RESPONSE OF LOWLAND RICE (*Oryza sativa* L.) VARIETIES TO MOISTURE STRESS AT DIFFERENT LEVELS OF POTASSIUM

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ABSTRACT

An experiment was conducted to determine the effectiveness of potassium in mitigating drought stress and improving yield in lowland rice ecosystems at Sokoine University of Agriculture Morogoro Tanzania. The main plot constituted three soil moisture levels viz. flooding, 20 and 40 kPa soil moisture tensions. Subplot factor constituted three lowland rice varieties viz. SARO, NERICA4 and SUPA while potassium levels were 0,50 and 100 kg K ha^{-1} for field experiment and 0, 25 and 50 mg K kg^{-1} of soil for pot experiment as sub-subplot factor. The experimental design was split-split plot in randomized complete block design with three replicates. The results showed that rice plants subjected to saturation soil moisture level had higher panicle length, number of spikelets and number of grains panicle^{-1}, percentage spikelets fertility, grain yield, root dry matter, straw dry matter and total dry matter yield. However, unfilled grains increased as soil moisture tension increased. The results indicated that the studied rice varieties differed on plant height, tiller number, shoot dry matter, grain yield, root dry matter and straw dry matter. SARO variety had the highest grain yield followed by NERICA 4, while SUPA revealed the least grain yield for pot and field experiment. Potassium nutrition at 50 kg K ha^{-1} enhanced yield and yield components of rice varieties under saturation soil moisture level and drought conditions. Grain yield was significantly and positively correlated with number of grains panicle^{-1} and percentage spikelets fertility. The study confirmed that potassium alleviated drought stress and improved yield and yield components of rice varieties. However, saturation soil moisture level should be maintained under lowland rice ecosystem for high grain yield.

DECLARATION

I LEMA DANIEL NDWASINDE, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

Lema Daniel Ndwasinde Date
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The above declaration is confirmed

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Prof. S. O. W. M. Reuben Date
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DEDICATION

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LIST OF SYMBOLS AND ABREVIATIONS

g	Gram
^{0}C	Degree Celsius
ANOVA	Analysis of variance
CEC	Cation exchange capacity
cm	centimeter
cmol kg^{-1}	centimols of positive charge per kilogram of soil
DITPA	Diethylenetriaminepentaacetic acid
e.g.	For example
FAOSTAT	Food and Agriculture Organization Statistics
ha	Hectare
HCL	Hydrochloric Acid
hrs	Hours
IRRI	International rice research Institute
K level	Potassium levels
KCL	Potassium Chloride
kg	Kilogram
kPa	Kilo paschal
MANOVA	Multivariate Analysis of Variance
mg	milligram
mm	millimiter
NERICA	New rice for Africa
n.s	Not significant
NSS	National Soil Services

pH	Hydrogen ion concentration
RCBD	Randomized complete design
RYMV	Rice yellow mottle virus
SAS	Statistical Analysis Software
Spp	Species
SUA	Sokoine University of Agriculture
TEA	Triethanolamine
TSP	Triple supper phosphate
USDA	United States Department of Agriculture
Viz	Synonyms for "namely", "that is to say",
WARDA	West Africa Rice Development Association

CHAPTER ONE

1.0 INTRODUCTION

Rice (*Oryza sativa* L.) is a cereal grain that belongs to the family *Poaceae* and ranks second highest in worldwide production after maize. The annual moisture requirement ranges from 500 to over 2000 mm (Grist, 1986). Over half of the world's population depends on rice as a staple crop. The crop is becoming increasingly important for food security in a number of low-income, food-deficit countries in sub-Saharan Africa (Oikeh *et al.*, 2008). In Eastern and Southern Africa, Tanzania is the leading country where rice ranks the second most popular staple food and cash grain after maize (*Zea mays* L.). More than one third of rice produced in Tanzania comes from Sukumaland (Ngailo *et al.*, 2007).

It has been estimated that more than 200 million tons of rice are lost every year due to environmental stresses, diseases and insect pests (Sarvestaini *et al*., 2008). Drought stress is a major constraint for about 50% of the world production area of rice. Yield losses from drought in lowland rice can occur when soil water contents drop below saturation (Bouman and Toung, 2001).

Some genotypes are more drought resistant than others, out-yielding non resistant varieties. According to Zheng *et al.* (2006) Azucena rice variety was found to be drought resistant while IR1552 was sensitive to drought. The development of drought resistant cultivars may be assisted if mechanisms of drought resistance are known. The crop, soil and water management could be improved by increasing root penetration and improving water use efficiency or photosynthetic capacity (Athar and Ashraf, 2005).

Apart from water shortages, soil infertility is among the major constraints to crop production and productivity in most of the tropical regions of the world (Bationo *et al.*, 2008). It has been reported that potassium (K) is one of the three essential macronutrients required in the largest amount for plant growth and yield (Yan-bo *et al.*, 2008). Potassium supply improves water use efficiency and thus extends the period over which a given amount of water can be utilized by a crop. Umar (2006) reported that potassium fertilization proved helpful in mitigating the adverse effects of water stress.

Many rice growing areas of Tanzania experience water stress of varying severity during the growing period, thus varieties that can tolerate drought are likely to yield more than those without tolerance. Similarly, supply of adequate levels of key nutrients such as potassium can improve yields by improving water use efficiency so that utilization of a given quantity of water is enhanced. Umar (2006) reported that potassium applied in a pot experiment at the rate of 0, 30, 60 and 120 mg kg^{-1} soil and in field at the rate of 0, 25, 50 and 75 kg ha^{-1} revealed that the concentration of K+ in leaves played a vital role in increasing water stress resistance and stabilizing yield in sorghum, mustard and groundnuts. Under water stress conditions sorghum seed yield at the K rate of 120 mg Kg^{-1} was 358.3 % higher than that of K_0 (Umar, 2006).

Potassium nutrition to plants stimulates root growth and hence, efficient exploration of soil water (Umar, 2006). Further, it decreases the loss of soil moisture by reducing the transpiration and increasing the retention of water in plants (Umar and Moinuddin, 2002). In general Potassium maintains the osmotic potential and turgor of the cells (Waraich *et al.*, 2011) and regulates the stomatal functioning under water stress conditions (Kant and Kafkafi, 2002), which is reflected in improved crop yield under drought conditions (Umar and Moinuddin, 2002). Drought stress during vegetative growth and flowering stage can interrupt floret initiation (which causes spikelet sterility) and grain filling respectively (Mostajera and Rahimi-Eichi, 2009).

It has been reported that potassium application lessens the detrimental effects of drought and soil compaction on root growth and yield of upland rice (Tanguilig and Datta, 1988). However, little is known on the response of lowland rice varieties to moisture stress at different levels of potassium. The aim of this study was to determine the effectiveness of potassium in mitigating drought stress in lowland rice ecosystems. The overall objective of this study was therefore to determine the effectiveness of potassium in mitigating drought stress in lowland rice ecosystem.

The specific objectives were

i. To evaluate the effects of moisture stress on yield and yield components of lowland rice varieties

ii. To evaluate the effectiveness of potassium on yield and yield components of lowland rice varieties.

iii. To find out the relationships between yield and yield components at different levels of potassium.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Global Importance of Rice

Rice (*Oryza sativa L.)* is a cereal grain that belongs to the family *Poaceae* and ranks second highest in worldwide production, after maize. Nutritionally husked rice grain provides 20% and 15% of global human per capita energy and protein respectively (IRRI, 1993). In other countries such as Japan and Korea, rice is used for food and alcoholic products as well as supplying building materials, mats and hat making materials (Grist, 1986). In Africa, rice is a strategic component of food security and crucial element for several countries and the demand for rice are postulated to be rising continuously (Nwanze *et al.*, 2001).

2.2 Rice Production in Tanzania

Tanzania is the second largest producer of rice in Eastern, Central, and Southern Africa after Madagascar. In 2004, the country produced about 680,000 t of rice from an area of 355,000 ha (FAO, 2009). The average yield is very low at 1−1.5 t ha^{-1}, as farmers grow a number of traditional varieties that are tall and prone to lodging. Moreover, these varieties have long maturity and are not suitable for areas with a marginal rainfall pattern. The occurrence of rice blast and rice yellow mottle virus (RYMV) contributes to yield decline Luzi-Kihupi (2001).

Small holders grow about 90% of rice, producing under three main ecosystems, namely lowland rainfed shallow (74%), upland rainfed (20%) and lowland irrigated (6%) (Mghase *et al.*, 2010). The potential hydromorphic valleys (basin) for rice production in

Tanzania include Usangu, Rukwa, Kirando, Iringa, and Ruvuma. Other areas include Kilombero and Wami (Morogoro), Kalimawe (Tanga), Shinyanga and Mwanza regions (Mghogho, 1992). In Sukumaland, the construction of bunds is essential for rainfed lowland rice on slopes in order to catch and control the uncertain water supply because of highly unreliable rainfall and relatively low total annual amount of rainfall (700–1000 mm).

The only exceptions are rice fields in flood plains near rivers which receive water from floods (Meertens *et al*., 1999). This so-called unbunded, flooded rainfed lowland rice system is more common in other parts of Tanzania (Kanyeka *et al.*, 1994).

The rain showers are very localized and unpredictable. Dry spells are common throughout the rainy season but are more pronounced during January. According to the water balance classification of Meertens *et al.* (1999), which based on water retention potential (slope, soil texture) and rainfall regime (amount of rainfall and length of growing season) the rainfed lowland rice system in Sukumal and is drought-prone. Water from higher elevated areas through lateral flow of runoff and groundwater accumulates in the lower situated rice fields.

These rice fields are often located on loamy soils (*Itogolo/Ibambasi*) with a hardpan horizon less than 50 cm below the surface, resulting in low infiltration of water (Meertens *et al.*, 1999). The heavy clay soils (Vertisols/*Mbuga*) in the valley bottoms also have low infiltration rates whenever they are flooded.

2.2.1 Botany of Rice

Rice is normally grown as an annual plant, although in tropical areas it can survive as a perennial and can produce a ratoon crop. The rice plant can grow to 1–1.8 m tall, occasionally more depending on the variety and soil fertility. The grass has long, slender leaves 50–100 cm long and 2–2.5 cm broad (FAO, 2006). The small wind-pollinated flowers are produced in a branched arching to pendulous inflorescence 30–50 cm long. An inflorescence is made up of spikelets bearing flowers that produce the fruit, or grain. The edible seed is a grain (caryopsis) 5 –12 mm long and 2 – 3 mm thick (FAO, 2006).

2.2.2 Ecology of rice

In rainfed and upland rice, rainfall is a major yield determinant, particularly in coarse textured soils with poor water retention. Rice is considered as semi aquatic annual grass plant .The cultivated species, *Oryza sativa* and *Oryza glaberrima* can be grown in wide range of soil water regimes from flooded land to dry and hilly slopes. Its adaptation extends from 53^0 N to 40^0 S of the equator and from sea level to an altitude of 3000 m (Rachelle, 2007). World wide rice is produced under three ecologies namely irrigated (52%) rainfed lowland (34%) and upland (14%). About 80% of the world rice is now produced from modern rice varieties grown under rainfed lowlands (IRRI, 1993).

Average temperature required throughout the life of the plant ranges from 20^0 C to 37^0C.The annual moisture requirement ranges from 500 mm to over 2000 mm (Grist, 1986) but rice grows in wide ranges of soil types e.g. Oxisol, Ultisols and Alfsols from infertile to acid sand to saline soils.

2.2.3 Effects of lowland rice varieties on drought tolerance

Water stress may occur at different growth stages and by varying duration and intensities, thereby affecting growth and yield. Different reports showed that rice grain yield is affected by water stress. If water stress occurs at tillering stage, it causes the reduction of number of productive tillers and panicles per hill (Wopereis *et al.*, 1996). However, some experiments showed that water stress event at flowering and early grain filling period, grain sterility and panicles fertility will be reduced (Sarvestaini *et al*., 2008).

Water stress after flowering stage reduced grain weight (Bouman and Tuong, 2001). However, it is shown that different varieties performance varies in response to water stress; some of them are susceptible at vegetative stage and others at flowering and grain filling period (Sarvestaini *et al*., 2008).

Farmers should use drought-tolerant rice varieties to cushion the effects of soil water deficit. In Philippine, farmers are advised to use NSIC Rc192 and NSIC Rc 9, bred by the International Rice Research Institute (IRRI, 2010). These varieties have the capability to withstand tension in their cells under reduced soil water, giving them rigidity and keeping them erect. Also these varieties recover quickly when the stress period ends. The diversity of affected production systems, variability of drought in terms of timing and severity, and the multiple traits involved in drought tolerance require strategic research to prioritize and develop environment-specific approaches for developing drought-tolerant rice cultivars (Manneh, *et al*., 2007). Cultivars with low or medium water requirements are important rice cultivars in Sukumaland. Cultivars with high water requirements, such as *Tondogoso* and ‘Lugata’, are popular in the valley bottoms and on the hardpan plains. Farmers experience with new cultivars revealed that some cultivars perform better under certain circumstances than others. Choice of cultivar is strongly connected to the water circumstances of a field. Water circumstances differ according to variations in soils, location on the slope, size of catchments area, rainfall pattern and the proportion of rice cultivation to the length of the slope.

2.2.4 Drought escape through short duration varieties

Drought is the major abiotic stress limiting rice production and yield stability in rainfed lowland and upland ecosystems. Root systems play an important role in drought resistance (Abd Allah *et al*., 2010).

Among the abiotic stresses, the availability of water is the most important factor that limits the productive potential of higher plants (Mayra *et al.*, 2005). Drought is generally avoided in irrigated rice production systems, but it is a consistent feature across much of the 63.5 million hectares of rainfed rice sown annually, most of which is in tropical Asia, Africa, and Latin America (Narciso and Hossain, 2002).

WARDA’s breakthrough in producing the ‘New Rice for Africa’ (NERICA), based on crossings between African rice (*Oryza glaberrima* Steud.) and Asian rice (*O. sativa* L.), offers welcome relief to Africa’s rice farmers. Also it has been reported that NERICA varieties have high yield potential, short growth cycle, and mature early (80-100 days; i.e. 50 -70 days earlier than farmers’ varieties) under low altitude conditions (WARDA, 2008). The lowland rice trial conducted in Cholima Research station using NERICA L60, 29, 8, 48 and 33, out yielded local varieties such as TXD 306, TXD 85 and TXD 88 (Price *et al.,* 2001). Traditional rice varieties such as SUPA are tall and prone to lodging. Moreover, these varieties have long maturity and are not suitable for areas with a marginal rainfall pattern (Luzi-Kihupi, 2001).

2.2.5 Potassium nutrient

2.2.5.1 Potassium in soils

Potassium in rice producing soils is one of the limiting factors for increasing rice yield (Quampah *et al.,* 2011). There is a considerable decrease in available K due to increased cropping intensity (Quampah, *et al.,* 2011).

Annual global demand of K fertilizer has ascended from 23 million tonnes in 2001 to 30 million tonnes in 2008, which would further rise to 33 million tonnes in 2012 (Quampah, *et al.,* 2011). For irrigated rice in Asia, the K fertilizer demand will be about 9 to 15 million tonnes in 2025, which represents an increase of 65% to 70% over the 1990s requirements (Dobermann *et al.,* 1998). More than half of the 40 million hectares of rain-fed lowland rice worldwide suffer water scarcity at some growth stage (Quampah *et al.,* 2011).

Mzee (2001) reported exchangeable Potassium levels in some soils of Morogoro, Coast and Mbeya Region as ranging from 0.1 to 1.51 cmol (+) kg^{-1} soil, considered to range from low to high levels. It is estimated that for every one tone of rice grain harvested, about 15-20 kg N, 2-3 kg P and 15-20 kg K is removed from the soil (Buri *et al*., 2008). For obtaining higher yields, there has been excessive use of natural resource based inputs mainly the water and nutrients. Among the nutrients, potassium (K) is a macro element known to be very dynamic and a major contributor to the organic structure and metabolic functions of the plant.

When K supply is low, plants can, therefore, become very sensitive to environmental stresses (Cakmak, 2005). Potassium deficiency is an important nutritional problem affecting crop production. Improvement of K nutrition sustained high yields under rainfed conditions while deficiency caused severe reduction in photosynthetic, CO_2 fixation and impairment in partitioning and utilization of photosynthates (Cakmak, 2005). Potassium (K) is reported be valuable in ameliorating the ill-effects of soil water stress for the survival of crop plants (Umar, 2006).

