.30 and was highest at KARI.

Filter germination percent (96.54 %), sand germination percent (93.92 %), seedling length (12.30 cm and seedling vigor index (1155.30) at KARA, were significantly different (p<0.05) from MIAD while abnormal seedling number

(4.40) was significant at MIAD. There were significant interactions (Site x variety) for filter paper germination (%) sand germination (%) and number of abnormal seedling across sites (Appendix 4).

Sand (field) germination percent ranged from 88.72 to 93.61 for water regime 10 and water regime 20 respectively (Table 13).Abnormal seedling number ranged from 2.22 to 4.83 for water regime 20 and water regime 10 respectively.

Sand germination percent for water regime 20 (93.61), water regime 15 (92.60) were significantly different from regime 10 (88.72 %) but not different from water regime 0 (91.44 %). Abnormal seedling number for water regime 10 (4.83) was significantly different from water regime 0 (2.94), water regime 15 (2.44) and water regime 20 (2.22).

Filter paper germination percent, seedling length and seedling vigor index were not significantly different.

Results concluded that that water regimes 15 and water regime 20 for combined and site analyses were not significantly different for sand (field) germination percent and number of abnormal seedling hence, considered the minimum and maximum level of withholding irrigation water for producing quality seed. Water regime 10 gave the lowest germination percentage for sand germination and the highest for number of abnormal seedling. The second highest abnormal seedling was recorded under regime 0. Similar result was reported by Abou-khalifa (2012), when he reported no significant effect between regime 15 and regime 20 on chlorophyll content at different stages, leaf area index and spikelets-leaf area ratio.

Filter paper germination percent ranged from 84.44 to 98.90 for Basmati-370 and Nerica-10 respectively. Sand germination percent ranged from 86.80 to 95.10 for Nerica-1 and Nerica-10 respectively (Table 14). Abnormal seedling number ranged from 2.13 to 4.80 for Nerica-10 and Nerica-1 respectively.

Filter paper germination percent for Nerica-10 (98.90), Nerica-4 (98.90) and Nerica-1 (96.80) were significantly different from Basmati-370 (84.44). There was no significant difference between the Nerica varieties. Sand germination percent for Nerica-10 (95.10), Nerica-4 (92.90) were significantly different from Nerica-1 (86.80). Abnormal seedling number for Nerica-1 (4.80) was significantly different from Nerica-4 (2.50) and Nerica-10 (2.13), respectively. As mentioned (Table 11), Basmatic-370 did not form part of the second germination (sand) test conducted due to prolong dormancy period.

The studies conducted two methods (filter paper and sand/field) of germination test on seeds produced. Filter paper germination test was conducted in the laboratory while sand/field germination test was conducted in the field. Germination test conducted in the laboratory was done to determine viability of the seed and sand/field test was done to determine field performance (seedling emergence and seedling vigor index) under natural or harsh environment.

The term “emergence” is defined as development of seedling from the seed embryo of those essential structures (embryo, endosperm and seed coat), which indicate its ability to satisfactorily produce normal plant under favorable conditions (ISTA, 2004). Embryo in due course gives rise to the new plant, endosperm (storage tissues) nourish the embryo during development and seed coat gives protective covering which shields the embryo and endosperm and further control factors (moisture and gaseous exchange) that initiate germination. Germination occurs when the seed coat has imbibed adequate water becoming soft and elastic. The coleorhiza (shealth covering the radical) elongates slightly, emerging through the seed coat and the radical breaks through the coleorhiza becomes anchored in the soil. Under dry-seeded or aerobic conditions, the radical (young root) emerges before the coleoptiles. This may be the opposite (coleoptile may emerge before the radical) under water-seeded (anaerobic) conditions.

These two tests are similar however; vigor test further classified the seedlings into “strong” and “weak”. These classifications further provide information about seedlings free from deficiencies. Though there are many ways (medium) to determine seed viability, germination test is incomplete whereto, without using soil either under smooth or rough environment. Seed may germinate using different types of germination method but the germinant may fail to perform it normal duties as it grows into a full plant in farmer’s field, as it is in the case of rice seed. Quality seed is determined by number of genetic (genetic make-up, seed size and bulk density) and physiological (injury during harvest, processing, planting and establishment, growing condition during seed development, physical damage during storage by either human, machine or pest and, moisture and temperature during storage and age and maturity of seed) characteristics.

Both tests were conducted to determine the germination percentage and seedling vigor of various seeds produced under different irrigation regimes period. Following ISTA rules of 1977, one of the two criteria (relationship between vigor test and results of seedling emergence in field soil) employed by ISTA seed vigor committee was adapted to evaluate the germination percentage and seed performance under field conditions. Vigor test provides estimate value of the potential field performance, leading to farmers planting value.

Germination test conducted in the laboratory clearly expressed the proportion of the total number of seed that are alive. This determination is justified through controlled tests and actual counts of the number of seed that germinate. As it is in the case of this study, seed that failed to germinate within 3 to 6 days period was either considered dead seed and seed that germinated but failed to satisfactorily performed it genetic potential as stated under ISTA rule was considered abnormal seedling due to it abnormality. This process clearly indicates the genetic potential and nutritional quality (physiological and biochemical) of seed to germinate and perform it normal function. Germination percentage allow seed growers to determine the level of quality associated with the seed before planting, which further determine field rate, field emergence and crop uniformity. However, percentage germination test conducted in the laboratory only gives an idea of the performance of a category of seeds in the field. This cannot be 100% considered for calculation seed rate per hectare because said test (laboratory) is often conducted in an optimum condition specific to different species.

Table 12: Seed quality attributes across sites

Site	Filter paper germination %	sand germination %	abnormal seedling (No.)	seedling length (cm)	seedling vigor index
KARI	96.54a	93.92a	1.83b	12.30a	1155.30a
MIAD	93.04b	89.30b	4.40a	5.85b	520.40b

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Table 13: Seed quality attributes for water regimes across sites

Location Regime	Filter paper germination %	sand germination %	abnormal seedling (No.)	seedling length (cm)	seedling vigor index
0	96.60a	91.44ab	2.94b	9.00a	825.40a
10	94.50a	88.72b	4.83a	8.80a	792.80a
15	93.90a	92.60a	2.44b	9.35a	872.30a
20	94.50a	93.61a	2.22b	9.13a	861.22a

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Table 14: Seed quality attributes for varieties across sites

Variety	Filter paper germination %	sand germination %	abnormal seedling (No.)	seedling length (cm)	seedling vigor index
N-1	96.80a	86.80b	4.80a	8.90a	785.21a
N-4	98.90a	92.90a	2.50b	9.40a	877.92a
N-10	98.90a	95.10a	2.13b	8.92a	850.63a
BS-370	84.44b				

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

4.3 Results of yield and yield components for different rice varieties and water regimes at different sites

Results revealed that filled grain per panicle was significantly different ($p<0.05$) for the regimes at KARI. Flag leaf length, number of matured tillers per hill, panicle length, single panicle weight, filled grain weight per panicle, unfilled grain per panicle, unfilled grain weight per panicle, grain weight per hill, grain size, 1,000 grain weight, straw weight per hill and percent moisture content were not significantly different ($p<0.05$).