Potassium-efficient varieties are valuable not only as breeding resource for developing K efficient or water-efficient cultivars, but also as research materials for investigating some other physiological mechanisms (Quampah, *et al.*, 2011). In view of the fact that water and potassium resources are limited worldwide, there is an urgent need for a more detailed research. Still the role of K fertilization to overcome water shortage in rice has not been explored fully.

2.2.5.2 Role of potassium in mitigating moisture stresses

Plants exposed to drought stresses suffer from oxidative damage catalyzed by reactive oxygen species, which are primarily responsible for impairment of cellular function and growth depression under stress conditions (Cakmak, 2007). Potassium (K) nutrition greatly lowers the reactive oxygen species production by reducing activity of NAD (P) H oxidases and maintaining photosynthetic electron transport (Cakmak, 2007). Potassium deficiency causes severe reduction in photosynthetic CO_2 fixation and impairment in partitioning and utilization of photosynthates (Cakmak, 2007). Potassium nutrition might be of great importance for the survival of crop plants under drought stress conditions.

Potassium (K) is among essential mineral nutrient reported to be valuable in ameliorating the ill-effects of soil water stress for the survival of crop plants (Umar, 2006). Potassium nutrition to plants stimulates root growth and hence, efficient exploration of soil water and nutrients in an extensive area. Further, it decreases the loss of soil moisture by reducing the transpiration and increasing the retention of water in plants. Also, potassium maintains the osmotic potential and turgor of the cells and regulates the stomatal functioning under water stress conditions (Umar, 2006).

2.2.5.3 Functions of potassium in plants

(a) Water and Nutrient Transport

Potassium plays a major role in the transport of water and nutrients throughout the plant in the xylem. When K supply is reduced, translocation of nitrates, phosphates, calcium (Ca), magnesium (Mg), and amino acids is depressed (Malvi, 2011). As with phloem transport systems, the role of K in xylem transport is often in conjunction with specific enzymes and plant growth hormones. An ample supply of potassium is essential to efficient operation of these systems.

(b) Photosynthesis

The role of K in photosynthesis is complex. The activation of enzymes by K and its involvement in adenosine triphosphate (ATP) production is probably more important in regulating the rate of photosynthesis than is the role of K in stomatal activity (Malvi, 2011). When the sun’s energy is used to combine CO_2 and water to form sugars, the initial high-energy product is ATP. The ATP is then used as the energy source for many other chemical reactions. The electrical charge balance at the site of ATP production is maintained with K ions. When plants are K deficient, the rate of photosynthesis and the rate of ATP production are reduced, and all of the processes dependent on ATP are slowed down (Balotf and Kavoosi, 2011). Conversely, plant respiration increases which also contributes to slower growth and development. In some plants, leaf blades re-orient toward light sources to increase light interception or away to avoid damage by excess light, in effect assisting to regulate the rate of photosynthesis (Malvi, 2011).

These movements of leaves are brought about by reversible changes in turgor pressure through movement of K into and out of specialized tissues.

(c) Stomatal activity (water use)

Plants depend upon K to regulate the opening and closing of stomates the pores through which leaves exchange carbon dioxide (CO_2), water vapor, and oxygen (O_2) with the atmosphere. Proper functioning of stomates is essential for photosynthesis, water and nutrient transport, and plant cooling. When K moves into the guard cells around the stomates, the cells accumulate water and swell, causing the pores to open and allowing gases to move freely in and out (Prajapati and Modi, 2012).

When water supply is short, K is pumped out of the guard cells. The pores close tightly to prevent loss of water and minimize drought stress to the plant. If K supply is inadequate, the stomates become sluggish – slow to respond – and water vapor is lost. Closure may take hours rather than minutes and is incomplete. As a result, plants with an insufficient supply of K are much more susceptible to water stress. Accumulation of K in plant roots produces a gradient of osmotic pressure that draws water into the roots (Prajapati and Modi, 2012). Plants deficient in K are thus less able to absorb water and are more subject to stress when water is in short supply.

(d) Enzyme activation

Enzymes serve as catalysts for chemical reactions, being utilized but not consumed in the process. They bring together other molecules in such a way that the chemical reaction can take place. Potassium "activate s" at least 60 different enzymes involved in plant growth (Prajapati and Modi, 2012). The K changes the physical shape of the enzyme molecule, exposing the appropriate chemically active sites for reaction. Potassium also neutralizes various organic anions and other compounds within the plant, helping to stabilize pH between 7 and 8 which is optimal for most enzyme reactions. The amount of K present in the cell determines how many of the enzymes can be activated and the rates at which chemical reactions can proceed. Thus, the rate of a given reaction is controlled by the rate at which K enters the cell

(e) Transport of sugars

Sugars produced in photosynthesis must be transported through the phloem to other parts of the plant for utilization and storage. The plant's transport system uses energy in the form of ATP. If K is inadequate, less ATP is available, and the transport system breaks down. This causes photosynthates to build up in the leaves, and the rate of photosynthesis is reduced. Normal development of energy storage organs, such as grain, is retarded as a result. An adequate supply of K helps to keep all of these processes and transportation systems functioning normally (Prajapati and Modi, 2012).

(f) Protein synthesis

Potassium is required for every major step of protein synthesis. The "reading" of the genetic code in plant cells to produce proteins and enzymes that regulate all growth processes would be impossible without adequate K. When plants are deficient in K, proteins are not synthesized despite an abundance of available nitrogen (N) **(**Balotf, *et al.* 2012). Instead, protein "raw materials" (precursors) such as amino acids, amides and nitrate accumulate. The enzyme nitrate reductase catalyzes the formation of proteins, and K is likely responsible for its activation and synthesis.

(g) Starch synthesis

The enzyme responsible for synthesis of starch (starch synthetase) is activated by K. Thus, with inadequate K, the level of starch declines while soluble carbohydrates and N compounds accumulate. Photosynthetic activity also affects the rate of sugar formation for ultimate starch production (Balotf *et al.,* 2012). Under high K levels, starch is efficiently moved from sites of production to storage organs.

(h) Crop quality

Potassium plays significant roles in enhancing crop quality. High levels of available K improve the physical quality, disease resistance, and shelf life of fruits and vegetables used for human consumption and the feeding value of grain and forage crops. Fiber quality of cotton is improved. Quality can also be affected in the field before harvesting such as when K reduces lodging of grains or enhances winter hardiness of many crops. The effects of K deficiency can cause reduced yield potential and quality long before visible symptoms appear. This “hidden hunger” robs profits from the farmer who fails to keep soil K levels in the range high enough to supply adequate K at all times during the growing season (Prajapati and Modi, 2012). Even short periods of deficiency, especially during critical developmental stages, can cause serious losses.

(i) Photoperiodism in lowland rice varieties

Plants set seed at appropriate seasons. One major mechanism responsible for this adaptation involves photoperiodic flowering. Most plants are classified as either long-day plants that flower if a certain maximum number of hours of day length are attained, or short-day plants, that will flower if a certain minimum number of hours of day length are attained. A third group, day-neutral plants, is not responsive to changes in number of hours of day length.

The flowering of the rice plant is mainly controlled by two ecological factors viz. day length and temperature which are often interrelated. Temperature affects both the photoperiod-sensitive and photoperiod insensitive cultivars. Generally, high temperature accelerates and low temperature delays heading (Vaghefi *et al*., 2011). Some reports, however, have shown that high temperature delays flowering (IRRI, 1985). Day length changes rhythmically within a year and varies depending upon the latitude. The amount of change in day length during the rice cropping season differs from latitude to latitude. Even in locations at the same latitude the day length during the cropping season may differ because the planting dates may differ greatly depending mostly on the rainfall pattern at each location.

CHAPTER THREE

3.0 MATERIALS AND METHODS

The study was conducted in Morogoro Region in the screen house and in the field at Sokoine University of Agriculture situated at 37^0S 39^0E and 525 m a.s.l. The field experiment was conducted in the crop museum area. The area experiences bimodal rainfall pattern (Appendix 3).

3.1 Soil Sampling and Sample Preparation

Soil sample was collected from the experimental site at different spots to the depth of 20 cm from the soil surface basing on the slope, vegetation cover, soil colour and general physical appearance of soil. The sub samples were collected from sampling spots and mixed thoroughly to form a composite sample according to Joseph (1995). A representative sample of one kilogramme (1kg) of soil for laboratory analysis was obtained by continuous mixing and quartering the composite sample. The representative composite sample obtained was air dried for three days then ground to pass through a 2 mm sieve for laboratory analysis.

3.1.1 Soil analysis

The parameters analyzed in the laboratory included, soil particle size analysis, soil pH, exchangeable bases i.e. Ca, Mg, K and Na, extractable phosphorus, total nitrogen, organic carbon, cation exchange capacity, zinc and copper.

3.1.1.1 Soil particle size analysis

Soil particle size analysis was determined by the hydrometer method after soil particles dispersion with the sodium hexametaphosphate according to National soil service (NSS, 1990). The textural class was determined by using the USDA textural class triangle.

3.1.1.2 Soil pH

Soil pH was measured in water by using pH meter at the ratio of 1:2.5 that is soil and water respectively according to McLean (1982).

3.1.1.3 Cation exchange capacity and exchangeable bases

Cation Exchange Capacity of the soil was determined by using the ammonium acetate saturation method according to Chapman (1965). Five (5g) grams of soil was saturated with neutral NH_4OAC, shaken for thirty (30) minutes and filtered, the filtrate was used to determine exchangeable K, Ca, Mg and Na by using atomic Absorption steptrophotometry. Excess NH_4OAC remained in the soil sample was removed by washing the sample twice with methanol. The NH^+_4 saturated soils was equilibrated with 4% KCL and shaken for thirty minutes and filtered. The filtrate was used for the determination of NH^+_4 by Micro – Kjeldahl distillation in the presence of 40% NaOH and the NH_3 liberated was collected in 4% boric acid (with mixed indicator) and titrated with standard 0.1 NH_2SO_4. The titre was used for estimation of CEC of the soil.

3.1.1.4 Extractable phosphorus

The soil sample was analyzed for available Phosphorus by using the Bray 1 procedure (Bray and Kurtz, 1945). For Bray 1 procedure, the extracting solution containing NH_4 F 0.025 HCL was used. A sample of three grams (3g) air dried soil was placed in a plastic bottle with 20 ml of extracting solution added and shaken for one minute and filtered. The available phosphorus was determined in the filtrate by spectrophotometry at 884nm following colour development by the molybdenum blue method (Watanabe Olsen, 1968).

3.1.1.5 Total nitrogen

Total Nitrogen was determined by using Micro-Kjeldahl digestion distillation method as according to Bremner and Mulvaney (1982). One gram of soil was digested with concentrated sulphuric acid (H_2SO_4) in presence of a mixture of (K_2) SO_4, $CuSO_4$ and Selenium powder mixed in the ratio of 10:1:0.1 by weight). The digest was distilled in the presence of 40% NaOH. The ammonia liberated was collected in 4% boric acid (with mixed indicator) and then titrated with standard H_2SO_4. The titre was used to calculate the total N of the soil sample.

3.1.1.6 Organic carbon

The organic carbon was determined by using the Walkey and Black method (Nelson and Sommers, 1982). A sample of soil one gram (1g) was weighed and placed in a container where 10 ml of $K_2Cr_2O_7$ and 20 ml of concentrated H_2SO_4 were added to oxidize organic carbon. The amount of dichromate reduced was used to estimate the organic carbon content of the soil

3.1.1.7 Extractable copper and zinc

The DTPA extractable micronutrients were determined by using the procedure by Lindsay and Norvell (1978). The extractant contained 0.005 M DITPA (diethylenetriaminepentaacetic acid), 0.01M $CaCl_2$. $2H_2O$ and 0.1M TEA (Triethanolamine) adjusted to pH 7.3. Twenty grammes (20 g) of air dried soil were mixed with 40 ml of extracting solution and shaken for two hours and then filtered.

The micronutrients copper and zinc were determined by atomic adsorption spectrophotometer by using the appropriate standards.

3.2 Plant tissue Analysis

Dried plant samples were ground and sieved by using 0.5 mm sieve in the laboratory. The ground sample of each treatment was used for determination of nitrogen and potassium concentration in plant tissues.

Nitrogen concentration in the plant tissues was determined by using Micro-Kjeldahl digestion distillation method according to Bremner and Mulvaney (1982). A plant sample of 0.2 g was weighed and digested with concentrated sulphuric acid (H_2SO_4) in presence of mixture of (K_2) SO_4, $CuSO_4$ and Selenium powder mixed in the ratio of 10:1:0.1 by weight). The digest was distilled in the presence of 40% NaOH. The ammonia liberated was collected in 4% boric acid (with mixed indicator) and then titrated with standard H_2SO_4. The titre was used to calculate the total N of the plant sample. For potassium determination, one gram (1g) of plant sample was weighed and put into a crucible.

The sample was then placed into muffle furnace for ashing at a temperature of 450 to 500 ^{0}C for three hours. The ash obtained was dissolved in 10 ml of 6 N HCl at a ratio of 1:1. The sample was filtered and made up to the volume of 50 ml by using distilled water. Potassium concentration in the plant sample was determined by Flame photometer.

3.3 Pot Experiment

3.3.1 Soil preparation

Soil samples from different spots in the experimental site were collected and thoroughly mixed to obtain a composite sample for pot experiment. A bulk sample of 324 kg of soil was collected which was then air dried and ground to pass through an 8 mm sieve.

3.3.2 Mixing fertilizers with soils for pot

According to soil analysis results, deficient mineral nutrients were replaced through incorporation to soils before filling soil portion into pots and top dressing. Fertilizers which were incorporated to the whole lot of soils were TSP and zinc sulphate. Potassium which was one of the treatments tested was incorporated into soil portions at different rates viz. 0, 25 and 50 mg kg^{-1} of soil.

3.3.3 Filling soils into pots

Eighty one (81) unperforated pots were used in the experiment whereby each pot was filled with four kilogrammes of soil and labeled as per treatment. After filling soils in pots they were arranged on the table in the screen house as per design (Split –split plot in a Randomized Complete Block Design) in three replicates.

3.4 Husbandry Practices

Irrigation water was estimated according to Savage (1979). Soil samples from soils prepared for pot experiment were taken and filled in to three 100 ml measuring cylinders to a mark of 100 cm^3 then weighed and recorded as W_1. Fifteen milliliters of water was added at once to each cylinder for uniform infiltration of water to the soils. Then cylinders with moistened soils were left to drain freely for 24 hours. Wetting front for each measuring cylinder was measured and average data was recorded as V_1.

Data obtained were used to calculate the percentage of water required to moisten the soils to field capacity as shown on Appendix 6. The amount of water applied to each pot of 4 kg dried soils was 1.101 liters.

3.4.1 Sowing

Before sowing, each pot of 4 kg of soil was wetted with 1.101 liter of distilled water and left to drain off for twenty four hours. Rice seeds were sown such that three holes arranged in triangular fashion around pot centre and each hole sown with five seeds. Then reference weights for three pots meant for moisture control were recorded and maintained by replacing the weight loss by equivalent amount of distilled water up to the first split of nitrogen fertilizer application. After first nitrogen application water was applied and maintained at flooded level up to booting stage. Seedlings were thinned at 14 days after sowing to three seedlings per pot arranged in a triangular form around pot centre. Early weeding was done routinely by hand picking. The dominating weeds were Mimosa species and nut grass.

3.4.2 Fertilizer application

3.4.2.1 Nitrogen

Nitrogen fertilizer was applied in three splits of equal proportion to each experimental unit. Two sources of Nitrogen fertilizer were used in the pot experiment namely urea and ammonium sulphate. Nitrogen source for the first and third split application was UREA which was applied 21 days after sowing (26/01/2011) and 45 days (19/02/2011) respectively. The second split of Nitrogen fertilizer was applied at 38 days (13/02/2011) after sowing and the fertilizer source was Ammonium Sulphate. Nitrogen fertilizer was applied at a rate of 150 mg kg^{-1} of soil. Fertilizer was applied by broadcasting to each pot at respective time of application.

3.4.3 Tiller number and plant height

Tiller number was determined by counting tillers for two plants per pot at booting stage and average number recorded. Plant height was determined by measuring two plants per pot from the soil level to the apex of the longest leaf at early booting growth stage and average was computed on a per plant basis and recorded.

3.4.4 Plant sampling for dry matter determination

Plant samples were randomly collected from each experimental unit (pot) at booting stage whereby one plant was harvested by cutting it one centimeter from soil level. Lowland rice varieties studied varied in reaching booting stage, therefore plants harvesting was done in phases. For NERICA 4 samples for dry matter determination were sampled on the 50th day (25/02/2011) from sowing. For SARO rice variety, samples for dry matter determination were harvested at 77 days (21/03/2011), while for SUPA variety samples were harvested at 90 days after planting (14/04/2011).

3.4.5 Soil moisture stress imposition

Lowland rice varieties were subjected to different moisture levels including flooded (control), moisture stress of 20 kPa and, 40 kPa at booting stage in phases. NERICA 4 rice variety was subjected to different moisture levels from 25/02/2011, SARO rice variety was subjected to different moisture levels from 22/03/2011 while SUPA variety was subjected to different moisture levels from 15/04/2011.

3.4.6 Water management from booting stage to maturity

Rice varieties were subjected to different moisture levels which included flooding (Control), moisture stress of 20 and 40 kPa at booting stage. Tensiometers were installed in pots marked for moisture stress at a depth of 11cm from the soil level at the booting stage of rice growth. Tensiometers were used to monitor soil moisture tension. The estimation of amount of water to irrigate when tensiometer readings were high was done by interpolation from moisture release curve. However, the results obtained indicated that the plots require frequent rewetting which could not be managed manually. So the results obtained were used as a basis for rewetting plan. Rewetting was done twice or thrice per day basing on tensiometer readings.

For the moisture level of 20 kPa, if the tensiometer readings were high the amount of water was estimated and applied to reduce tension to a range of 18 to 25 kPa, while for the moisture level of 40 kPa if the tensiometer readings were high the estimated water was applied to reduce tension to a range of 38 to 45 kPa. For the control treatment, soils were flooded from the first split of Nitrogen fertilizer up to five days to harvesting.

3.4.7 Harvesting

The pot experiment involved 81 pots of which each pot represented one experimental unit. Two hills were intended for grain yield. Before harvesting eighty one containers were prepared to save panicles harvested from each pot. Harvesting was done in phases due to varieties variation in reaching maturity. At each harvesting stage, panicles from the two hills in each pot were harvested and sun dried prior to threshing.

3.4.7.1 Root biomass determination

After harvesting rice panicles and straws from each pot, roots for dry matter determination were washed with tap water to remove soil particles. The washing was made simple by flooding pots overnight before the actual activity. A 6 mm sieve was used during roots washing to ensure all roots were collected. After washing, the roots were air dried for two days before oven drying to a temperature of 70 ^{O}C for 48 hours. Roots were removed from the oven and left for 10 minutes to cool before weighing. Weight of roots per pot was obtained and recorded.

3.4.7.2 Grain yield per pot determination

Grain yield per pot was determined by weighing grains harvested from each pot after being air dried for seven days to attain the storage moisture content of 12%. Unfilled grains yield per pot were determined by weighing unfilled grains obtained from each pot after air drying for seven days and winnowed. Obtained data were recorded.

3.4.7.3 Panicle straw dry matter yield

Panicle straws from each pot were weighed on a sensitive weighing balance after being air dried for seven days to attain the storage moisture content of 12%.

3.4.7.4 Straw mass

After rice had been harvested by cutting panicles the straw was also harvested separately from each pot by cutting it 1 cm above the soil level. The straw was air dried for two days before oven drying for 48 hours and then cooled for 10 minutes before weighing. After weighing the data obtained were recorded on per pot.

3.4.7.5 Root mass

Harvested roots in each pot were washed, and air dried for two days before oven drying to a temperature of 70 ^{O}C for 48 hours. Then roots were removed from the oven and left for 10 minutes to cool before weighing. Roots were weighed by using weighing balance and obtained data was recorded according to respective treatments.

3.4.7.6 Total mass

Total biomass was determined for pot experiment by determining total of panicle biomass (Grains and straws per panicle), straw biomass and root biomass per pot at harvesting. The data obtained was recorded on per pot basis.

3.5 Field Experiment

3.5.1 Location

The field experiment was conducted in the crop museum, Sokoine University of Agriculture, Morogoro. The site had been used for rice cultivation for more than five years.

3.5.2 Land preparation and layout of the experiment

Land preparation involved clearing, plowing and layout of the experimental area based on the split - split in randomized block design (Gomez and Gomez, 1984). Trenches of 1 m deep were excavated surrounding the main plots where plastic sheets were installed to minimize water movement from one main plot to another. Plastic sheets were thoroughly covered with soil to form bunds restricting water movement from one main plot to another and from outside (Fig. 1).

Each main plot had nine experimental units which were separated by bunds to restrict water movement from unit to unit. Three moisture levels namely saturation, 20 and 40 kPa were employed as main plot (Factor A) treatments. The sub-plots (Factor B) were three lowland rice varieties namely SARO, Lowland NERICA 4 and SUPA. The sub-subplots (Factor C) were three levels of Potassium namely, control, 50 kg Kha^{-1} and 100 kg K ha^{-1}.

Figure 1: Plastic sheets installation to restrict water movement

Rice seeds were obtained from the Crop Science and Production Department of SUA. Potassium was applied at three levels namely, control, 50 kg Kha^{-1} and 100 kg K ha^{-1} before sowing (Umar, 2006). The source of potassium was muriate of potash (KCL) which was bought from farm inputs stockiest in Morogoro town. The lowland rice varieties in different main plots were subjected to moisture level of control (saturation), stressed to 20 and 40 kPa tensions at booting stage (Naoki and Tushihiro, 2009). Tap water was used as the source of water for irrigation. Soil moisture levels were monitored by using Tensiometers.

In this experiment, split-split plot in a Randomized Complete Block Design with three replications was adopted. The size of experimental plot was 395.67 m^2; which was provided by the Soil Science Department (SUA) as well as the space in the screen house for pot experiment.

3.5.3 Estimation of amount of water to irrigate

Before subjecting paddy into moisture stress an experiment to determined the percent water content at different soil suctions was conducted adjacent to the experimental site. The site was well prepared by clearing all vegetation cover without disturbing the soil and then flooded using tap water. The site was left for over night (24 hours) to drain. Then, five tensiometers were installed randomly in the site at a depth of 15 cm and monitored. At every 5 kPa tensiometer reading interval, a soil sample was collected at a depth of 10 -15 cm interval. Fresh weight of soil sample was recorded immediately before oven drying at a temperature of 105^{o}C for 48 hours to constant weight. After oven drying, soil samples were weighed and oven dried weight recorded. From bulk density and suction (kPa), percent soil moisture content was calculated.

3.5.3.1 Calculation of percentage (%) soil moisture content

A= {Moist soil} – {Soil Oven dry} = Moisture

B= {Soil Oven dry – Core weight} = Oven dry Soil

$\theta m = A/B X100$ ……………………………………………………………………..(1)

$\theta m \; X \; \ell_b = \theta \; v$ …………………………………………………………………..………(2)

θv = Moisture by Volume

Whereas, θm =Moisture Content, ℓ_b = Bulk Density

$$\text{Moisture content (\%)} = \frac{\{\text{Moist Soil – Oven Dry Soil}\}}{\{\text{Dry Soil}\}} \text{ x 100 x Bulk density} \quad \ldots\ldots\ldots..(3)$$

3.5.3.2 Soil bulk density determination

Bulk density was determined at 50 cm depth whereby core samples were taken at five layers viz. 0-10, 10-20, 20-30, 30-40, and 40-50 cm. Samples were placed in the oven where 105^{0}C was set and left for 48 hours. Then cores were removed from oven and placed in the desiccators for cooling before weighing. Data recorded were core number, soil layer depth, core weight, oven dry weight + core, oven dry weight of soil, core volume, bulk density, average bulk density.

$$\text{Soil bulk density} = \frac{\text{Mass of dry soil}}{\text{Core volume}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

3.5.3.3 Construction of moisture release curve

The moisture release curve was constructed by plotting suction (kPa) against percent soil moisture content (Fig. 2). Through the soil moisture release curve the estimation of water to be added into soils in case the soil moisture tension reads higher than the planned was obtained by interpolation.

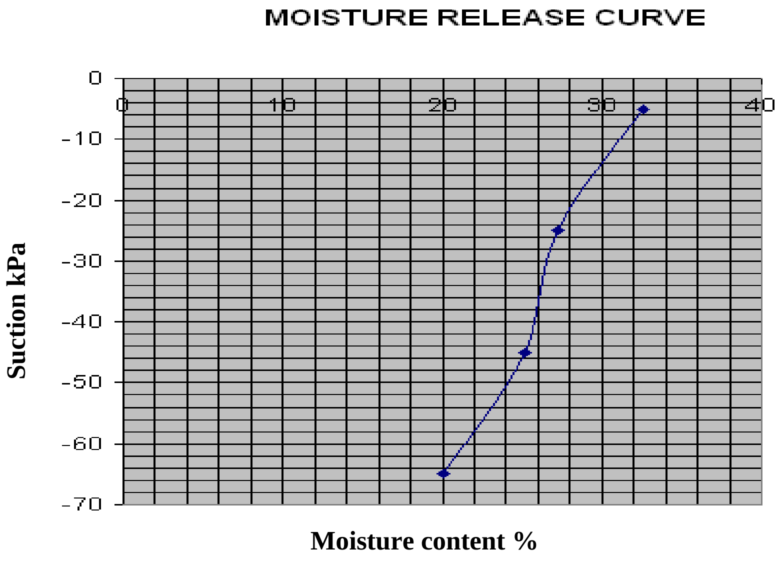

Figure 2: Soil moisture release curve

3.5.3.4 Interpolation and calculation for water content between two tensions

For plots which were subjected to moisture stress of 20kPa, it was ensured that moisture tension did not exceed 25 kPa and not less than 18 kPa. Through interpolation, percentage moisture content between 18 kPa and 25 kPa was determined.

A% - B% =X%

Determine soil bulk density at active root zone of 15cm = Y g cm^{-3}

Where A% = % moisture content at upper soil moisture tension limit

B% = % moisture content at lower soil moisture tension limit

Y = Bulk density in g cm^{-3}

Bulk density = Mass /Volume

V = Mass /Density

Water content between two tensions = Volume of soil x water content percent between two tensions. …………………………………………………………………….....(5)

The obtained volume of water was very small compared to daily consumption and thus required frequent irrigation to maintain the intended soil moisture tension. For manual work, the volume of water obtained was multiplied three times and rewetting was done two to three times per day depending on the rate of evapotranspiration.

3.6 Husbandry Practices

3.6.1 Sowing

Prior to sowing, P and Zn fertilizer was applied and incorporated thoroughly into the soil. The source of P was Triple super phosphate (TSP) and was applied at a rate of 30 kg ha $^{-1}$ while the source of Zn was zinc sulphate was applied at a rate of 10 kg ha^{-1}. Potassium was applied at three levels namely 0.50 and 100 kg ha^{-1}. SARO and SUPA rice seeds were soaked over night to accelerate germination and uniform emergency. Also seeds were treated with APRON STAR to control rice blast prior to sowing.

One day before sowing seeds the experimental units were irrigated to saturation and then left for twenty four hours to drain off to field capacity**.** SUPA and SARO rice seeds were directly sown in the field on 22nd November at a spacing of 20 by 20 cm with 5 rows each with 11 plants. Three seeds were sown per hill and later thinned to two seedlings on the fourteenth days after emergence. Seeds of NERICA 4 were soaked for forty eight hours before sowing on 14th December 2009.

3.6.2 Irrigation

After seeds were sown, soil water was maintained at field capacity up to germination. The irrigation water was applied to the experimental units to saturation moisture level after first split application of nitrogen fertilizer and maintained up to early booting stage. At the booting stage, two hills randomly selected were collected from each experimental unit for dry matter determination and shoots tissue analysis. Tensiometers were installed at booting stage for monitoring soil moisture levels especially for plots which were subjected to soil moisture stress. For control plots, irrigation was done twice a day to ensure soil is saturated throughout. For plots subjected to moisture stress of 20 and 40 kPa, irrigation water was applied only if tensiometer readings were higher than the required tensions. Two tensiometers were installed in each stressed experimental units for more accuracy.

3.6.3 Weeding

First weeding for SUPA and SARO was done on 14thNovember 2010 by hand picking. The dominant weeds were *Mimosa spp*, star grass and nut grass. The second weeding was done on the 28th day by hand picking. Weeding for NERICA 4 rice variety was done manually by hand picking on 28th December 2010 and the second weeding done on 14th January 2011.

3.6.4 Application of nitrogenous fertilizer

Nitrogen fertilizer was applied in three splits in equal proportions. Two sources of nitrogen (viz. urea and ammonium sulphate) were used in this experiment due to soil fertility status of the site. Source of nitrogen for the first and second split application was Urea that was done at 21 days and 42 days after sowing respectively. Urea was applied at a rate of 100 kg N ha^{-1}. The third split was applied at 70 days for SUPA and SARO varieties whereby nitrogen source was Ammonium Sulphate (SA) which was applied at a rate of 50 kg N ha^{-1}.

3.6.5 Sheltering

During the rain season the moisture stressed plots were covered with plastic sheets to avoid rain water into the plots. Six main plots out of nine were moisture stressed at varying levels from booting stage. The stressed plots were covered with plastic sheets raised to height of 3m during rain days only (Table 3). On sunny days, the covers were removed (Fig. 3). The Weather Underground website was visited daily for seven days rainfall prediction. Also the daily appearance of the sky was another way used to predict rainfall. When there was an indication that it might rain then the six main plots in moisture stress were covered by plastic sheets. The remaining three main plots were supplied with tap water to saturation level throughout the growing season.

Figure 3: Sheltering rice plots to protect rice plants against rain water.

3.6.6 Soil moisture stress imposition

Two tensiometers were installed in each main plot specifically for plots which were subjected to soil moisture stress. Varieties were considered in these installations to ensure that each variety had two tensiometers installed at the centre of the experimental unit. The tensiometers were installed when the soil moisture was at saturation point. It took 3- 5 days for tensiometers to start indicating the required soil moisture stress. Tensiometer readings were observed and recorded two to three times daily to ensure the required tension is attained and maintained by addition of water to reduce soil moisture tension in case readings are higher than required. The lowland rice varieties were subjected to moisture stress of 20 kPa and 40 kPa and control plot was flooded. For plots which were subjected to moisture stress of 20 kPa, it was ensured that moisture tension did not exceed 25 kPa and not less than 18 kPa.

For plots which were subjected to soil moisture stress of 40 kPa, it was ensured that moisture tension did not exceed 45 kPa and not less than 38 kPa. If soil moisture tension rose to 45 kPa while the required tension is 40 kPa, the plots were rewetted by applying 5 litres of water evenly over a 2.2 m2 area to reduce soil moisture tension to 38- 40 kPa.

3.6.7 Harvesting

Rice harvesting operation was done in phases due to differences in days to maturity of varieties tested

Rice was harvested when 90% of grains in the panicle changed colour from greenish to light brown or hard when pressed. Harvesting was done by cutting the panicle with enough stem to allow threshing by hand. The panicles were sun dried prior to threshing.NERICA 4 variety was harvested at 107 days (31/03/2011), SARO at 126 days (04/04/2011) and SUPA was harvested at 155 days (08/05/2011) in control plots. SUPA rice plants subjected to moisture stresses delayed flowering as well as reaching maturity and were harvested at 162 days (15/05/2011) which was seven days later.

Before harvesting a random sampling of four panicles from sample rows was done for spikelet counting in each experimental unit. Each panicle was harvested separately to its container. Spikelets from each panicle were counted and then unfilled grains were separated from filled grains. Panicles from guard rows were harvested separately from those of sample rows and kept in separate container. The panicles harvested from sample rows were sun dried for three days then threshed and winnowed to separate filled and unfilled spikelets. The grain weighing and moisture determination of filled grain was done simultaneously and obtained data recorded.

3.6.7.1 Harvest area

Each experimental unit had an area of 2.2 m^2 and guard rows were left around each plot leaving a harvest area of 1.6 m^2.