Results revealed that flag leaf length, number of matured tillers per hill, panicle length, single panicle weight, number of filled grain per panicle, filled grain weight per panicle, unfilled grain per panicle, unfilled grain weight per panicle, grain size, 1,000 grain weight, straw weight per hill and percent moisture content were significantly different (*p*<0.05) for the varieties at KARI.

Results revealed that number of unfilled grain per panicle and grain weight per hill were significantly different (*p*<0.05) for the regimes at MIAD. Flag leaf length, number of matured tillers per hill, panicle length, single panicle weight, number of filled grain per panicle, filled grain weight per panicle, unfilled grain weight per panicle, grain weight per m^2, grain size, 1,000 grain weight, straw weight per hill and percent moisture content were not significantly different (*p*<0.05).

Results revealed that flag leaf length, number of matured tillers per hill, panicle length, single panicle weight, number of filled grain per panicle, filled grain weight per panicle, unfilled grain per panicle, grain weight per hill, grain size, 1,000 grain weight and percent moisture content where significantly different (*p*<0.05) for the varieties at MIAD. Unfilled grain weight per panicle, grain weight per m^2 and straw weight per hill were not significantly different (*p*<0.05).

Filled grain number per panicle ranged from 104.73 to 119.97 for regimes at KARI (Table 15). Similar result was also reported at MIAD. Results from the two sites revealed that as the number of days to water withholding increases, number of filled grain per panicle significantly increases. This report is in agreement with Abou-khalifa. (2012) when he reported that grain filling rate gradually increased by increase number of days from complete heading.

Filled grain number per panicle for water regime 20 (119.97) was significantly different (*p*<0.05) from water regime 0 (104.73) but not water regime 10 (110.15) and water regime 15 (114.70).

At KARI, flag leaf length ranged from 22.03 cm to 28.15 cm for Basmati-370 and Nerica-10 respectively (Table 16). Matured tillers per hill ranged from 7.42 to 13.20 for Nerica-4 and Basmati-370, panicle length ranged from 21.43 cm to 23.73 cm for Nerica-10 and Basmati-370, single panicle weight ranged from 1.95 g to 3.60 g for Basmati-370 and Nerica-4, filled grain number per panicle ranged from 90.32 to 129.98 for Basmati-370 and Nerica-4, filled grain weight per panicle ranged from 1.80 g to 3.30 g for Basmati-370 and Nerica-4, unfilled grain number per panicle ranged from 9.83 to 14.70 for Basmati-370 and Nerica-1, unfilled grain weight per panicle ranged from 0.04 g to 0.08 g for Basmati-370 and Nerica-4 respectively. Grain size ranged from 18.81 mm to 26.16 mm for Basmati-370 and Nerica-1. 1,000 grain weight ranged from 17.74 g to 24.61 g for Basmati-370 and Nerica-1 respectively. Straw weight per hill ranged from 60.42 g to 104.23 g for Nerica-1 and Basmati-370 and percent moisture content ranged from 11.10 to 11.78 for Nerica-1 and Basmati-370, respectively. Grain weight per hill was not significantly difference (p<0.05).

Flag leaf length for Nerica-10 (28.15 cm), Nerica-4 (27.60 cm) and Nerica-1 (25.90 cm) were significantly different (*p*<0.05) from Basmati-370 (22.03 cm). The varieties within water regimes were not significantly different in all the water regimes for flag leaf length (Appendix 5). There was no significant difference between the Nerica varieties. Numbers of tillers per hill for Basmati-370 (13.20) was significantly different from Nerica-10 (8.60), Nerica-4 (7.42) and Nerica-1 (7.42), respectively. Basmati-370 had the highest numbers of tillers per hill in all the treatments as compared to the Nerica varieties (Appendix 6). Panicle length for Basmati-370 (23.73 cm) was significantly different from Nerica-4 (21.76 cm), Nerica-10 (21.43 cm) and Nerica-1 (21.30 cm). Basmati-370 has the longest panicle length that was significantly different from the other varieties in water regime 0, 10, 15 and regime 20 as compared to Nerica varieties (Appendix 7). There was no significant different between the Nerica varieties. Single panicle weight for Nerica-4 (3.60 g) was significantly different from Nerica-1 (3.17 g), Nerica-10 (3.11 g) and Basmati-370 (1.95 g). Number of filled grain per panicle for Nerica-4 (129.98) and Nerica-10 (120.57) were significantly different from Nerica-1 (108.70) and Basmati-370 (90.32). Filled grain weight per panicle for Nerica-4 (3.30 g) was significantly different from Nerica-1 (2.98 g), Nerica-10 (2.90 g) and Basmati-370 (1.80 g). Nerica-1 was significantly different from Basmati-370 but not significantly different from Nerica-10. Unfilled grain number per panicle for Nerica-1 (14.70), Nerica-4 (13.40 and Nerica-10 (13.10) were significantly different from Basmati-370 (9.83). Unfilled grain weight per panicle for Nerica-4 (0.08 g) and Nerica-1 (0.07 g) and Nerica-10 (0.07 g) were significantly different from Basmati-370 (0.04 g). Grain size for Nerica-1 (26.16 mm) was significantly different from Nerica-10 (24.35 mm) and Basmati-370

(18.81 mm) but not significantly different from Nerica-4 (25.40 mm). 1,000 grain weight was for Nerica-1 (24.61 g) was significantly different from Nerica-4 (22.78 g), Nerica-10 (22.23 g) and Basmati-370 (17.74 g). Straw weight per hill for Basmati-370 (104.23 g) was significantly different from all the Nerica varieties (Nerica-10 (70.60 g), Nerica-1 (60.42 g) and Nerica-4 (68.33 g). Similarly, percent moisture content for Basmati-370 (11.78) was significantly different from all the Nerica varieties (Nerica-4 (11.18), Nerica-1 (11.10) and Nerica-10 (10.96). This indicates that the varieties were distinct from each other probably due to difference in the genotypes.