3.6.7.2 Rice grain moisture content determination

Rice grain moisture content was determined by using moisture meter after harvesting. Hundred grammes (100 g) of harvested grains was sampled from each experimental unit and fed in moisture meter for determination of grain moisture content. Data obtained was recorded and used for mathematical conversion of the total experimental produce to the required storage moisture content of 12 % (Appendix 7).

3.7 Data Collection

3.7.1 Plant height

Plant height was determined by measuring four plants randomly selected in each experimental unit at flowering stage, whereby plant height was measured from ground level to the apex of the longest panicle and average data was recorded.

3.7.2 Number of tillers at booting stage

Number of tillers for four plants per experimental unit was counted and average data recorded at booting stage.

3.7.3 Shoot dry matter determination

Two hills were randomly sampled in each experimental unit at 82, 82 and 60 days (14/02/2011) for SUPA, SARO and NERICA 4 respectively for shoot biomass and plant tissue analysis for N and K concentration. Samples were sun dried in the screen house for a week then taken to oven dry at the temperature of 70 ^{0}C for 48 hours. After oven drying, samples were weighed and data recorded as dry mass.

3.7.4 Panicle length

Samples of four plants were randomly selected from each experimental unit for panicle length measurement and average data was recorded. A ruler was used to measure length of panicle from the upper most node of the tiller to the apex of the panicle.

3.7.5 Number of spikelets per panicle

A random sampling of four panicles from sample rows was done for spikelet counting in each experimental unit. Each panicle was harvested separately to its container and filled and unfilled spikelets were counted and average data were recorded.

3.7.6 Determination of spikelets fertility

Percentage spikelets fertility was determined for each experimental unit as follows:

$$\text{Spikelet fertility \%} = \frac{\text{Number of ffilledgrains}}{\text{Total number of spikelets}} \text{x} \, 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(6)$$

Data obtained were recorded.

3.7.7 Grain yield (t ha^{-1}).

Grain yield per hectare was determined by converting yields obtained per experimental unit to hectare.

3.7.8 Unfilled grain yield (t ha^{-1}).

Unfilled grain yield per hectare at 12 % moisture content was determined by using weighing scale and data were recorded.

3.7.9 Data analysis

The data collected were analyzed by the analysis of variance (ANOVA) procedure (SAS, 1990), and multivariate analysis of variance (MANOVA) for calculating partial correlation coefficients for yield and yield components. All variables recorded were analyzed according to the following statistical model.

$Y_{ijkl} = \mu + R_i + V_j + (E\ a)_{ij} + M_k + (VM)_{jk} + (E\ b)_{ik} + (F)_l + (V\ F)_{jl} + (M\ F)_{kl} + (V\ M\ F)_{jkl} + (E\ c)_{ijkl}$

Where,

Y_{ijkl} = Response, μ = General mean, R_i = Replication effect (i th), V_j = j th effect of varieties, $(E\ a)_{ij}$ = Main plot error, $(M)_k$ = k th effect of moisture, $(V\ M)_{jl}$ = Interaction of varieties and soil moisture $(E\ b)_{ik}$ = Sub-plot error F_i = Moisture effect $(V\ F)_{jl}$ = Interaction of varieties and fertilizer, $(M\ F)_{kl}$ = Interaction of moisture and fertilizer, $(V\ M\ F)_{jkl}$ = Interaction of varieties, soil moisture and fertilizer, $(E\ c)_{ijkl}$ = Experimental error.

ANOVA table was prepared according to experimental design, followed by Multiple comparisons (mean separation test) done using Duncan Multiple Range Test.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Properties of the Experimental Soils

The data on chemical and physical properties of the soils used in the study are indicated in Table 1. The textural class of experimental site soil was clay while the pH was noted as slightly acidic. The soil analysis indicated that the content of potassium, organic matter and cation exchange capacity were at medium levels while calcium, magnesium, sodium and copper were at higher levels. On the other hand, total nitrogen, phosphorus and zinc were rated as low.

Table 1: Soil physical and chemical characteristics of the experimental site

Parameter	Value	Interpretation
Particle size analysis		
Sand %	44.4	Clay
Silt %	6.2	
Clay %	49.2	
Soil pH	6.05	Slightly acid
Exchangeable cations		
Calcium (cmol kg^{-1})	11.1	High
Magnesium (cmol kg^{-1})	4.3	High
Potassium (cmol kg^{-1})	0.4	Medium
Sodium (cmol kg^{-1})	0.6	High
Phosphorus (cmol kg^{-1})	1.7	Low
Organic carbon (%)	1.51	Medium
Total Nitrogen (%)	0.13	Low
Cation exchange capacity (cmol kg^{-1})	20.0	Medium
Extractable micronutrients		
Zinc (mg kg^{-1})	0.46	low
Copper (mg kg^{-1})	1.44	high
Sulphur (SO_4) (mg kg^{-1})	22.55	high

Potassium as a key essential nutrient for normal plant growth has to be supplied in adequate amount. Soil analysis results revealed high quantity of calcium, magnesium, and sodium that can affect the availability of potassium to plants and raise the need for potassium supply. The deficient mineral nutrients such as phosphorus zinc and potassium was incorporated in to soils before sowing while nitrogen was top dressed in three splits during vegetative growth stage. The temperature data collected in the screen house during the cropping season are presented in Appendix 1.

4.2 Pot Experiment

Visual assessment of rice growth

The seed emergence was uniform for all tested rice varieties on the 5th day from the sowing date. The seedlings were thinned to one seedling per hill on the 14th day after sowing thus three seedlings were left around the pot centre. At this period the difference in height was not so clear among the studied lowland varieties. The height differences among varieties were clearly noted at 45 days after sowing during vegetative growth phase (Fig. 4).

4.2.1 Effects of soil moisture levels on growth parameters, yield and yield components of studied rice varieties

Soil moisture levels had very highly significant ($P \leq 0.001$) effects on plant height, panicle length, grain yield per pot, straw dry matter weight and total dry matter weight (Table 2). Also, soil moisture levels had highly significant ($P \leq 0.01$) effects on unfilled grain yield per pot they had significant ($P \leq 0.05$) effects on root dry matter weight (Table 2).

Figure 4: Plant height variation among studied lowland rice varieties.

[NERICA 4 (left) SUPA (Middle) and SARO (right)]

4.2.1.1 Effect of moisture levels on plant height.

Soil moisture levels had very highly significant ($P \leq 0.001$) effects on plant height (Appendix 2). Rice plants subjected to saturation soil moisture level (control) had the tallest plants and there was general decline in height with increasing soil moisture tension (Table 2). This result agrees with results reported by Sikuku *et al.* (2010) in rice, that drought affects nearly all the plant growth processes. However, the stress response depends upon the intensity, rate, and duration of exposure and the stage of crop growth.

The reduction in plant height was more pronounced in plants subjected to soil moisture tension of 40 kPa (Table 2). Plant growth involves both cell growth, cell enlargement and differentiation and these processes are sensitive to water deficit because of their dependence on turgor (Sikuku *et al.,* 2010).

The inhibition of cell expansion is usually followed closely by the reduction in cell wall synthesis. This may have affected plant height of rice under soil moisture stresses. These results imply that saturation soil moisture levels for studied rice varieties could be of vital importance on optimum plant height.

4.2.1.2 Effect of soil moisture levels on panicle length.

Soil moisture levels had very highly significant ($P \leq 0.001$) effects on lowland rice panicle length (Appendix 2). Rice plants subjected to saturation moisture level had the longest panicle (23.482 cm) and the reduction in length increased with soil moisture tension (Table 2). Soil moisture stress is one of the most environmental stresses affecting agricultural productivity around the world and may result in considerable yield reductions (Sikuku *et al.*, 2010). It has been reported that soil moisture stress at reproductive stage leads to greater decrease in panicle length as compared with soil moisture stress at vegetative stage (Bakul *et al*., 2009).

The reduction of panicle length was more pronounced in plants subjected to moisture levels of 40 kPa (Table 2). The current results are consistent with the results reported by Rahman *et al*. (2002) that panicle length decreased with soil moisture stress in rice. The panicle length reduction under soil moisture stress might be due to slowed down number of cell division and or reduced length of individual cells (Bakul *et al*., 2009).

4.2.1.3 Effect of soil moisture levels on rice grain yield

Soil moisture levels had very highly significant ($P \leq 0.001$) effects on rice grain yield per pot (Appendix 2). Grain yield was highest for rice plants grown under saturation (control) and decreased as soil moisture tension increased (Table 2).

Table 2: Effects of soil moisture levels on growth parameters, yield and yield components of lowland rice varieties

Moisture levels (kPa)	Plant Height (cm)	Tiller Number (No)	Shoot dry matter (g pot^{-1})	Panicle Length (cm)	Grain yield (g Pot^{-1})	Unfilled grain yield (g Pot^{-1})	Root dry Matter (g Pot^{-1})	Straw dry matter (g Pot^{-1})	Total dry Matter (g Pot^{-1})
Control	129.556a	8.444 a	37.924a	23.482a	32.619a	0.703b	23.343a	45.871a	104.021a
20	121.704b	8.296 a	36.683a	22.444b	28.376b	1.134a	23.190ab	39.745b	93.760 b
40	114.148c	8.963 a	38.216a	21.778c	26.436b	1.317a	21.089 b	38.249b	88.395 c
MEAN	121.803	8.568	37.608	22.568	29.143	1.051	22.541	41.289	95.392
S.E±	1.381	0.214	0.808	0.179	0.557	0.114	0.484	1.494	1.968
CV (%)	4.568	19.728	10.029	3.596	15.654	63.576	17.191	13.767	8.492
$LSD_{0.05}$ (±)	2.923	0.902	1.998	0.402	1.996	0.342	1.890	2.409	3.988
F-test	***	ns	ns	***	***	**	*	***	***

Means within a column bearing the same letter are not significantly different at ($P \leq 0.05$)

However, the 20 and 40 kPa soil moisture levels had comparable grain yields. Reduced grain yield under soil moisture tensions might be due to inhibition of photosynthesis and less translocation of assimilates towards grains due to soil moisture stress. Similar results were reported by Bouman and Tuong, (2001) that irrigated rice yield declined as soon as the field water content dropped below saturation.

For studied rice varieties, the magnitude of yield reduction depended mostly on the severity of the drought that occurred during reproductive stage. There was yield reduction of 10% when rice grown in saturated moisture regime as compared to flooded condition (Zulkarnain *et al*. (2009). However, grain yield of rice grown under field capacity condition was significantly lower as compared to saturated and flooded condition. The percentage of filled grain was, however comparable between flooded and saturated conditions. These results imply that, maintaining saturation soil moisture level throughout the growing season improves yield for lowland rice varieties.

4.2.1.4 Effect of soil moisture levels on unfilled grain yield.

Soil moisture levels had highly significant ($P \leq 0.01$) effects on unfilled grain yield per pot (Appendix 2). Unfilled grain yield per pot was less for rice plants subjected to saturation moisture levels and increased with increasing soil moisture tension (Table 2). These results imply that under soil moisture tensions unfilled grains increased which might be due to inadequate dry matter partitioned to grain filling. Similar results were reported by Zubaer *et al*. (2007) that water stress at or before panicle initiation decreased translocation of assimilates to the grains, which result to decreased sound grains and increased empty grains.

Lowland rainfed rice experiences water shortage during critical crop growth stages that leads to low yield. In semiarid and dry subhumid agroecosystems rainfall variability generates dry spells almost every rainy season (Rockstrom *et al*., 2007).

4.2.1.5 Effect of soil moisture levels on root dry matter

Soil moisture levels had significant ($P \leq 0.05$) effects on root dry matter weight per pot (Appendix 2). The highest root dry matter weight per pot was noted for rice plants grown under saturation (Table 2). Root dry matter weight decreased as the soil moisture tension increased whereas root dry matter weight for plants subjected to soil moisture tension of 40 kPa was significantly less than root dry matter weight for plants subjected to saturation (control) soil moisture levels (Table 2). These results are comparable to those reported by (Baque *et al.*, 2006) that root dry weight in wheat decreased due to water stress. Sikuku *et al*. (2010) reported that the decline in root dry weight under water deficit may be attributed to root damage and death. There was inhibition of root growth which may be attributed to reduced extensibility of the root tip tissue due to hardening of the expanding cell walls. Reduced root growth would impact negatively on plant growth owing to the fact that available surface area for absorption of water and mineral salts is reduced (Sikuku *et al.*, 2010).

4.2.1.6 Effect of soil moisture levels on straw dry matter yield.

Soil moisture levels had significant ($P \leq 0.05$) effects on straw dry matter yield (Appendix 2). The straw dry matter weight for plants stressed to 20 and 40 kPa soil moisture tensions was not significantly different although had slight difference while the control (saturation soil moisture levels) registered heaviest straws (Table 2). Agronomic practices (weeding, spraying and fertilizer application) for rice under study were kept constant with exception of potassium nutrition and soil moisture which applied at different levels from booting stage. The highest rice straw dry matter yield was noted for plants subjected to saturation soil moisture levels (control) (Table 2). This result implies that the less the soil moisture tension the higher the straw dry matter yield. Similar results have been reported by Kandil *et al. (*2010) that irrigation treatments had significant effect on rice straw dry matter yield and that straw dry matter yield was detrimentally reduced by water stress.

4.2.1.7 Effect of soil moisture levels on total dry matter yield

Soil moisture levels had very highly significant ($P \leq 0.001$) effects on total dry matter yield (Appendix 2). Rice plants subjected to saturation moisture levels (control) had the highest total dry matter yield (104.021 g pot^{-1}) (Table 2). Total dry matter yield significantly declined as soil moisture tensions increased. Plants subjected to 20 kPa soil moisture tension had average total dry matter yield of (93.760 g pot^{-1}), while plants subjected to soil moisture stress of 40 kPa had average total dry matter yield of (88.395 g pot^{-1}) (Table 2). The results imply that soil moisture played a vital role in plant growth processes. These results are similar to those reported by Sikuku *et al*. (2010) that water deficit is one of the most environmental stress factors affecting agricultural productivity and may result in considerable yield reductions. Soil moisture stress affects all the plant growth processes; however, the stress response depends upon the intensity, rate and duration of exposure and the stage of crop growth. Soil moisture stress limits plant leaf area production and eventually plants rate of transpiration.

The photosynthesis reduction in plant leaves for plants stressed with moisture may be due to stomatal closure. Higher stomatal conductance increases carbon dioxide diffusion into the leaf and favours higher photosynthetics rates. Higher photosynthetic rates could in turn favour higher biomass and crop yields. Generally, the study results indicated that saturation soil moisture level enhanced yield and yield components of studied lowland rice varieties. The performance of yield components decreased as soil moisture tension increased with exception of unfilled grain which was observed to increase as soil moisture tension increased.

4.2.2 Variation of among rice varieties for growth parameters, yield and yield components

Lowland rice varieties had very highly significantly ($P \leq 0.001$) effects on plant height, tiller number per hill per pot, root dry matter yield, shoot dry matter yield, straw dry matter yield per pot, panicle straw dry matter yield per pot, total dry matter yield per pot, grain yield per pot, unfilled grain yield per pot (Appendix 2).

4.2.2.1 Variation of studied rice varieties on plant height

Rice varieties significantly ($P\leq 0.001$) differ on plant height (Appendix 2). The results revealed variations in height among three rice varieties. SUPA variety was the tallest (152.741 cm) followed by NERICA 4 (112.0 cm) and the shortest was SARO (100.648 cm) (Table 3). These results imply that variation in height might be attributed to varietal inherent characteristic and differences in utilization ability of available nutrients. Similar results were reported by Ndaeyo *et al*. (2008) that plant height differed significantly among studied upland rice varieties due to differences in genetic make up. Short to medium plant heights are mostly preferred due to resistance to lodging. Therefore, SARO and NERICA 4 rice varieties could be the mostly preferred varieties. Tall rice varieties such as SUPA are susceptible to lodging.

Table 3: Variation of studied rice varieties on growth parameters, yield and yield components

VARIETY	Plant Height (cm)	Tiller Number (No)	Panicle Length (cm)	Grain yield per pot (g)	Unfilled grains per pot (g)	Shoot dry Matter (g)	Root dry matter weight (g)	Straw dry matter (g)	Total dry matter (g)
SARO	100.6 c	13.0 a	22.4 a	33.8 a	1.8 a	46.5 a	25.6 b	38.9 b	101.7 b
		(12.8)	(22.0)	(33.0)	(5.1)	(45.7)	(25.0)	(38.0)	
NERICA 4	112.0 b	6.0 b	22.6 a	30.0 b	1.3 b	32.7 b	9.0 c	21.0 c	62.5 c
		(9.5)	(36.0)	(48.0)	(4.1)	(52.0)	(14.0)	(33.6)	
SUPA	152.7 a	6.7 b	22.7 a	23.7 c	0.1 c	33.7 b	33.0 a	64.0 a	121.9 a
		(5.5)	(18.7)	(19.0)	(0.6)	(27.6)	(27.0)	(52.5)	
MEAN	121.8	8.6	22.6	29.1	1.1	37.6	22.5	41.3	95.4
S.E (±)	1.07	0.22	0.14	0.97	0.15	0.66	1.19	1.25	2.18
CV (%)	4.4	19.4	3.3	14.3	60.0	9.8	15.4	10.7	7.7
LSD$_{0.05}$ (±)	2.9	0.9	0.4	2.0	0.3	2.0	1.9	2.4	4.0
F- test	***	***	ns	***	***	***	***	***	***

Numbers in bracket indicate percentage dry matter allocated to the respective variable
***** Very highly significant**
Means within the same column bearing the same letter are not significantly different at ($P \leq 0.05$)

However; they are of high quality in terms of aroma, grain length and cooking (Shayo *et al.,* 2006). The result suggests that the high qualities of SUPA such as aroma, grain length and cooking quality to be incorporated in short to medium plants height varieties which are mostly preferred.

4.2.2.2 Variation of the studied rice varieties on number of tillers

Rice varieties significantly (P≤ 0.001) differ on number of plant tillers per plant per pot (Appendix 2). The results indicated that SARO variety had the highest number of tillers per plant (13) (12.8%) followed by SUPA variety (7) (5.5%) and NERICA 4 (6) (9.5%), the latter two varieties being not significantly different in tiller number (Table 3). Deference in tiller numbers for the studied rice varieties is attributed to genetic make up and differences in partitioning of assimilates to plant parts.

This result complies with those reported by Ndaeyo *et al.* (2008) that differences in the number of tillers per plant could be due to differences in the ability of the cultivars to utilize available nutrients and optimally partitioning photosynthates to plant parts. The results imply that SARO variety partitioned higher percentage of dry matter to tillerring which might be due to differences in the genetic make up. Tillerring is one of the most important agronomic traits because tiller number per plant determines panicle number, a key component of grain yield (Xueyong *et al*., 2003).

4.2.2.3 Variation of studied rice varieties on shoot dry matter weight

Rice varieties significantly (P≤ 0.001) differ on shoot dry matter weight (Appendix 2). SARO variety had the highest shoot dry matter weight (46.5 g). The dry matter weight for SUPA (33.7 g) and NERICA 4 (32.7 g) varieties had no significant difference although

SUPA had slightly higher dry matter than NERICA 4 (Table 3). The results revealed that SARO variety had the highest shoot dry matter weight while SUPA and NERICA 4 had comparable shoot dry matter weights. Similar results were reported by Fageria *et al*. (2008) that variation in shoot dry weight among genotypes may be associated with differences in the amount of intercepted photosynthetically active radiation by the canopy and the radiation use efficiency.

Also, genotypes producing the highest grain yield should produce reasonably good dry matter yield for partitioning. It has been reported that the high yield potential of hybrid rice is attributed to high vegetative biomass production, leaf area, large panicle and high tillerring capacity (Islam *et al*., 2009). The results indicated that NERICA4 allocated highest percentage dry matter to shoots followed by SARO and lastly SUPA variety. These results implied that rice varieties varied in dry matter partitioning to plant parts which might be due to inherent characteristics of rice varieties

4.2.2.4 Variation of studied rice varieties on grains yield

Rice varieties significantly ($P \leq 0.001$) differ on grain yield (Appendix 2). The results showed that SARO variety had the highest grain yield per pot (33.8 g pot^{-1}) followed by NERICA 4 (30.0 g pot^{-1}) (48%) and lastly SUPA variety (23.7 g pot^{-1}) (Table 3). SARO rice variety revealed high grain yield per pot which might be due to high percentage of dry matter (33%) partitioned to grains and high productive tiller number while NERICA 4 had the least number of tillers but all were productive, high number of spikelets, high spikelets fertility and the highest dry matter percentage (48%) partitioned to grains filling (Table 3). SUPA had least dry matter percentage (19%) partitioned to grains filling and (5.5%) to tillers (Table 3). These results imply that variation in grains yield for rice varieties under study might be due to inherent characteristics. Improved rice varieties such as SARO and NERICA 4 have high grains yield potentials, short growth cycle and early maturity. On the other hand, there are improved varieties are bred specifically for lateness depending on the environment. Traditional rice varieties such as SUPA have low grain yield potential, long growth cycle and delayed maturity. The obtained results might be due to variation of studied rice varieties in yield potentials and assimilates partitioning to grain filling.

4.2.2.5 Variation of studied rice varieties on unfilled grain

Rice varieties significantly ($P \leq 0.05$) differ on unfilled grains (Appendix 2). SARO variety had the highest unfilled grains (1.8 g pot^{-1}) followed by NERICA 4 variety (1.3 g pot^{-1}) and the least SUPA variety (0.14 g pot^{-1}) (Table 3). High yielding rice varieties had higher unfilled grain which might be attributed to competitions for assimilates during grain filling. However, traditional variety (SUPA) had least percentage grain and unfilled grains. These results might be due to inherent characteristics of the variety.

4.2.2.6 Variation of studied rice varieties on root dry matter yield

Rice varieties significantly ($P \leq 0.001$) differ on root dry matter yield (Appendix 2). SUPA variety had the highest root dry matter yield (33.0 g pot^{-1}) followed by SARO (25.6 g pot^{-1}) and the least NERICA 4 variety (9.0 g pot^{-1}) (Table 3). SUPA variety among studied lowland rice varieties revealed high percentage dry matter (27%) partitioned to roots which imply that SUPA can extract nutrients and moisture in a more extensive area and thus more tolerant to drought. However, SUPA variety had long growth cycle and delayed maturity. SARO variety partitioned 25% of total dry matter to roots which implies that SARO extracts nutrients and soil moisture in a relatively less extensive area as compared with SUPA rice variety. However, SARO had high dry matter partitioned to tillers production and grain filling (Table 3). Grain and roots compete for assimilates, thus one develops at the expense of the other. Thus, a variety that is drought tolerant might be low yielding and vice versa especially under saturation moisture levels.

NERICA 4 had the least percentage dry matter (14%) partitioned to roots. However, NERICA 4 variety had high percentage dry matter partitioned to spikelets formation and grain filling (Table 3). The results indicated variation in total dry matter partitioning to roots among studied rice varieties which might be due to inherent characteristics. It has been reported that root traits such as thickness, depth and penetration ability help to avoid drought by increased water uptake from deeper soils (Babu, 2010).

4.2.2.7 Variation of studied rice varieties on straw dry matter yield

Rice varieties significantly ($P \leq 0.001$) differ on straw dry matter yield (Appendix 2). SUPA had the highest straw weight per pot (64.0 g) followed by SARO variety (39.0 g) and the least NERICA 4 variety (21.0 g) (Table 3). The variation in straw dry matter yield among the studied rice varieties might be due to inherent characteristics. The results indicated that SUPA variety had the highest straw dry matter yield among the studied variety which might be due to inherent characteristics (tall, vigorous vegetative growth and long growth cycle). These results are in consistency to results reported by Baset Mia and Shamsuddin, (2011) that straw yield was significantly different among the tested aromatic and modern rice varieties.

NERICA 4 had the least dry matter allocated to straws while higher dry matter was partitioned to grain yield (Table 3). These results revealed that rice varieties varied in straw dry matter yield which might be due to varietal differences in assimilates partitioning to plant parts.

4.2.2.8 Variation of studied rice varieties on total dry matter yield

The results indicated that rice varieties significantly (P≤ 0.001) differ on total dry matter yield per pot (Appendix 2). SUPA variety had the highest total dry matter yield (121.9 g) followed by SARO variety (101.7 g) and the least NERICA 4 variety (62.5 g) (Table 3). SUPA rice variety had the highest total dry matter yield which might be due to inherent characteristics of the variety. SUPA variety partitioned the highest dry matter to straws (52%), followed by roots (27%) and least (19%) to grains filling (Table 3). SARO variety partitioned accumulated dry matter to grain filling (33%), roots (25%) and (38%) to straws (Table 3). These results are in consistency to results reported by Shahidullah *et al*., (2010) on studied improved rice varieties including three non-aromatic checks that exhibited enormous variations for crop growth rate, net assimilation rate, grain yield, total dry matter, harvest index and photosynthetic efficiency at heading stages.

NERICA 4 rice variety had the least dry matter accumulated which was partitioned at different percentages to plant parts that is grains filling (48%) followed by straws (33.6%) and lastly to roots (14%) which was reflected to high grain yield. Regardless of greater amount of total dry matter accumulation, the traditional variety (SUPA) produced lower grain yields signifying low harvest index. This might be due to poor rate of assimilates translocation from vegetative organs to reproductive sinks. These results imply that variation in total dry matter accumulated might be due to genetic make up of rice varieties and their partitioning to various plant parts.

4.2.3 Effect of Potassium levels on growth parameters, yield and yield components of rice varieties

Potassium levels had very highly significant ($P \leq 0.001$) effects on panicle length and root dry matter yield while highly significant ($P \leq 0.01$) effects was observed on plant height and lastly significant ($P \leq 0.05$) effects was observed on number of tillers per hill (Appendix 2). Potassium levels had non significant ($P \geq 0.05$) effects on total dry matter yield and grain yield (Appendix 2).

4.2.3.1 Effects of Potassium levels on rice plant height, number of tillers per plant, panicle length, root dry matter yield, total dry matter yield and grain yield

Potassium levels had significant ($P \leq 0.01$) effects on rice plant height (Appendix 2). The results show that lowland rice plants treated with 25 mg K kg^{-1} of soil indicated significant change in plants height (Table 4). Potassium nutrition treatment at 25 and 50 mg K kg^{-1} of soil had comparable plant heights. Rice plants that were not treated with potassium nutrition had the lowest plant heights. Therefore the optimum and economical potassium nutrition for studied rice varieties was 25 mg K kg^{-1} of soil for soils with medium potassium content. These results are in agreement with results reported by Zayed, *et al*. (2007) on inbred and hybrid rice cultivars treated with potassium that increasing potassium rates significantly encourage cell division and elongation resulting in tallest plants. The soil used in pot experiment had medium content of potassium. However, the presence of high quantities of calcium, magnesium and sodium affects the availability of potassium leading to plants suffering deficiency in potassium. Therefore, rice plants treated with potassium of 25 mg K kg^{-1} had significant change in plant height.

Table 4: Effect of potassium levels on growth parameters, yield and yield components of rice under greenhouse conditions

Potassium (Klevel) (mg kg^{-1} of soil)	Plant Height (cm)	Tiller Number (No)	Shoot dry Matter (g)	Panicle Length (cm)	Grain yield (g pot^{-1})	Unfilled grain (g pot^{-1})	Root dry matter (g pot^{-1})	Straw dry matter (g pot^{-1})	Total dry matter (g pot^{-1})
Control	119.2b	7.9 b	37.3 a	21.5 b	30.4 a	0.93 a	20.2 b	40.6 a	93.5 a
25	122.4a	8.9 a	38.3 a	23.1 a	28.6 a	1.0 a	24.2 a	41.0 a	96.1 a
50	123.8a	8.9 a	37.2 a	23.2 a	28.4 a	1.25 a	23.2 a	42.3 a	96.6 a
MEAN	121.8	8.6	37.6	22.6	29.1	1.1	22.5	41.3	95.4
S.E±	1.07	0.32	0.71	0.14	0.72	0.12	0.67	0.85	1.41
CV (%)	4.6	19.7	10.0	3.6	15.7	63.6	17.2	13.8	8.5
$\text{LSD}_{0.05}$ (±)	2.9	0.9	2.0	0.4	2.0	0.3	1.9	2.4	4.0
F- test	**	*	ns	***	ns	ns	***	ns	ns

* = Significant, *** = Very highly significant, ** = Highly significant and ns = Non significant
Means within the same column bearing the same letter are not significantly different at ($P \le 0.05$)

Potassium levels had significant ($P \leq 0.01$) effects on number of tillers per plant (Appendix 2). The results indicated that rice plants treated with 25 mg K kg^{-1} of soil had the highest number of tillers per plant while increasing potassium nutrition to 50 mg K kg^{-1} of soil had comparable tiller numbers per plant (Table 4). Rice plants without potassium (control) had least number of tillers (Table 4).These results imply that increasing potassium rates up to 25 mg K kg^{-1} of soil significantly increased number of tillers to the maximum. Bahmanaiar and Ranjbar (2007) reported comparative results that potassium application added the number of tillers in Tarrom and Neda rice genotypes by 55% and 91% respectively. Potassium levels had significant ($P \leq 0.001$) effects on panicle length (Table 4). The result shows that lowland rice plants treated with 25 mg K kg^{-1} of soil had significant increase in panicle length (Table 4). Potassium nutrition treatment at 25 and 50 mg K kg^{-1} of soil had comparable panicle length (Table 4).

Rice plants without potassium had the lowest panicle length (Table 4). The results imply that increasing potassium levels to 25 mg K kg^{-1} of soil significantly encourage cell division and elongation resulting to increased panicle length. The results obtained comply with the results reported by Kandil, *et al*. (2010) on performance of some rice cultivars as affected by irrigation and potassium fertilizer that increasing potassium rate significantly encouraged cell division and elongation.

Potassium is one of the three essential macronutrients required in the largest amount for plant growth and yield. Jia *et al*. (2008) reported that potassium deficiency in paddy soils is becoming one of the limiting factors for increasing rice yields. Current study revealed that potassium levels had significant ($P \leq 0.001$) effects on root dry matter yield (Appendix 2).

Rice plants without potassium treatment had least root dry matter weight while those treated with 25 mg K kg^{-1} of soil had the highest root dry matter weight (Table 4). Potassium nutrition treatment at 25 and 50 mg K kg^{-1} of soil had comparable root dry matter yield (Table 4). The results indicated that potassium nutrition played role in changing root dry matter yield. These results imply that potassium nutrition of 25 mg K kg^{-1} of soil been an optimum rate for increasing root dry matter yield that in turn improves plant growth, tolerance to soil moisture tension hence grain yield. Potassium nutrition treated to studied rice varieties had no significant effects on total dry matter and grain yield which might be ascribed to soils used in the experiment which was not deficient in potassium.

4.2.4 Interaction effect between lowland varieties and soil moisture levels

Soil moisture levels and varieties had significant ($P \leq 0.01$) interaction effect on panicle length and total dry matter yield while very highly significant ($P \leq 0.001$) interaction effect was observed on grain yield per pot, root dry matter yield and straw dry matter yield. Also significant ($P \leq 0.05$) interaction effect was observed on unfilled grains per panicle (Appendix 2).

Table 5: Interaction between rice varieties and moisture levels on panicle length

Treatments		**Variety**		**Mean**	**SE(±)**
Moisture levels (kPa)	SARO	NERICA 4	SUPA		
Control	23.4	23.0	24.0	23.5	0.18
20	22.4	22.9	22.0	22.4	
40	21.3	21.8	22.2	21.8	
Mean	22.4	22.6	22.7	22.6	
SE(±)	0.14				
$LSD_{0.05}$ (±) within table	0.4				

Interaction between varieties and soil moisture levels had significant ($P \leq 0.01$) effect on panicle length (Appendix 2). Interaction between rice varieties and saturation moisture levels gave longer panicles with SUPA variety (Table 5). Under drought condition (40 kPa), SUPA rice variety also gave longest panicles. The study revealed that SUPA variety partitioned highest percentage dry matter to roots among studied rice varieties (Table 3). Therefore, SUPA could be drought tolerant due to its ability to extract moisture and nutrients from more extensive area as compared with the other two varieties. These results indicated that SUPA variety under drought condition had best performance on panicle length which might be due to varietal inherent characteristics.

Similar results had been reported by Rahman *et al*. (2002) that there were remarkable differences on panicle length among rice varieties under soil moisture stresses. These results imply that SUPA had best performance on panicle length under saturation level and drought conditions among the studied rice varieties.