Varieties within same water regime (regimes 0, 10, 15 and 20) were not significant (Appendix 8). Grain sizes of Nerica varieties (N-1, and N-4) were significantly different from Basmati-370 within same water regimes (Appendix 9). Similarly, 1000 grain weight for Nerica-1 was significantly different from Basmati-370 within same water regime (Appendix 10). Straw weight per hill of Basmat-370 was significantly different for water regime 0, 15 and 20 (Appendix 11). Unfilled grain number per panicle ranged from 9.03 to 13.95 and grain weight per hill from 12.14 to 16.86 for regimes at MIAD (Table 17).

Unfilled grain number per panicle for water regime 15 (13.95) was significantly different ($p<0.05$) from water regime 20 (11.83) and water regime 10 (9.03) but not significantly different from water regime 0 (12.52). Grain weight per hill for water regime 10 (16.86 g) was significantly different ($p<0.05$) from water regime

20 (12.97 g) and water regime 10 (12.14 g) but not significantly different from water regime 0 (15.88 g). Water regime 0 was significantly different from water regime 10.

Morphological characters for all treatments at MIAD were not significantly different. This report is in agreement with Abou-khalifa, (2012) when he reported no significant difference in regimes treatment when two varieties were subjected to water withholding.

At MIAD, flag leaf length ranged from 19.58 cm to 24.30 cm for Basmati-370 and Nerica-4 respectively (Table 18). Matured tillers per hill ranged from 5.10 to 11.67 for Nerica-1 and Basmati-370, panicle length ranged from 18.88 cm to 23.22 cm for Nerica-1 and Basmati-370, single panicle weight ranged from 2.40 g to 4.11 g for Basmati-370 and Nerica-4, filled grain number per panicle ranged from 108.10 to 139.43 for Basmati-370 and Nerica-4, filled grain weight per panicle ranged from 2.22 g to 3.87 g for Basmati-370 and Nerica-4, unfilled grain number per panicle ranged from 10.18 to 13.30 for Basmati-370 and Nerica-1, grain weight per hill ranged from 10.69 g to 16.50 g for Nerica-10 and Nerica-1, respectively. Grain size ranged from 20.20 mm to 26.96 mm for Basmati-370 and Nerica-1, 1,000 grain weight ranged from 18.78 g to 24.73 g for Basmati-370 and Nerica-1 while percent moisture content ranged from 10.88 to 11.62 for Basmati-370 and Nerica-1, respectively.

Flag leaf length for Nerica-4 (24.30 cm) was significantly different (p<0.05) from Nerica-1 (20.93 cm) and Basmati-370 (19.58 cm). Flag leaf length of all the varieties (3 NERICAs and Basmati-370) was similar in most water regimes except Nerica-4 which was significantly different in water regime 20 at MIAD (Appendix 12). Numbers of tillers per hill for Basmati-370 (11.67) was significantly different from Nerica-10 (5.75), Nerica-4 (5.42 cm) and Nerica-1 (5.10 cm). There was no significant difference between the three Nerica varieties. Basmati-370 had the highest numbers of tillers per hill (Appendix 13). The Nerica varieties within the same water regimes behaved the same. Panicle length for Basmati-370 (23.22 cm) was significantly different from Nerica-4 (20.21 cm), Nerica-10 (19.20 cm) and Nerica-1 (18.88 cm). Nerica-4 was significantly different from Nerica-1 but not significantly different from Nerica-10. Panicle lengths of Basmati-370 within same water regimes were significantly different from Nerica varieties (Appendix 14). The Nerica varieties behaved the same in all treatments. Single panicle weight for Nerica-4 (4.11 g) was significantly different from Nerica-10 (3.55 g) and Basmati-370 (2.40 g) but not significantly different from Nerica-1 (3.75 g). Nerica-10 was significantly different from Basmati-370 but not significantly different from Nerica-1. Number of filled grain per panicle for Nerica-4 (139.43) was significantly different from Nerica-10 (123.88), Nerica-1 (120.30) and Basmati-370 (108.10). Nerica-10 was significantly different from Basmati-370 but not significantly different from Nerica-1 while Nerica-1 was not significantly different from Basmati-370. Filled grain weight per panicle for Nerica-4 (3.87 g) was significantly different from Nerica-10 (3.35 g) and Basmati-370 (2.22 g) but not significantly different (*p*<0.05) from Nerica-1 (3.53 g). Nerica-10 was significantly different from Basmati-370 but not significantly different from Nerica-1. Unfilled grain number per panicle for Nerica-1 (13.30) and Neria-10 (12.58) were significantly different from Basmati-370 (10.18) but not significantly different from Nerica-4 (11.30). Grain weight per hill for Nerica-1 (16.50 g), Basmati-370 (16.30) and Nerica-4 (14.10 g) were significantly different from Nerica-10 (10.69 g). Grain weight per hill was significantly different within water regime 0 as compared to Nerica-4, 10 and Basmati-370 (Appendix 15). Grain size for Nerica-1 (26.69 mm) was significantly different from Nerica-4 (25.23 mm), Nerica-10 (24.59 mm) and Basmati-370 (20.20 mm). Nerica-4 was significantly different from Basmati-370 but not significantly different from Nerica-10. Nerica-1 (24.73 mm) had the biggest seed while Basmati-370 (18.78 mm) had the smallest seed, and all the varieties were significantly different from each other. Similar results (*p*<0.05) were manifested within same water regimes for grain size and 1,000 grain weight (Appendix 16 and 17)

Percent moisture content for Nerica-4 (11.62), Nerica-1 (11.58) and Nerica-10 (11.40) were significantly different from Basmati-370 (10.88).

Unfilled grain weight per panicle, grain weight per m^2 and straw weight per hill were not significantly different. Straw weight per hill was not significantly different for varieties within same treatment (Appendix 18).

Bridging between rice consumption and production, alternate wetting and drying irrigation promote tillering ability in paddy that could help spark up farmer's effort in realizing bumper harvest. Yield output from data analyses reported for water regimes treatment were (i) Water regime zero produced 3.10 metric tons (mt) ha^{-1} (ii) Water regime 10 produce 2.90 metric tons (mt) ha^{-1} (iii) Water regime 15 produced 3.24 metric tons (mt) ha^{-1} (iv) Water regime 20 produced 2.80 metric tons (mt) ha^{-1}, and varieties were (1) Nerica-1 produced 3.20 metric tons (mt) ha^{-1} (ii) Nerica-4 produced 2.98 metric tons (mt) ha^{-1} (Nerica-10 produced 2.62 metric tons (mt) ha^{-1} (iv) Basmati-370 produced 3.32 metric tons (mt) ha^{-1}. Results revealed that there were no significant difference between regimes and varieties. The technology has generated an increase paddy yields from 1.5 metric tons (mt) ha^{-1} under rainfed to 3.0 metric tons (mt) ha^{-1} under irrigated system for Nerica-1, Nerica-4 and Nerica-10 with minimum inputs (less fertilizer, less water and less seed rate per ha^{-1}).

Table 15: Yield and yield components for water regimes at KARI

Regime	Flag leaf length, (cm)	tillers per hill (No.)	panicle length (cm)	single panicle weight (g)	number of filled grain per panicle, (No.)	filled grain weight per panicle (g)	unfilled grain per panicle (No.)	unfilled grain weight per panicle (g)	grain weight per hill (g)	grain size (mm)	1,000 grain weight (g)	straw weight per hill (g)	moisture content %
0	25.40a	8.70a	22.13a	2.77a	104.73b	2.60a	10.50a	0.10a	14.24a	22.62a	21.73a	68.83a	11.23a
10	25.34a	9.25a	22.12a	2.92a	114.70ab	2.75a	13.40a	0.10a	16.99a	24.22a	21.83a	78.60a	11.10a
15	26.23a	9.25a	22.66a	2.90a	110.15ab	2.68a	13.40a	0.10a	17.40a	24.03a	22.40a	86.20a	11.31a
20	26.70a	9.42a	21.30a	3.20a	119.97a	2.95a	13.70a	0.10a	14.20a	22.84a	21.43a	70.00a	11.40a

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Table 16: Yield and yield components for varieties at KARI

Variety	Flag leaf length, (cm)	tillers per hill (No.)	panicle length (CM)	single panicle weight (g)	number of filled grain per panicle, (No.)	filled grain weight per panicle (g)	unfilled grain per panicle (No.)	unfilled grain weight per panicle (g)	grain weight per hill (g)	grain size (mm)	1,000 grain weight (g)	straw weight per hill (g)	% moisture content
N-1	25.90a	7.42b	21.30b	3.17b	108.70b	2.98b	14.70a	0.07a	15.53a	26.16a	24.61a	60.42b	11.10b
N-4	27.60a	7.42b	21.76b	3.60a	129.98a	3.30a	13.40a	0.08a	14.61a	25.40ab	22.78b	68.33b	11.18b
N-10	28.15a	8.60b	21.43b	3.11b	120.57a	2.90b	13.10a	0.07a	16.80a	24.35b	22.23b	70.60b	10.96b
BS-370	22.03b	13.20a	23.73a	1.95c	90.32c	1.80c	9.83b	0.04b	15.89a	18.81c	17.74c	104.23a	11.78a

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Table 17: Yield and yield components for water regimes at MIAD

Regime	Flag leaf length, (cm)	tillers per hill (No.)	panicle length (CM)	single panicle weight (g)	number of filled grain per panicle, (No.)	filled grain weight per panicle (g)	unfilled grain per panicle (No.)	Grain weight per hill (g)	grain weight per m^2 (g)	grain size (mm)	1,000 grain weight (g)	straw weight per hill (g)	moisture content %
0	20.86a	6.75a	19.94a	3.35a	119.10a	3.20a	12.52ab	15.88ab	307.48a	24.50a	22.27ab	78.92a	11.33a
10	21.96a	6.00a	20.34a	3.50a	130.13a	3.32a	9.03c	12.14c	288.67a	23.92a	21.65b	68.50a	11.40a
15	21.50a	7.58a	20.67a	3.64a	124.60a	3.38a	13.95a	16.86a	323.87a	23.98a	22.44a	86.10a	11.30a
20	23.03a	7.58a	20.51a	3.28a	117.88a	3.10a	11.83b	12.97cb	277.43a	24.53a	21.87ab	94.30a	11.50a

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Table 18: Yield and yield components for varieties at MIAD

Variety	Flag leaf length, (cm)	tillers per hill (No.)	panicle length (CM)	single panicle weight (g)	number of filled grain per panicle, (No.)	filled grain weight per panicle (g)	unfilled grain per panicle (No.)	grain weight per hill (g	grain weight per m^2 (g)	grain size (mm)	1,000 grain weight (g)	straw weight per hill (g)	moisture content %
N-1	20.93cb	5.10b	18.88c	3.75ab	120.30bc	3.53ab	13.30a	16.50a	316.73a	26.96a	24.73a	72.92b	11.58a
N-4	24.30a	5.42b	20.21b	4.11a	139.43a	3.87a	11.30ab	14.40a	298.15a	25.23b	22.95b	81.92ab	11.62a
N-10	22.55ab	5.75b	19.20bc	3.55b	123.88b	3.35b	12.58a	10.69b	261.58a	24.59b	21.77c	69.00b	11.40a
BS-370	19.58c	11.67a	23.22a	2.40c	108.10c	2.22c	10.18b	16.30a	320.99a	20.20c	18.78d	103.92a	10.88b

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

4.4 Results of seed quality attributes of different rice varieties and water regimes for different sites

Results revealed that seedling vigor index (SVI) was significantly different ($p<0.05$) for water regimes at KARI. Percent filter paper germination, percent sand germination, abnormal seedlings and seedling length were not significantly different ($p<0.05$).

Results revealed that percent filter paper germination and percent sand germination were significantly different ($p<0.05$) for varieties at KARI. Abnormal seedlings, Seedling length and seedling vigor index were not significant difference ($p<0.05$).

Results revealed that sand germination and abnormal seedling were significantly different ($p<0.05$) for water regimes at MIAD. Percent filter paper germination, seedling length and seedling vigor index were not significantly different.

Results revealed that filter paper germination percent, sand germination percent, abnormal seedling and seedling vigor index were significantly different for varieties at MIAD. Seedling length was no significant difference.

AT KARI, Seedling vigor index ranged from 1062.90 to 1252.80 for water regime 0 and regime 20 respectively (Table 19).

Seedling vigor index for water regime 20 (1252.80) was significantly different from water regime 0 (1062.90) but not significantly different ($p<0.05$) from water regime 10 (1103.90) and water regime 15 (1201.60). Nerica-4 had the highest seedling vigor index that was significantly different from Nerica-1 and Nerica-10 in water regime 0 (Appendix 19). Other water regimes were not significantly different

Filter paper germination percent, sand germination percent, abnormal seedlings and seedling length were not significantly different therefore, withholding of water did not affect those four seedling components.