Table 6: Interaction between rice varieties and soil moisture levels on grain yield

Treatments		Variety		Mean	SE(±)
Moisture levels (kPa)	SARO	NERICA 4	SUPA		
Control	38.5	36.1	23.2	32.6	0.56
20	32.6	27.8	24.7	28.4	
40	29.7	25.9	23.1	26.2	
Mean	33.6	30.0	23.7	29.1	
SE(±)	0.97				
$LSD_{0.05}$ (±) within table	2.0				

Interaction of varieties and soil moisture levels had significant ($P \leq 0.01$) effect on grain yield per pot (Appendix 2). SARO variety had the highest grain yield under saturation soil moisture level (Table 6). SARO grain yield under drought (40 kPa) conditions was higher followed by NERICA 4 variety. The results showed that grain yield decreased as soil moisture tensions increased. Similar results were reported by Bouman and Toung, (2001) that irrigated rice yield declines as soon as the field water content drops below saturation and the magnitude of yield reduction depends mostly on the severity of the drought and crop growth stage. The study showed that improved rice varieties such as SARO and NERICA 4 partitioned higher percentage dry matter to grain filling as compared with traditional varieties such as SUPA which had least dry matter partitioned to grain filling (Table 3). These results imply that studied rice varieties varied in grain yield across soil moisture levels. SARO and NERICA 4 rice varieties could be mostly preferred under drought conditions due to their ability to produce reasonable yields under saturation and drought conditions.

Interaction of rice varieties and soil moisture levels had very highly significant ($P\leq 0.001$) effects on unfilled grains per pot (Appendix 2). SARO and NERICA 4 had higher unfilled grains under saturation (control) moisture level (Table 7). Also SARO and NERICA 4 varieties indicated higher unfilled grains per pot under the most moisture stress (40 kPa) (Table 7). Similar results reported by Liu *et al*. (2006) that lowland rice varieties are susceptible to water deficit and the flowering stage is a critical stage to water limited condition.

The results indicated that SARO had the highest unfilled grain per pot under drought conditions followed by NERICA 4. However, SARO had highest grain yield followed by NERICA 4 under saturation moisture level and under stressed moisture tensions. Zubaer *et al.* (2007) reported that increased unfilled grains under soil moisture tensions might be due to insufficient assimilate production and its distribution to grains.

Table 7: Interaction effect between varieties and moisture levels on unfilled grain per pot (gpot^{-1})

Treatments Moisture levels (kPa)	Variety SARO	 NERICA 4	 SUPA	Mean	**SE(±)**
Control	1.18	0.83	0.10	0.70	0.11
20	1.63	1.62	0.16	1.13	
40	2.47	1.32	0.16	1.32	
Mean	1.76	1.25	0.14	1.05	
SE(±)	0.15				
$LSD_{0.05}$ (±) within table	0.34				

Zubaer *et al*. (2007) reported that water stress during reproductive growth stage affected aman rice in assimilates translocation and grain development. These results imply that variation in unfilled grains per pot under soil moisture levels might be due to inherent variability on assimilates translocation and grain development during water stress.

Interaction of rice varieties and soil moisture levels had significant ($P \leq 0.001$) effect on root dry matter yield (Appendix 2). Interaction between rice varieties and saturation soil moisture levels revealed that SUPA variety had higher root dry matter yield (Table 8). Rice varieties subjected to drought conditions (40 kPa) revealed that SUPA had higher root dry yield. Gowda *et al.* (2011) reported similar results that proportion of total dry matter allocated to root part depended on the rate of soil moisture levels and variety. The results indicated that SUPA variety partitioned higher percentage dry matter to roots among studied varieties (Table 3). These results imply that SUPA variety might have high ability of exploration of soil moisture and nutrients from extensive area under both saturation and drought conditions.

Table 8: Interaction effect between rice varieties and moisture levels on root dry matter yield

Treatments	Variety			Mean	SE (±)
Moisture levels (kPa)	SARO	NERICA 4	SUPA		
Control	24.7	12.143	33.2	23.3	0.48
20	25.7	7.658	36.2	23.2	
40	26.5	7.067	29.7	21.1	
Mean	25.6	8.956	33.0	22.5	
SE(±)	1.18				
$LSD_{0.05}$ (±)within table	1.9				

Interaction of rice varieties and soil moisture levels had significant ($P \leq 0.001$) effect on straw dry matter yield (Appendix 2). Combination of SUPA variety and saturation soil moisture levels indicated highest straw dry matter yield (Table 9). SUPA variety showed higher straw dry matter yield under drought (40 kPa).

Table 9: Interaction effect between rice varieties and moisture levels on straw dry matter yield

Treatments	Variety			Mean	SE(±)
Moisture levels (kPa)	SARO	NERICA 4	SUPA		
Control	38.8	23.8	75.1	45.9	1.49
20	38.2	20.2	60.8	39.7	
40	39.6	19.0	56.1	38.2	
Mean	38.9	21.0	64.0	41.3	
SE(±)	1.25				
$LSD_{0.05}$ (±) within table	2.4				

Mostajeran and Rahimi (2009) reported that decreased shoot dry matter yield under lower soil moisture levels might be due to reduction of leaf area and photosynthesis rate. The results revealed that SUPA rice variety partitioned high percentage dry matter to straws under saturation and under drought conditions which might be due to robust nature of the variety.

Interaction of rice varieties and soil moisture levels had significant ($P \leq 0.001$) effects on total dry matter yield (Appendix 2). Total dry matter accumulation was higher under saturation (control) soil moisture levels in all varieties (Table 10). SUPA variety had the highest total dry matter yield under saturation soil moisture levels (Table 10). Rice varieties subjected to drought (40 kPa) conditions revealed that SUPA had highest total dry matter weight that might be manifested by robust nature and biomass of variety.

Table 10: Interaction effect between rice varieties and moisture levels on total dry matter yield

Treatments	Variety			Mean	SE (±)
Moisture levels (kPa)	SARO	NERICA 4	SUPA		
Control	104.8	74.6	132.6	104.0	1.97
20	99.7	58.6	123.0	93.8	
40	100.6	54.4	110.2	88.4	
Mean	101.7	62.6	121.9	95.4	
SE(±)	2.18				
$LSD_{0.05}$ (±) within table	4.0				

Zubaer *et al*. (2007) reported similar results that total dry matter production decreased with the decreasing soil moisture levels. The results revealed that SUPA variety accumulated higher total dry matter which might be manifested by higher biomass of the variety.

4.2.5 Interaction effect between soil moisture levels and potassium levels

Interaction between soil moisture levels and potassium levels had significant effect on plant height, panicle length, root dry matter and total dry matter yield (Appendix 2). Interaction effect of soil moisture levels and potassium levels had significant effect on plant height of lowland rice varieties (Appendix 2). Interaction of saturation (control) soil moisture level and 50 mg K kg^{-1} revealed the tallest plants (Table 11).

Table 11: Interaction between soil moisture levels and potassium levels on plant height

Treatments	Potassium (mg K kg^{-1} of soil)			Mean	SE (±)
Moisture levels (kPa)	Control	25	50		
Control	127.9	129.6	131.2	129.6	1.38
20	119.0	121.4	124.7	121.7	
40	110.8	116.1	115.6	114.1	
Mean	119.2	122.4	123.8	121.8	
SE(±)	1.06				
LSD$_{0.05}$ (±)within table	2.9				

Rice plants treated with 25 mg K kg^{-1} and subjected to drought (40 kPa) had medium plant height (Table 11). These results imply that potassium nutrition at 25 mg K kg^{-1} could be optimum for plant height under saturation and drought conditions. Medium rice plant height of 116 cm could be mostly preferred for lodging resistance. Interaction between soil moisture levels and potassium levels had significant ($P\leq 0.01$) effect on number of tillers per plant (Appendix 2). Rice plants subjected to saturation soil moisture level and treated with 25 mg K kg^{-1} of soil had higher number of tillers (Table 12). Under drought (40 kPa) conditions plants treated with 50 K mg kg^{-1} of soil registered higher number of tillers per plant. Potassium nutrition to plants stimulates root growth and thus efficient exploration of soil moisture and nutrients (Umar, 2006).

Table 12: Interaction between soil moisture levels and potassium levels on number of tillers

Treatments	Potassium (mg K kg^{-1} of soil)			Mean	SE(±)
Moisture levels (kPa)	Control	25	50		0.29
Control	8.6	8.7	8.1	8.4	
20	7.3	9.3	8.2	8.3	
40	7.7	8.8	10.4	9.0	
Mean	7.9	8.9	8.9	8.6	
SE(±)	0.64				
$LSD_{0.05}$ (±)within table	0.9				

It has been reported that potassium treatment to rice plant significantly increased number of tillers per plants (Bhiah *et al*., 2010). The current results revealed that rice plants treated with potassium had higher number of tillers under drought conditions compared with saturation level. These results might be due to accumulation of K in plant roots that produces a gradient of osmotic pressure which draws water into the roots under soil moisture stress. Tanguilig and Datta, (1988) reported that K minimizes the damaging effects of drought and soil compaction on root growth of lowland rice. These results indicated that rice plants required 50 K $kgha^{-1}$ to increase number of tillers under drought conditions.

Interactive effect of soil moisture level and potassium levels had significant ($P\leq 0.001$) effect on panicle length of lowland rice varieties (Appendix 2). Rice plants treated with 25 and 50 mg kg^{-1} of soil under saturation (control) soil moisture levels had longest panicle lengths (Table 13). The increment of potassium nutrition to 50 mg K kg^{-1} of soil had no significant change in panicle length (Table 13). Rice plants subjected to 40 kPa soil moisture tensions and treated with 50 mg K kg^{-1} of soil had longer panicles but not significantly different from 25 mg K kg^{-1} (Table 13).

Table 13: Interaction effect of soil moisture and potassium levels on panicle length

Treatments	Potassium	(mg K kg^{-1} of soil)		Mean	SE (±)
Moisture levels (kPa)	Control	25	50		
Control	23.3	23.6	23.6	23.5	0.18
20	20.8	23.2	23.3	22.4	
40	20.3	22.4	22.6	21.8	
Mean	21.5	23.1	23.1	22.6	
SE(±)	0.09				
$LSD_{0.05}$ (±) within table	0.4				

The results showed that 25 mg K kg^{-1} of soil could be an optimum and economical level in increasing panicle length of studied rice varieties under saturation and drought soil moisture levels. These results imply that soil moisture and potassium nutrition played a vital role in changing panicle length under saturation soil moisture levels and under drought (40 kPa soil moisture tension) conditions.

Table 14: Interaction effect of soil moisture and potassium levels on root dry matter yield

Treatments	Potassium levels (mg K kg^{-1} of soil)			Mean	SE(±)
Moisture levels (kPa)	Control	25	50		
Control	22.2	24.2	23.6	23.3	0.48
20	19.5	26.0	24.1	23.2	
40	18.8	22.4	22.0	21.1	
Mean	20.2	24.2	23.2	22.5	
SE(±)	0.43				
$LSD_{0.05}$ (±) within table	1.9				

Interaction effect of soil moisture level and potassium levels had significant ($P \leq 0.01$) effect on root dry matter yield of lowland rice varieties (Appendix 2). Rice plants subjected to different saturation soil moisture levels and treated with 25 mg K kg^{-1} of soil had higher root dry matter yield (Table 14). High root biomass enhanced plants ability of extracting nutrients and soil moisture in an extensive area that leads plants to moisture stress tolerance. These results imply that potassium nutrition at 25 mg K kg^{-1} of soil played a vital role in changing root dry matter weight of rice varieties under saturation and drought soil moisture levels.

Table 15: Interaction of soil moisture levels and potassium levels on total dry matter weight

Treatments	Potassium levels (mg K kg^{-1} of soil)			Mean	SE(±)
Moisture levels (kPa)	Control	25	50		
Control	103.9	101.6	106.6	104.0	1.97
20	89.0	96.9	95.4	93.8	
40	87.7	89.7	87.8	88.4	
Mean	93.5	96.0	96.6	95.4	
SE(±)	0.96				
$LSD_{0.05}$ (±)within table	4.0				

Interaction effect of soil moisture levels and potassium levels had significant ($P \leq 0.001$) effect on total dry matter yield (Appendix 2). Rice plants subjected to saturation soil moisture levels indicated higher total dry matter yield regardless of potassium levels (Table 15). Rice plants subjected to saturation soil moisture levels (control) and treated with 50 mg K kg^{-1} of soil had highest total dry matter weight. Under drought (40 kPa) rice plants treated with 25 mg K kg^{-1} of soil had higher total dry matter. These results imply that saturation moisture level at all potassium levels gave higher total dry matter yield which might be due importance of moisture in nutrients absorption, translocation and utilization by plant. Under drought (20 and 40 kPa) condition and potassium level at 25 mg K kg^{-1} of soil gave higher total dry matter production. Therefore, 25 mg K kg^{-1} of soil could be an optimum and economical level under drought conditions for biomass production.

4.2.6 Interaction effect between lowland rice varieties and potassium levels

Interaction of rice varieties and potassium levels had significant ($P \leq 0.001$) effects on plant height, tiller number per plant, shoot dry matter, grain yield, unfilled grain pot^{-1}, root dry matter weight, straw dry matter weight and total dry matter weight (Appendix 2).

Table 16: Interaction effect of rice varieties and potassium levels on plant height

Treatments	Potassium levels (mg K kg^{-1})			Mean	SE(±)
Varieties	Control	25	50		
SARO	100.6	100.3	101.1	100.6	1.07
NERICA 4	108.9	113.0	114.1	112.0	
SUPA	148.2	153.8	156.2	152.7	
Mean	119.2	122.4	123.8	121.8	
SE(±)	1.06				
LSD$_{0.05}$ (±)within table	2.92				

Interaction of rice varieties with potassium levels had significant ($P \leq 0.001$) effect on plant height (Appendix 2). SARO variety treated with 50 mg K kg^{-1} of soil under saturation soil moisture level had taller plants (Table 16). NERICA 4 and SUPA plants treated with 25 mg K kg^{-1} had significant change in plant height while increased potassium nutrition to 50 mg K kg^{-1} had insignificant increase in height. The interaction between rice varieties and potassium nutrition at 25 mg K kg^{-1} could be an optimum and economical level in increasing plant height for NERICA 4 and SUPA varieties. These results imply that studied rice varieties differed in height which might be due to varietal inherent characteristics and potassium nutrition utilization.

Table 17: Interaction between rice varieties and potassium levels on number of tillers

Treatments	Potassium levels (mg K kg^{-1})			Mean	SE(±)
Varieties	Control	25	50		
SARO	12.1	13.6	13.4	13.0	0.22
NERICA 4	5.4	6.3	6.2	6.0	
SUPA	6.0	6.9	7.1	6.7	
Mean	7.9	8.9	8.9	8.6	
SE(±)	0.31				
$LSD_{0.05}$ (±)within table	0.9				

Interaction of rice varieties and potassium levels had significant ($P\leq 0.001$) effect on number of tillers per plant (Appendix 2). SARO variety had the higher number of tillers regardless of potassium nutrition (Table 17). SARO variety plants treated with 25 mg K kg^{-1} of soil had the highest number of tiller per plant (Table 17). NERICA 4 plants treated with potassium nutrition at all levels had no statistical differences. SUPA rice variety treated with 50 mg K kg^{-1} of soil had higher tiller number per plant while potassium nutrition at 25 mg K kg^{-1} of soil had insignificant change in tiller number (Table 17). These results imply that tiller number variations among studied rice varieties under potassium levels might be due to genetic make up of varieties and utilization of potassium nutrition. SARO variety could be mostly preferred due to its inherent high ability in tillerring and response potassium nutrition in changing number of tillers per plant. Tillerring is one of the most important agronomic traits because tiller number per plant determines panicle number, a key component of grain yield (Xueyong *et al*., 2003).