At KARI, filter paper germination percent ranged from 80.10 to 98.92 for Basmati-370 and Nerica-1 respectively (Table 20). Sand germination percent ranged from 91.70 to 96.00 for Nerica-1 and Nerica-10 respectively.

Filter paper germination percent for Nerica-4 (98.92), Nerica-10 (98.17) and Nerica-1 (94.33) were significantly different from Basmati-370 (80.10) Sand germination percent for Nerica-10 (96.00) was significantly different from Nerica-1 (91.70) but not significantly different from Nerica-4 (94.10). Results (sand germination %) for Nerica varieties within same water regime of treatments (regimes-10, 15 and 20) showed no significant difference. However, Nerica-4 (sand germination %) was significantly different from Nerica-1 and 10 under water regime-0 (Appendix 20). Abnormal seedlings, seedling length and seedling vigor index were not significantly different. Seedling length within water regimes showed no significant different both at KAIR and MIAD (Appendix 21 and 22).

Therefore, withholding of water did not affect three major components which indicated that varieties behaved the same way.

At MIAD on the contrary, sand germination percent ranged from 85.33 to 92.11 for regime 10 and regime 20 respectively (Table 21). Abnormal seedling ranged from 2.89 to 6.33 for regime 20 and regime 10 respectively.

Sand germination percent for water regime 20 (92.11) and water regime 0 (90.11) were significantly different from water regime 10 (85.33) but not significantly different from water regime 15 (89.44). Water regime 0 was significantly different from water regime 10 but not significantly different from water regime 15. Abnormal seedling number for water regime 10 (6.33) was significantly different from water regime 20 (2.89) but not significantly different from water regime 0 (4.22) and water regime 15 (4.11). Filter paper germination percent, seedling length and seedling vigor index were not significantly different. Similarly at KARI, the same variables were not significant therefore, withholding of water had the same effect in both sites.

At MIAD, filter paper germination percent ranged from 89.20 to 99.58 for Basmati-370 and Nerica-10 respectively (Table 22). Sand germination percent ranged from 81.92 to 94.20 for Nerica-1 and Nerica-10 respectively. Abnormal seedling ranged from 2.58 to 7.33 for Nerica-10 and Nerica-1 respectively. Seedling vigor index ranged from 461.67 to 571.58 for Nerica-1 and Nerica-4 respectively.

Filter paper germination percent for Nerica-10 and 1 (99.58), were significantly different from Basmati-370 (89.20). Sand germination percent for Nerica-10 (94.20) and Nerica-4 (91.67) were significantly different from Nerica-1 (81.92). Results (sand germination %) within same water regime for Nerica-4 and 10 were not significantly different in all water regimes (significantly different). Nerica-10 had the highest percentage sand germination that was significantly different from Nerica-1 in water regimes 0, 10 and 15 (Appendix 23). Abnormal seedling for Nerica-1 (7.33) was significantly different from Nerica-4 (3.30) and Nerica-10 (2.58). Seedling vigor index for Nerica-4 (571.58) was significantly different from Nerica-1 (461.67) but not significantly different from Nerica-10 (528.42). Results (seedling vigor index) from further investigation for Nerica-1, 4 and 10 within water regime 15 and 20 behaved the same (Appendix 24). Within regime 0, Nerica-4 was significantly different from Nerica-1 and 10. Seedling vigor index was highest for Nerica-4 in water regime 0 and was significantly differently from Nerica-1 and Nerica-10 while in water regime 10, Nerica-10 had the highest seedling vigor index compared with Nerica-4 and Nerica-1 (Appendix 24). Nerica-10 had the lowest dormancy since it had the highest both in filter paper germination percent (99.58) which is approximately 100% and sand/field germination (94.20) in table 22. It had the least abnormal seedling. The highest abnormal seedling was reported in Nerica-1. Basmati-370 had the highest dormancy (10.8 %) compared to other varieties tested since it had the lowest germination percent in filter paper test (89.20). The high level of dormancy in

Basmati-370 could probably be attributed to variation in genotype because it is classified as traditional variety.

Table 19: Seed quality attributes for water regimes at KARI

Location Regime	Filter paper germination **%**	sand germination %	abnormal seedling (No.)	seedling length (cm)	seedling vigor index
0	94.42a	92.77a	1.67a	11.44a	1062.88b
10	91.80a	92.11a	3.33a	11.98a	1103.90ab
15	93.00a	95.66a	0.78a	12.56a	1201.60ab
20	92.33a	95.11a	1.56a	13.16a	1252.80a

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Table 20: Seed quality attributes for varieties at KARI

Variety	Filter paper germination **%**	sand germination %	abnormal seedling (No.)	seedling length (cm)	seedling vigor index
N-1	94.33a	91.70b	2.20a	12.11a	1108.75a
N-4	98.92a	94.10ab	1.70a	12.54a	1184.25a
N-10	98.17a	96.00a	1.70a	12.21a	1172.83a
BS-370	80.10b				

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Table 21: Seed quality attributes for water regimes at MIAD

Location Regime	Filter paper germination **%**	sand germination %	abnormal seedling (No.)	seedling length (cm)	seedling vigor index
0	98.10a	90.11a	4.22ab	6.56a	587.88a
10	96.75a	85.33b	6.33a	5.60a	481.66a
15	94.75a	89.44ab	4.11ab	6.12a	543.00a
20	96.58a	92.11a	2.89b	5.09a	469.66a

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Table 22: Seed quality attributes for varieties at MIAD

Variety	Filter paper germination **%**	sand germination %	abnormal seedling (No.)	seedling length (cm)	seedling vigor index
N-1	98.58a	81.92b	7.33a	5.68a	461.67b
N-4	98.83a	91.67a	3.30b	6.23a	571.58a
N-10	99.58a	94.20a	2.58b	5.63a	528.42ab
BS-370	89.20b				

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Results indicated that withholding irrigation water after complete heading has no effect on the yield and yield components such as tillers per hill, panicle length, filled grain per panicle and 1,000 grain weight, therefore area under rice production may be increased when less water is used per unit area. Also withholding water has no effect on morphological characters of rice such as flag leaf length, number of matured tillers per hill, panicle length, single panicle weight, number of filled grain per panicle, grain size and straw weight. Seed quality attributes such as filter paper germination, seedling length and seedling vigor index except on sand (field) germination and abnormal seedling are not influenced by withholding water.

Results also indicated that varieties were distinct from each other in morphological characters. Nerica-1, Nerica-4 and Nerica-10 exhibited shorter period of dormancy and therefore, it may be planted immediately after harvest. Basmati-370 exhibited longer period of dormancy and therefore, it should not be planted immediately after harvesting. Withholding water improve the quality attributes of rice seed.

5.2 Recommendations

From the analyses and discussions of the results, the following required further investigation:

- The period of dormancy in Basmatic-370 as this was the major constraint in determining the sand/field germination percentage, abnormal seedling, seedling length and seedling vigor index as it was paramount component of the study.
- Effect of root extension and initiations under water stress environment.
- The mechanism plant adopt when they encounter drought.
- Observation on withholding irrigation water needs to be scaled up so that water is withheld at 10, 15 and 20 days after complete heading in large acreage of land
- Determination of irrigation frequency and levels of nutrition for paddy and upland rice and, their effects on components of yield**.** This is paramount because upland rice may also be grown under rainfall conditions and irrigation should enhance productivity.
- Irrigation supply can be withheld 10 days after complete heading of rice without substantially affecting productivity and 20 days to produce quality seed for regeneration.

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APPENDICES

Appendix 1: KARI-MWEA field layout

	Regime 20				**Regime-0**			
Replicate – 1	N-1 **Plot-1**	N-10 P-2	N-4 P-3	BS P-4	N-10 P-5	N-1 P-6	N-4 P-7	BS P-8
	Regime-10				**Regime-15**			
	BS **P-16**	N-4 P-15	N-1 P-14	N-10 P-13	BP P-12	N-1 P-11	N-4 P-10	N-10 P-9
Replicate - 2	**Regime 0**				**Regime 20**			
	N-10 P-17	BS P-18	N-1 P-19	N-4 P-20	N-4 P-21	BS P-22	N-10 P-23	N-1 P-24
	Regime 15				**Regime 10**			
	BS **P-32**	N-10 P-31	N-4 P-30	N-1 P-29	N-1 P-28	N-4 P-27	N-10 P-26	BS P-25
Replicate- 3	**Regime 15**				**Regime 0**			
	N-4 P-33	N-10 P-34	N-1 P-35	BS P-36	BS P-37	N-1 P-38	N-10 P-39	N-4 P-40
	Regime 10				**Regime 20**			
	N-1 **Plot-48**	N-4 P-47	N-10 P-46	BS P-45	N-10 P-44	N-4 P-43	N-1 P-42	BS P-41

4_t x 4_v x 3_r = 48 treatment combinations

Appendix 2: MIAD-Mwea field layout

	Replicate-1				**Rgm**	**Replicate - 2**				**Rgm**	**Replicate – 3**			
Regime-15	N-10 **Plot-1**	BS P-2	N-4 P-3	N-1 P-4	**20**	N-1 P-17	BS P-18	N-10 P-19	N-4 P-20	**10**	N-10 P-33	N-4 P-34	N-1 P-35	BS P-36
Regime-10	N-1 P-8	N-10 P-7	BS P-6	N-4 P-5	**0**	N-4 P-24	N-10 P-23	BS P-22	N-1 P-21	**20**	N-1 P-40	BS P-39	N-4 P-38	N-10 P-37
Regime-20	N-10 P-9	N-4 P-10	N-1 P-11	BS P-12	**15**	N-10 P-25	N-4 P-26	BS P-27	N-1 P-28	**0**	N-10 P-41	N-4 P-42	BS P-43	N-1 P-44
Regime-0	BS P-16	N-1 P-15	N-4 P-14	N-10 P-13	**10**	N-4 P-32	N-10 P-31	N-1 P-30	BS P-29	**15**	N-10 **P-48**	N-1 P-47	N-4 P-46	BS P-45

$4_t \times 4_v \times 3_r$ = 48 treatment combinations

Appendix 3: Combined analysis for yield and yield components across sites

Regime	Flag leaf length, (cm)	tillers per hill (No.)	panicle length (CM)	single panicle weight (g)	number of filled grain per panicle, (No.)	filled grain weight per panicle (g)	unfilled grain per panicle (No.)	unfilled grain weight per panicle (g)	grain weig ht per hill (g)	grain size (mm)	1,000 grain weight (g)	straw weig ht per hill (g)	moisture content (%)
Site*Variety	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
P=value	0.29	0.74	0.03	0.89	0.34	0.91	0.69	0.42	0.10	0.30	0.20	0.72	<.0001
Regime*Variety	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
P=value	0.74	0.80	0.76	0.32	0.28	0.32	0.31	0.56	0.20	0.12	0.10	0.75	0.11

NS = Not significant. * Significant at α=0.05

Appendix 4**:** Combined analysis for seed quality attributes across sites

Regime	Filter paper germination %	Sand/normal germination %	Abnormal seedling	Seedling length (cm)	Seedling vigor index
Site*Variety	*	*	*	NS	NS
P=value	0.02	0.01	0.01	0.95	0.90
Regime*Variety	NS	NS	NS	NS	NS
P=value	0.70	0.13	0.30	0.25	0.10

NS = Not significant. * Significant at α=0.05

Appendix 5: Flag Leaf Length for different regimes and varieties at KARI

	REGIME-0	REGIME-10	REGIME-15	REGIME-20	Mean
Nerica-1	25.82a	26.06a	26.65a	25.10a	25.90^{a}
NERICA-4	26.93a	27.87a	27.37a	28.10a	27.60^{a}
NERICA-10	28.34a	27.89a	28.12a	28.23a	28.15^{a}
BASMATI-370	20.49a	19.54a	22.77a	25.34a	22.03^{b}
Mean	25.40_{a}	25.34_{a}	26.23_{a}	26.70_{a}	

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Means with the same superscript in the same column are not significantly different using LSD at α=0.05

Means with the same subscript in the same row are not significantly different using LSD at α=0.05

Appendix 6: Tillers per hill for different regimes and varieties at KARI

	REGIME-0	REGIME-10	REGIME-15	REGIME-20	Mean
Nerica-1	5.67a	8.00a	7.00a	9.00a	7.42^{b}
NERICA-4	7.67a	7.67a	7.33a	7.00a	7.42^{b}
NERICA-10	8.33b	8.67a	9.67b	7.67a	8.60^{b}
BASMATI-370	13.00b	12.67b	13.00b	14.00b	13.20^{a}
Mean	8.70_{a}	9.25_{a}	9.25_{a}	9.42_{a}	

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Means with the same superscript in the same column are not significantly different using LSD at α=0.05

Means with the same subscript in the same row are not significantly different using LSD at α=0.05