Table 18: Interaction between rice varieties and potassium levels for root dry matter weight

Treatments	Potassium levels (mg K kg^{-1})			Mean	SE(±)
Varieties	Control	25	50		
SARO	22.1	27.9	26.9	25.6	1.19
NERICA 4	8.2	9.6	9.1	9.0	
SUPA	30.2	35.1	33.7	33.0	
Mean	20.2	24.2	23.2	22.5	
SE(±)	0.43				
LSD$_{0.05}$ (±) within table	1.9				

Interaction between rice varieties and 25 mg K kg^{-1} revealed higher dry matter partitioned to roots (Table 18). SARO and SUPA rice varieties treated with 25 mg K kg^{-1} indicated statistical increase in root dry matter weight while NERICA 4 had insignificant increase in root dry matter weight. NERICA 4 had no statistical increase in root dry matter under varied potassium levels which might be attributed to low percentage dry matter partitioned to roots (Table 3). The results imply that studied rice varieties varied in dry matter partitioned to roots under potassium nutrition which might be attributed to varietal inherent characteristics. The optimum and economical potassium nutrition for soils deficient in potassium could be 25 mg K kg^{-1} for high potassium affinity varieties such as SARO and SUPA.

Table 19: Interaction between rice varieties and potassium levels for total dry matter yield

Treatments	Potassium levels (mg K kg^{-1})			Mean	SE(±)
Varieties	Control	25	50		
SARO	98.4	102.3	104.4	101.7	2.18
NERICA 4	64.6	62.0	61.1	62.5	
SUPA	117.6	123.9	124.3	121.9	
Mean	93.5	96.0	96.6	95.4	
SE(±)	0.96				
$LSD_{0.05}$ (±) within table	4.0				

Interaction between rice varieties and potassium levels had significant ($P \leq 0.001$) effects on total dry matter yield (Appendix 2). Interaction between SARO rice variety and 50 mg K kg^{-1} of soil indicated significant increase in total dry matter yield while decreased potassium nutrition to 25 mg K kg^{-1} of soil had comparable total dry matter yield (Table 19). SUPA variety plants treated with 25 mg K kg^{-1} of soil revealed significant increase in total dry matter yield. Interaction between NERICA 4 rice variety and potassium nutrition at all levels had no statistical increment in total dry matter which might be attributed to inherent characteristic of the variety. The differences of rice varieties in total dry matter accumulated under potassium nutrition might be due to varietal genetic make up in potassium utilization. These results imply that SARO and SUPA had higher potassium nutrition affinity as compared with NERICA 4 variety.

4.2.7 Partial correlation coefficients among vegetative and reproductive variables of lowland rice varieties

4.2.7.1 Relationship between Variables

The yield and yield components were correlated to determine their influence on each other and results are presented in Table 20. Variables that were significant and negatively correlated were between plant height and tiller number per plant per pot; shoot dry matter weight per pot and root dry matter weight per pot; shoot dry matter weight per pot and straw dry matter weight per pot; straw dry matter weight per pot and grain yield per pot; shoot dry matter weight per pot and total dry matter.

Plant height and number of tillers per plant were found to be significant ($P \leq 0.001$) and negatively correlated. Plants with single shoots were taller compared with normally tillered cereals implying that lowering tillerring ability may increase plant height. The results comply with those reported by Cui *et al*. (2004) that rice plant height and number of tillers per plant revealed significant and negative correlation at different growth stages for two consecutive years. The negative relationship might be attributed to competitions for limited nutrient supply and available assimilates for tillerring and stem elongation. Relationship between shoot dry matter and root dry matter weight per pot was found very high significant ($P \leq 0.001$) and negatively correlated. The tested lowland rice varieties varied in percentage dry matter partitioning to plant parts.

Table 20: Partial correlations between vegetative and reproductive variables of rice varieties on the study done at Sokoine University of Agriculture Morogoro during 2010/2011 cropping season

Variables	1	2	3	4	5	6	7	8	9
1. Plant height	1	- 0.46***	0.12	0.25*	0.30*	0.33**	-0.02	-0.16	0.02
2. Tiller number		1	-0.09	0.03	-0.01	0.17	0.29*	0.14	0.25*
3.Shoot dry matter			1	0.10	-0.24	-0.08	-0.25*	-0.30*	-0.48***
4. Panicle length				1	-0.078	0.00	-0.09	0.04	-0.06
5. Grains yield pot^{-1}					1	0.64***	0.09	-0.37**	0.31*
6.Unfilled grain yield pot^{-1}						1	0.18	0.41***	0.10
7.Root dry matter weight pot^{-1}							1	0.23*	0.73***
8. Straw dry matter weight pot^{-1}								1	0.65***
9.Total dry matter weight pot^{-1}									1

* = Significant at $P \leq 0.05$ ** = Highly significant at $P \leq 0.01$ *** = Very highly significant at $P \leq 0.001$

The negative correlation might be due to competitions for limited resources supply and available assimilates between roots; lateral root formation and elongation and shoots development.

Straw dry matter yield and grain yield per pot was found to be significant ($P \leq 0.01$) and negatively correlated. The negative correlation might be attributed by competitions for limited resources supply and available assimilates between shoots development and grain filling. Shoot dry matter and total dry matter weight per pot was found significant ($P \leq 0.001$) and negatively correlated. The negative correlation might be ascribed by competitions for limited nutrient supply and available assimilates to biological parts and to economic plant parts.

Significant and positive correlations were observed between plant height and panicle length; plant height and grain yield per pot; grain yield per pot and unfilled grain per pot; tiller number and root dry matter weight per pot; unfilled grain per pot and straw dry matter weight; straw dry matter weight and root dry matter weight per pot; tiller number and total dry matter weight per pot; total dry matter weight per pot and root dry matter weight per pot; total dry matter weight per pot and straw dry matter weight per pot; grain yield per pot and total dry matter weight.

Plant height and total dry matter weight per pot was found to be positive and significantly ($P \leq 0.05$) correlated with grain yield per pot while unfilled grain yield per pot was found to be positively and significant ($P \leq 0.001$) correlated with grain yield per pot. This confirmed the use of plant height, total dry matter per pot and unfilled grain yield per pot as indicators of high grain yield. Abdus *et al.* (2010) reported that plant height was significant and positively correlated with grain yield per plant. Plant height is important in rice production. Selvaraj *et al*. (2011) reported that plant height had significant and positive association with grain yield production. Therefore, the significant and positive correlations between grain yield per pot and plant height indicated that they could also be used as a selection criterion for high yielding rice varieties taking into consideration the important yield components. Root dry matter, total dry matter weight per pot and tiller number was significantly ($P \leq 0.05$) and positively correlated. Plants with high tillerring ability characteristically increase roots biomass and accumulation of dry matter since each tiller contributes to the roots and total dry matter per pot.

Total dry matter and root dry matter weight per pot were significantly ($P \leq 0.001$) and positively correlated. Plants with high ability of intercepting solar radiation energy might have high dry matter accumulation and partition high percentage to plant parts. High percentage of dry matter partitioned to roots might improve nutrients and water supplies to plants hence high shoot dry matter and total dry matter.

4.2.8 Field experiment

Visual assessment of rice growth in the field experiment

Visual observations revealed that studied rice varieties varied in plant height (Fig. 5) and susceptibility to rice blast infection (Fig. 6 and 7). During vegetative growth stage, SUPA variety was observed to be healthy and the tallest among the rice varieties under study (Fig. 5). SUPA rice plants were infected by blast disease at flowering stage. These observations might be due to inherent characteristics of tested rice varieties.

Figure 5: SUPA rice variety at vegetative stage (72 DAS)

Figure 6: SUPA rice variety infected by rice blast disease

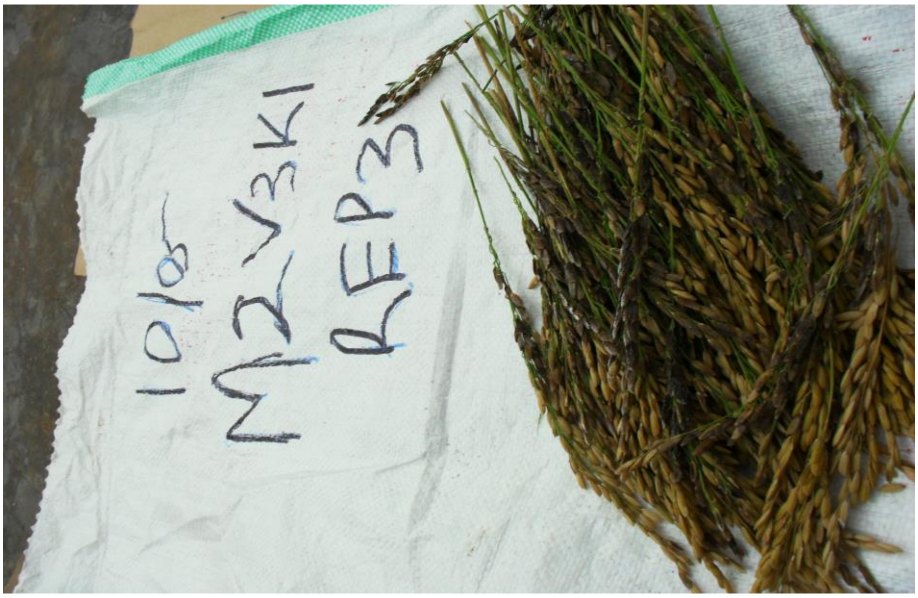

Figure 7: Rice panicles infected by rice blast

Effects of rice varieties on nitrogen and potassium concentration in plant shoots tissues are presented in Table 21 while the effects of potassium levels on nitrogen and potassium concentration in plant shoots tissues are presented in Table 22.

4.2.9 Mineral nutrients concentration in plant tissue

Table 21: Effects of varieties on nutrients concentration in plant shoot tissues

Treatments	Nutrients	Concentration
Varieties	N (%)	K(%)
SARO	1.55 b	0.84 b
NERICA 4	1.75 a	1.04 a
SUPA	1.31 c	0.87 a b
Mean	1.54	0.92
S.E±	0.03	0.06
CV %	9.07	35.02
LSD $_{0.05}$ (±)	0.08	0.17
F-test	***	*

Means within the same column bearing the same letter are not significantly different at P ≤ 0.05.

4.2.9.1 Nitrogen

The effect of N concentration in rice shoot tissues differ significantly **(**P≤ 0.05) among studied varieties (Table 21). NERICA 4 plant had the highest nitrogen concentration followed by SARO and the least SUPA variety (Table 21). The results indicated that NERICA 4 and SARO varieties had high nitrogen use efficiency while SUPA variety revealed low nitrogen use efficiency (Table 21). Nitrogen is one of the most yield limiting nutrients for lowland rice, and its adequate supply during crop growth is essential for improving yield.

In the vegetative growth stage, nitrogen is important in increasing leaf area and tillering while in reproductive growth stage nitrogen increase number of spikelets and grain filling (Fageria, 2011). These results indicated that NERICA 4 and SARO varieties were more efficient in nitrogen use than SUPA variety which might be due to genetic make up of studied lowland rice varieties. However, nitrogen concentration among studied rice varieties was inadequate. Hill *et al.* (1998) reported that optimum nitrogen concentration in rice at panicle initiation ranges from 3.3 - 3.8 %. These results imply that nitrogen concentration in shoots tissues of studied varieties was inadequate which leads to poor vegetative and reproductive growth, hence low grain yield. The results suggested that sufficient nitrogen fertilizer should be applied to rice varieties for better performance.

4.2.9.2 Potassium

The effects of K concentration in rice shoot tissues differ significantly (P≤ 0.05) among studied varieties (Table 21). NERICA 4 plants had the highest potassium concentration in shoots tissues followed by SUPA and the least SARO rice variety (Table 21). Potassium is required for a wide range of functions within the plant metabolism such as enzyme activation, osmotic turgor regulation and transportation of assimilates.

An adequate potassium supply is needed to improve the integrity of cell membranes and cell walls, increasing leaf area and leaf chlorophyll content and influences the plants health by increasing its tolerance to adverse climatic conditions, lodging, pests and diseases.

The potassium concentration in SARO and SUPA shoots were comparable but concentration in NERICA 4 was significantly higher than in SARO (Table 21). These results indicated that NERICA 4 had higher potassium use efficiency among studied rice varieties while the rest two varieties had relatively low potassium use efficiency. The variation in potassium use efficiency might be due inherent characteristics of studied rice varieties.

However, the potassium concentration in NERICA 4 shoots tissues was adequate while SARO and SUPA varieties had insufficient concentrations. Hill *et al.* (1998) reported that the adequacy potassium concentration in rice shoot tissues at panicle initiation ranges from 1.0 – 2.4 %. These results imply that shoots tissues potassium concentration in SARO and SUPA rice varieties was inadequate while concentration in NERICA 4 was at the lower limit of adequacy range. The results suggested that adequate potassium nutrition should be supplied to rice varieties for optimum performance.

4.3 Effects of Potassium Levels on Nitrogen and Potassium Concentration in Rice Shoot Tissues

4.3.1 Nitrogen concentration

Potassium levels applied to lowland rice plants had significant ($P \leq 0.01$) effects on nitrogen concentration in plant shoot tissues (Table 22). The results indicated that rice plants without potassium nutrition treatment had the least nitrogen concentration in shoots tissues (Table 22).

Table 22: Effects of potassium levels on nitrogen and potassium concentration in shoot tissues

Treatments	**N (%)**	**K (%)**
Potassium Levels (kg K ha^{-1})		
Control	1.49 b	0.80 b
50	1.61 a	1.05 a
100	1.52 b	0.90 ab
Mean	1.54	0.92
S.E±	0.03	0.06
CV%	9.07	35.02
$LSD_{0.05}$ (±)	0.08	0.17
F-test	**	**

Means within the same column bearing the same letter are not significantly different at $P \leq 0.05$.

Rice plants treated with 50 kg K ha^{-1} had highest nitrogen concentration in shoot tissues (Table 22). However, the increment of potassium level to 100 kg K ha^{-1} had comparable nitrogen concentration in rice shoot tissues.

Nitrogen is essential component of the proteins that build cell material and plant tissue and therefore important determinant of plant growth and crop yield. The results indicated that potassium nutrition at 50 kg K ha^{-1} was optimum and economical in changing nitrogen concentration in rice shoots tissues. However, nitrogen concentration in rice shoots tissues was inadequate across soil moisture levels. It has been reported that optimum nitrogen concentration in rice shoots tissues at panicle initiation ranges from 3.3 - 3.8 % (Hill *et al.*, 1998). These results suggested that sufficient quantities of nitrogen fertilizer should be applied to rice plants for better vegetative and reproductive growth.

4.3.2 Potassium concentration

Potassium levels applied to lowland rice plants had significant ($P \leq 0.01$) effects on potassium concentration in plant tissues (Table 22). Rice plants without potassium nutrition revealed least potassium concentration in shoots tissues while those treated with 50 kg K ha^{-1} had the highest potassium concentration (Table 22). Increment of potassium level to 100 kg K ha^{-1} had comparable change in potassium concentration in shoots tissues.

Potassium is one of the three essential macronutrients required in the largest amount for plant growth and yield (Jia *et al.*, 2008). These results imply that 50 kg K ha^{-1} was the optimum level for enhancing shoot tissues K^+ concentration.

However, shoots tissues nitrogen concentration in plants treated with 50 kg K ha^{-1} was at lower limit of adequate range while plants without potassium treatment and those treated with 100 kg K ha^{-1} were inadequate K. Hill *et al.* (1998) reported that shoot tissues potassium concentration in rice at panicle initiation ranges from 1.0 to 2.4 %. These results suggested that adequate potassium nutrition should be supplied to rice plants for better plant growth.

4.4 Effects of soil moisture levels on growth parameters, yield and yield components of rice under field conditions

Soil moisture levels had significant ($P \leq 0.05$) effects on panicle length and highly significant ($P \leq 0.001$) effects on number of spikelets per panicle, number of grains per panicle and grain yield per hectare. Soil moisture also had significant ($P \leq 0.01$) effect on percentage spikelets fertility (Appendix 4).

4.4.1 Effect of soil moisture levels on number of spikelets per panicle

Soil moisture levels had significant ($P \leq 0.001$) effects on number of spikelets per panicle per plant (Appendix 4). The results showed that rice plants grown under saturation (control) had the highest number of spikelets per panicle followed by plants subjected to 40 kPa and lastly plants subjected to 20 kPa soil moisture tension (Table 23). Rice plants subjected to 20 and 40 kPa soil moisture tensions had comparable number of spikelets per panicle which might be due to severe panicle blast infection for SUPA variety plants subjected to 20 kPa moisture stresses (Fig. 6 and 7). Drought exposure during the earlier stages of reproductive growth affects panicle formation and number of spikelets (Kim *et al.*, 2009). These results imply that number of spikelets per panicle increased under saturation soil moisture level and generally dropped under soil moisture stress. Spikelets per panicle are important component of rice yield and have high heritability and mainly determined by genotypes rather than environmental influence (He *et al.*, 2010).