Appendix 7: Panicle length for different regimes and varieties at KARI

	REGIME-0	REGIME-10	REGIME-15	REGIME-20	Mean
Nerica-1	21.94a	21.23a	21.56a	20.28a	21.30^{b}
NERICA-4	21.97a	22.65a	22.26a	20.17a	21.76^{b}
NERICA-10	21.13a	21.35a	22.28a	20.94a	21.43^{b}
BASMATI-370	23.46a	23.25b	24.53b	23.65b	23.73^{a}
Mean	22.13_{a}	22.12_{a}	22.66_{a}	21.30_{a}	

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Means with the same superscript in the same column are not significantly different using LSD at α=0.05

Means with the same subscript in the same row are not significantly different using LSD at α=0.05

Appendix 8: Grain weight per hill (g) for different regimes and varieties at KARI

	REGIME-0	REGIME-10	REGIME-15	REGIME-20	Mean
Nerica-1	12.22a	19.04a	16.74a	14.13a	15.54^{a}
NERICA-4	15.45a	17.27a	15.54a	10.20a	14.61^{a}
NERICA-10	14.24a	17.53a	19.84a	15.40a	16.80^{a}
BASMATI-370	15.04a	14.15a	17.39a	16.97a	15.89^{a}
Mean	14.24_{a}	16.99_{a}	17.40_{a}	14.20_{a}	

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Means with the same superscript in the same column are not significantly different using LSD at α=0.05

Means with the same subscript in the same row are not significantly different using LSD at α=0.05

Appendix 9: Grain size (mm) for different regimes and varieties at KARI

	REGIME-0	REGIME-10	REGIME-15	REGIME-20	Mean
Nerica-1	25.32a	28.35a	26.69a	24.30a	26.16^{a}
NERICA-4	25.53a	26.05a	25.37a	24.64a	25.40^{ab}
NERICA-10	23.50a	24.59b	25.97a	23.32a	24.35^{b}
BASMATI-370	20.12b	17.90b	18.10b	19.20b	18.81^{c}
Mean	22.62_{a}	24.22_{a}	24.03_{a}	22.84_{a}	

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Means with the same superscript(s) in the same column are not significantly different using LSD at α=0.05

Means with the same subscript in the same row are not significantly different using LSD at α=0.05

Appendix 10: 1,000 grain weight (g) for different regimes and varieties at KARI

	REGIME-0	REGIME-10	REGIME-15	REGIME-20	Mean
Nerica-1	24.33a	25.50a	25.94a	22.65a	21.61^{a}
NERICA-4	23.14a	22.57b	23.41b	22.00a	22.78^{b}
NERICA-10	21.40a	21.98b	22.53b	23.02a	22.23^{b}
BASMATI-370	18.03b	17.27b	17.59b	18.05b	17.74^{c}
Mean	21.73_{a}	21.83_{a}	22.40_{a}	21.43_{a}	

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Means with the same superscript in the same column are not significantly different using LSD at α=0.05

Means with the same subscript in the same row are not significantly different using LSD at α=0.05

Appendix 11: Straw weight per hill (g) for different regimes and varieties at KARI

	REGIME-0	REGIME-10	REGIME-15	REGIME-20	Mean
Nerica-1	54.67a	71.67a	65.00a	50.33a	60.42^{b}
NERICA-4	66.33a	73.00a	79.67a	54.33a	68.33^{b}
NERICA-10	59.33a	73.67a	86.00a	63.33a	70.60^{b}
BASMATI-370	95.00b	96.00a	114.00b	112.00b	104.23^{a}
Mean	68.83_{a}	78.60_{a}	86.20_{a}	70.00_{a}	

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Means with the same superscript in the same column are not significantly different using LSD at α=0.05

Means with the same subscript in the same row are not significantly different using LSD at α=0.05

Appendix 12: Flag Leaf Length for different regimes and varieties at MIAD

	REGIME-0	REGIME-10	REGIME-15	REGIME-20	Mean
Nerica-1	21.42a	19.74a	22.01a	20.53	20.93^{cb}
NERICA-4	21.51a	25.11a	23.88a	26.60b	24.30^{a}
NERICA-10	21.93a	23.01a	20.30a	24.97a	22.55^{ab}
BASMATI-370	18.60a	19.99a	19.71a	20.04a	19.58^{c}
Mean	20.86_{a}	21.96_{a}	21.50_{a}	23.03_{a}	

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Means with the same superscript (s) in the same column are not significantly different using LSD at α=0.05

Means with the same subscript in the same row are not significantly different using LSD at α=0.05

Appendix 13: Tillers per hill for different regimes and varieties at MIAD

	REGIME-0	REGIME-10	REGIME-15	REGIME-20	Mean
Nerica-1	5.67a	4.67a	6.00a	4.00a	5.10^{b}
NERICA-4	4.00a	5.67a	5.00a	7.00a	5.42^{b}
NERICA-10	4.67a	5.00a	5.67a	7.67a	5.75^{b}
BASMATI-370	12.67b	8.67b	13.67b	11.67b	11.67^{a}
Mean	6.75_{a}	6.00_{a}	7.58_{a}	7.58_{a}	

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Means with the same superscript in the same column are not significantly different using LSD at α=0.05

Means with the same subscript in the same row are not significantly different using LSD at α=0.05

Appendix 14: Panicle length for different regimes and varieties at MIAD

	REGIME-0	REGIME-10	REGIME-15	REGIME-20	Mean
Nerica-1	19.15a	18.31a	19.10a	18.95a	18.88^{c}
NERICA-4	18.99a	20.30a	21.17a	20.37a	20.21^{b}
NERICA-10	18.95a	18.85a	19.10a	19.79a	19.20^{bc}
BASMATI-370	22.67b	23.91b	23.40b	22.92b	23.22^{a}
Mean	19.94_{a}	20.34_{a}	20.67_{a}	20.51_{a}	

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Means with the same superscript (s) in the same column are not significantly different using LSD at α=0.05

Means with the same subscript in the same row are not significantly different using LSD at α=0.05

Appendix 15: Grain weight per hill (g) for different regimes and varieties at MIAD

	REGIME-0	REGIME-10	REGIME-15	REGIME-20	Mean
Nerica-1	26.78a	11.21a	17.79a	10.20a	16.50^{a}
NERICA-4	8.76b	17.55a	15.20a	15.99a	14.40^{a}
NERICA-10	10.10b	9.91a	10.69a	12.10a	10.69^{b}
BASMATI-370	17.90b	9.87a	23.76a	13.61a	16.30^{a}
Mean	15.88_{ab}	12.14_{c}	16.86_{a}	12.97_{cb}	

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Means with the same superscript in the same column are not significantly different using LSD at α=0.05

Means with the same subscript(s) in the same row are not significantly different using LSD at α=0.05

Appendix 16: Grain size (mm) for different regimes and varieties at MIAD

	REGIME-0	REGIME-10	REGIME-15	REGIME-20	Mean
Nerica-1	27.77a	26.20a	27.03a	26.83a	26.96^{a}
NERICA-4	24.10b	25.55a	25.78b	25.52a	25.23^{b}
NERICA-10	25.03b	25.01a	23.25b	25.10b	24.59^{b}
BASMATI-370	21.14b	18.93b	19.87b	20.67b	20.20^{c}
Mean	24.50_{a}	23.92_{a}	23.98_{a}	24.53_{a}	

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Means with the same superscript in the same column are not significantly different using LSD at α=0.05

Means with the same subscript in the same row are not significantly different using LSD at α=0.05

Appendix 17: 1,000 grain weight (g) for different regimes and varieties at MIAD

	REGIME-0	REGIME-10	REGIME-15	REGIME-20	Mean
Nerica-1	25.48a	24.32a	25.12a	24.00a	24.73^{a}
NERICA-4	23.27b	22.28b	23.30b	22.94a	22.95^{b}
NERICA-10	21.49b	21.17b	21.84b	22.58b	21.77^{c}
BASMATI-370	18.82b	18.84b	19.51b	17.95b	18.78^{d}
Mean	22.27_{ab}	21.65_{b}	22.44_{a}	21.87_{ab}	

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Means with the same superscript in the same column are not significantly different using LSD at α=0.05

Means with the same subscript in the same row are not significantly different using LSD at α=0.05

Appendix 18: Straw weight per hill (g) for different regimes and varieties at MIAD

	REGIME-0	REGIME-10	REGIME-15	REGIME-20	Mean
Nerica-1	78.67a	56.00a	85.33a	71.67a	72.92^{b}
NERICA-4	59.33a	87.00a	82.67a	98.67a	81.82^{ab}
NERICA-10	52.00a	64.00a	63.00a	97.00a	69.00^{b}
BASMATI-370	125.67_{a}	67.00_{a}	113.33_{a}	109.67_{a}	103.92^{a}
Mean	78,92a	68.50a	86.10a	94.30a	

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Means with the same superscript (s) in the same column are not significantly different using LSD at α=0.05

Means with the same subscript in the same row are not significantly different using LSD at α=0.05

Appendix 19: Seedling vigor index for different regimes and varieties at KARI

	REGIME-0	REGIME-10	REGIME-15	REGIME-20	Mean
Nerica-1	914.00b	1192.33a	1130.00a	1198.66a	1108.75^{a}
NERICA-4	1225.66a	947.66a	1232.66a	1331.00a	1184.25^{a}
NERICA-10	1049.00b	1171.66a	1242.00a	1228.66a	1172.83^{a}
Mean	1062.88_{b}	1103.90_{ab}	1201.60_{ab}	1252.80_{a}	

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Means with the same superscript in the same column are not significantly different using LSD at α=0.05

Means with the same subscript(s) in the same row are not significantly different using LSD at α=0.05

Appendix 20: Sand germination (%) for different regimes and varieties at KARI

	REGIME-0	REGIME-10	REGIME-15	REGIME-20	Mean
Nerica-1	89.00b	91.00a	93.66a	93.00a	91.70^{b}
NERICA-4	97.00a	88.00a	94.00a	97.33a	94.10^{ab}
NERICA-10	92.00b	97.33a	99.33a	95.00a	96.16^{a}
Mean	92.77_{a}	92.11_{a}	95.66_{a}	95.11_{a}	

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Means with the same superscript(s) in the same column are not significantly different using LSD at α=0.05

Means with the same subscript in the same row are not significantly different using LSD at α=0.05

Appendix 21: Seedling length (cm) for different regimes and varieties at KARI

	REGIME-0	REGIME-10	REGIME-15	REGIME-20	Mean
Nerica-1	10.32a	13.17a	12.10a	12.88a	12.11^{a}
NERICA-4	12.64a	10.73a	13.11a	13.67a	12.54^{a}
NERICA-10	11.37a	12.05a	12.50a	13.93a	12.46^{a}
Mean	11.44_{a}	11.98_{a}	12.56_{a}	13.16_{a}	

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Means with the same superscript in the same column are not significantly different using LSD at α=0.05

Means with the same subscript in the same row are not significantly different using LSD at α=0.05

Appendix 22: Seedling length (cm) for different regimes and varieties at MIAD

	REGIME-0	REGIME-10	REGIME-15	REGIME-20	Mean
Nerica-1	6.31a	4.91a	6.68a	4.82a	5.68^{a}
NERICA-4	7.41a	5.14a	6.76a	5.59a	6.23^{a}
NERICA-10	5.96a	6.74a	4.94a	4.87a	5.63^{a}
Mean	6.56_{a}	5.60_{a}	6.12_{a}	5.09_{a}	

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Means with the same superscript in the same column are not significantly different using LSD at α=0.05

Means with the same subscript in the same row are not significantly different using LSD at α=0.05

Appendix 23: Sand germination (%) for different regimes and varieties at MIAD

	REGIME-0	REGIME-10	REGIME-15	REGIME-20	Mean
Nerica-1	82.00b	73.33b	81.00b	91.33a	81.92^{b}
NERICA-4	93.33a	91.33a	91.66a	90.33a	91.67^{a}
NERICA-10	95.00a	91.33a	95.66a	94.66a	94.20^{a}
Mean	90.11_{a}	85.33_{b}	89.44_{ab}	92.11_{a}	

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Means with the same superscript in the same column are not significantly different using LSD at α=0.05

Means with the same subscript in the same row are not significantly different using LSD at α=0.05

Appendix 24: Seedling vigor index for different regimes and varieties at MIAD

	REGIME-0	REGIME-10	REGIME-15	REGIME-20	Mean
Nerica-1	506.33b	358.00b	541.66a	440.66a	461.67^{b}
NERICA-4	691.66a	470.33b	618.00a	506.33a	571.58^{a}
NERICA-10	565.66b	616.66a	469.33a	462.00a	528.42^{ab}
Mean	587.88_{a}	481.66_{a}	543.00_{a}	469.66_{a}	

Numbers with same letter in the same column are not significantly different using LSD at α=0.05

Means with the same superscript(s) in the same column are not significantly different using LSD at α=0.05

Means with the same subscript in the same row are not significantly different using LSD at α=0.05