4.4.2 Effects of soil moisture levels on grain yield

The study showed that, soil moisture levels had significant ($P \leq 0.001$) effects on grain yield per hectare (Appendix 4). The results indicated that plants subjected to saturation (control) had the highest grain yield per hectare followed by plants subjected to 20 kPa soil moisture stress (Table 23). The lowest grain yield was associated with plants subjected to a soil moisture stress of 40 kPa. The results revealed that rice grain yield declined as the soil moisture tension was increased. Zubaer *et al*. (2007) reported that grain yield losses resulting from water deficit are particularly severe when drought strikes at booting stage. Water stress at or before panicle initiation reduces potential spike number and decreases translocation of assimilates to the grains, which results to low grain weight and increased empty grains. The current results conform with the results reported by Bouman *et al.* (2001) on lowland rice that yield declines as soon as the field water content drops below saturation. This implies that studied lowland rice varieties require saturation soil moisture levels for maximum grain yield while other factors are kept constant.

4.4.3 Effect of soil moisture levels on rice spikelets fertility

Soil moisture levels had significant ($P\leq 0.01$) effects on percentage spikelets fertility (Appendix 4). Rice plants subjected to saturation (control) had the highest spikelets fertility percentage (86.7%) followed by plants subjected to 40 kPa (78%) and lastly plants subjected to 20 kPa soil moisture tension (Table 23).

Rice plants subjected to 20 kPa soil moisture tension had the least spikelets fertility percentage which might be due to panicle blast disease infection that was severe to SUPA rice plants imposed to 20 kPa soil moisture tensions (Fig. 6 and 7). Yang and Zhang (2006) reported that drought stress during flowering and terminal period of rice cultivation could interrupt floret initiation (cause spikelets sterility) and grain filling respectively. These results imply that maintaining saturation soil moisture levels for studied lowland rice varieties is the best option for spikelets fertility. However, supplying key nutrients such as K to rice plants enhances water use efficiency during drought stress, improves spikelets fertility and thus increase grain yield.

4.4.4 Effect of soil moisture levels on number of grains per panicle

Soil moisture levels had significant ($P\leq 0.001$) effects on number of grains per panicle (Appendix 4). Plants subjected to saturation soil moisture level (control) had the highest number of grains per panicle (Table 23). Rice plants subjected to 20 and 40 kPa soil moisture stress had comparable number of grains per panicle (Table 23). The results indicated that number of grains per panicle decreased as soil moisture level dropped from saturation. Similar results were reported by Mostajeran and Rahimi, (2009) that under non submerged condition panicle weight and the number of filled grains in 829 and 216 rice cultivars was reduced. These results indicated that reduced number of grains per panicle under moisture stress might be due to decreased translocation of assimilates to the grains which lowered grain filling and increased empties. Water stress at or before panicle initiation reduces potential spike number and decreases translocation of assimilates to the grains, which decrease number of grains and increased empty grains (Zubaer *et al*., 2007). These results imply that maintaining saturation soil moisture levels under lowland rice cultivation during reproductive stage is of vital importance in grain filling.

4.4.5 Effect of soil moisture levels on panicle length

Soil moisture levels had significant ($P \leq 0.05$) effects on panicle length (Appendix 4). The results indicated that plants subjected to saturation soil moisture level had the longest panicles (Table 23). Rice plants subjected to 20 and 40 kPa soil moisture stresses indicated reduced panicle length and had no statistical difference (Table 23). The results indicated that saturation (control) soil moisture level changed panicle length significantly while soil moisture levels below saturation had shorter panicles. These results agree with the results reported by Rahman *et al*. (2002) on rice that panicle length under soil moisture stresses decreased as compared with that of the control. These results imply that maintaining saturation soil moisture levels was important on panicle length of studied rice varieties.

Table 23: Effect of soil moisture levels on growth parameters, yield and yield components of lowland rice varieties

Moisture levels (kPa)	Panicle length (cm)	Spikelets per panicle (No.)	Grain per panicle (No.)	Grain yield (t ha^{-1})	Spikelets Fertility (%)
Control	23.4 a	164.0 a	142.1 a	4.6 a	86.7 a
20 kPa	22.4 b	136.8 b	102.2 b	3.3 b	67.7 b
40 kPa	22.7 ab	142.1 b	113.6 b	3.1 b	78.1 a
Mean	22.8	147.6	119.3	3.6	77.5
S.E±	0.26	5.36	6.28	0.20	3.74
CV (%)	5.64	17.4	27.3	27.0	24.4
$LSD_{0.05}$ (±)	0.7	14.1	17.8	0.5	10.4
F-test	*	***	***	***	**

Means within the same column bearing the same letter are not significantly different at ($P \leq 0.05$)

4.5 Variation of Rice Varieties on growth parameters, Yield and Yield Components

Rice varieties had very highly significantly ($P \leq 0.001$) effects on plant height, number of tillers per plant, grain yield , shoot dry matter weight, spikelets per panicle and number of grains per panicle while results indicated significant ($P \leq 0.05$) effects on percentage spikelets fertility and unfilled grain (Appendix 4).

Height differences among rice varieties were clearly observed in the experimental plot when SUPA and SARO had 72 days from sowing and NERICA 4 had 50 days from sowing (Figure 8). The variation of number of days is due to differences in sowing dates. NERICA 4 seeds were sown 22 days after SUPA and SARO varieties due to its short growth cycle.

Figure 8: Height variation among studied rice varieties

NERICA 4 (right) SARO (middle) and SUPA (left).

4.5.1 Variation of rice varieties on plant height

Studied rice varieties had very highly significant (P≤ 0.001) variation on plant height (Appendix 4). The results showed that SUPA plants were the tallest among the studied rice varieties followed by NERICA 4 and lastly SARO which had the shortest plants (Table 24). The variations in plant height among studied rice varieties might be attributed to differences in genetic make up and partitioning of available assimilates to different plant parts. Short and medium plant heights are more preferred than tall cultivars due to their lower susceptibility to lodging. Improved rice varieties which have short to medium plant heights such as SARO and NERICA 4 are more preferred due to their resistance to lodging, shorter growth cycle and high yield potentials compared with traditional varieties which are tall and low yielding. These results are comparable to those reported by Ndaeyo *et al.* (2008) on growth and yield performance of some upland rice cultivars. Ndaeyo *et al.* (2008) reported that differences in plant height were attributed to genetic make up of the varieties.

4.5.2 Variation of rice varieties on number of tillers

Rice varieties had very highly significant (P≤ 0.001) variation on number of tillers per plant (Appendix 4). The results indicated that SARO variety had the highest number of tillers (33) among the studied rice varieties followed by SUPA variety (17) and lastly NERICA 4 (11) that was identified to have the lowest number of tillers per hill (Table 24). The results revealed variations in tiller number per hill among the studied rice varieties. The variation in tiller number might be due to genetic make up of studied rice varieties, utilization of available nutrients and partitioning of photosynthate.

Table 24: Variation of rice varieties on growth parameters, yield and yield components

VARIETY	Plant Height (cm)	Tiller Number (No.)	Shoot dry matter (t ha^{-1})	Panicle length (cm)	No.of spikelet per panicle (No.)	No. of grain per panicle (No.)	Spikelets Fertility (%)	Unfilled grain ha^{-1} (tha^{-1})	**Grain yield (t ha^{-1})**
SARO	81.2 c	33.1 a	7.0 b	23.2 a	151.1 a	129.9 a	83.7 a	0.206 a	5.2 a
NERICA 4	95.5 b	11.8 c	5.5 c	22.4 b	163.3 a	134.7 a	81.1 a	0.209 a	3.6b
SUPA	130.3 a	17.9 b	7.9 a	22.9 a b	128.5 b	93.2 b	67.7 b	0.158 b	2.1c
Mean	102.3	20.9	6.8	22.8	147.6	119.3	77.5	0.191	3.6
S.E±	7.75	3.23	1.18	1.286	25.73	32.51	18.93	0.075	0.98
CV (%)	7.6	15.5	17.4	5.6	17.4	27.3	24.4	39.392	27.0
LSD$_{0.05}$ (±)	4.2	1.8	0.6	0.7	14.1	17.8	10.4	0.0412	0.5
F-test	***	***	***	*	***	***	*	*	***

ns = Non Significant, S.E± - Standard Error, CV (%) – Coefficient of Variation, *** = Very highly significant ($P \leq 0.001$), ** Highly significant and * = Significant ($P \leq 0.05$).

Means within the same column bearing the same letter are not significantly different at ($P \leq 0.05$).

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These results are similar to the results reported by Ndaeyo *et al*. (2008) on upland rice cultivars, that variation in number of tillers per plant was attributed to differences in the ability of the cultivars to utilize the fertilizer as well as partition their photosynthates and accumulated dry matter.

4.5.3 Variation of rice varieties on shoot dry matter

Rice varieties had very highly significant ($P \leq 0.001$) variation on shoot dry matter (Appendix 4). The results show that among studied lowland rice varieties, SUPA variety recorded the highest shoot dry matter weight per hectare followed by SARO variety and lastly NERICA 4 (Table 24). The results revealed that SUPA variety had highest shoot dry matter yield among the studied lowland rice varieties which might be due to its growth habit (tall) and long growth cycle. SARO variety had relatively less shoot dry matter yield as compared with SUPA variety which might be due to its short stature though high tillerring and medium growth cycle. NERICA 4 had the least shoot dry matter weight which might be due to its low tillerring, medium plant height and short growth cycle. The variation of lowland rice varieties in height might be due to genetic make up of varieties, differences in utilization of mineral nutrients and partitioning of available assimilates.

4.5.4 Variation of rice varieties on number spikelets

Rice varieties had very highly significant ($P \leq 0.001$) variation on number of spikelets per panicle (Appendix 4). The results showed that NERICA 4 had the highest number of spikelets per panicle followed by SARO and lastly SUPA (Table 24). Numbers of spikelets per panicle for NERICA 4 and SARO were not statistically different (Table 24). NERICA 4 had the highest number of spikelets per panicle which might be due to compensation for poor tillerring ability, hence less intraplant competition. SARO variety had relatively less number of spikelets per panicle compared with NERICA 4 which might be due to its high tillerring ability and thus high competition for assimilates during spikelets formation. SUPA variety had the least number of spikelets per panicle which might have been aggravated by blast infection during flowering stage which was very severe on this variety (Fig. 6 and 7). Also, least number of spikelets per panicle for SUPA might be due to poor partitioning of biomass to reproductive plant parts. These results imply that studied lowland rice varieties variations in number of spikelets per panicle might be due to varietal inherent characteristic and resistance to blast infection at flowering stage.

4.5.5 Variation of rice varieties on number of grains per panicle

Rice varieties had very highly significant ($P \leq 0.001$) variation on number of grains per panicle (Appendix 4). The results indicated that NERICA 4 rice variety had the highest number of grains per panicle followed by SARO variety although they were not statistically different and lastly SUPA rice variety (Table 24). Variation of studied lowland rice varieties in number of grains per panicle might be due to varietal inherent characteristic and assimilates partitioned to grain filling. Improved rice varieties such as NERICA 4 and SARO had higher number of spikelets and grains per panicle while traditional rice varieties such as SUPA had least number of spikelets and grains per panicle which might be due to genetic make up and susceptibility to blast infection. Luzi - Kihupi *et al.* (2009) reported that SUPA variety is too tall, photoperiod sensitive, has a long maturation period and is also susceptible to diseases such as rice blast and rice yellow mottle virus (RYMV).

4.5.6 Variation of rice varieties on percentage spikelets fertility

Rice varieties had highly significant (P≤ 0.01) variation on percentage spikelets fertility (Appendix 4). The results indicated that SARO had the highest percentage spikelets fertility (83.7 %) followed by NERICA 4 (81%) while SUPA had the least percentage spikelets fertility (67.6%) (Table 24). The variation of studied rice varieties in percentage spikelets fertility might be due to genetic make up. However, SUPA variety was infected by rice blast during flowering stage (Table 6 and 7). The results indicated that plant height had significant and negatively correlation with percentage spikelets fertility (Table 31).These results suggest that variation of studied rice varieties in percentage spikelets fertility might be due to varietal inherent characteristic, utilization of key nutrients such as potassium and susceptibility to blast infections.

4.5.7 Variation of rice varieties on grain yield

Rice varieties had very highly significant (P≤ 0.001) variation on grain yield (Appendix 4).The results showed that SARO had the highest grain yield followed by NERICA 4 variety and lastly SUPA (Table 24). SARO and NERICA 4 had higher grain yield among the studied rice varieties due to high number of grains per panicle and spikelets fertility. SUPA variety revealed the least grain yield per hectare which might be due genetic make up of the variety and effect of blast infections which led to low spikelets fertility and least number of grains per panicle. These results indicated that improved rice varieties such as SARO and NERICA 4 had high grain yield compared with SUPA. The variation in grain yield might be due to inherent characteristics of the varieties. SUPA is photoperiod sensitive, has a long growth cycle and is susceptible to blast disease. SUPA was severely infected by rice blast during flowering stage due to its long growth cycle which coincided with favorable conditions for blast development

(Fig. 6 and 7). SARO and NERICA 4 could be most preferred varieties due to high grain yield and resistance to blast infection.

4.6 Effects of Potassium Levels on Yield and Yield Components of Rice Varieties

Potassium levels had very highly significant ($P \leq 0.001$) effects on panicle length, number of spikelets per panicle, number grains per panicle and significant ($P \leq 0.05$) effects on spikelets fertility (Appendix 4).

4.6.1 Effects of Potassium levels on panicle length

Potassium levels applied to lowland rice had very highly significant ($P \leq 0.001$) effects on panicle length (Appendix 4) The rate of 50 kg K ha^{-1} resulted to significant increase in panicle length but increasing potassium level to 100 kg K ha^{-1} had insignificant increase in panicle length (Table 25). The least panicle length was recorded in plants without potassium (control). These results revealed that increasing potassium rate to 50 kg K ha^{-1} significantly encouraged cell division and elongation resulting to increased panicle length. The current result complies with the results reported by Kandil *et al.* 2010) on performance of some rice cultivars as affected by irrigation and potassium fertilizer that increasing potassium rates up to 48 kg K_2O ha^{-1} significantly increased panicle length with insignificant panicle length increment when treated with 96 kg K_2O ha^{-1}. The insignificant increment in panicle length might be due to the antagonism between K^+ and NH_4^+ particularly under higher level of potassium in root growth zones (Kandil *et al.*, (2010). Current results suggest that the potassium nutrition at 50 kg K ha^{-1} might be optimum for panicle length increment.

4.6.2 Effect of Potassium Levels on Number of Spikelets Per Panicle

Potassium levels had very highly significant ($P \leq 0.001$) effects on number of spikelets per panicle (Appendix 4). Rice plants treated with 100 kg K ha^{-1} had the highest number of spikelets per panicle followed by plants treated with 50 kg K ha^{-1} and lastly plants without potassium (Table 25). The results indicated that K was important in changing number of spikelets per panicle significantly. Similar results have been reported by IRRI, (2007) that potassium nutrition enhances and increases rice number of spikelets per panicle. These results imply that potassium nutrition at 50 kg K ha^{-1} was optimum for studied lowland rice varieties in increasing number of spikelets per panicle.

4.6.3 Effect of potassium levels on number of grains per panicle

Potassium levels applied to lowland rice plants had very highly significant ($P \leq 0.001$) effects on number of grains per panicle (Appendix 4). The rate of 50 kg K ha^{-1} had significant increased number of grains per panicle significantly while increasing potassium level beyond the 50 kg K ha^{-1} resulted in comparable grains count per panicle (Table 25). The least number of grains per panicle was noted in plants without K addition (control). Similar results were reported by Elliot (2009) that 80 kg K ha^{-1} increased rice yields by increasing the number of productive tillers per plant and fertile grains per panicle. These results imply that potassium nutrition for soils with medium potassium, high calcium, and magnesium and sodium content will increase number of grains per panicle. Therefore, the optimum potassium level for the studied lowland rice varieties could be 50 kg K ha^{-1} for soils with medium potassium content and high exchangeable bases such as calcium, magnesium and sodium.

Table 25: Effects of Potassium levels (K levels) on yield and yield components

Potassium levels (kg K ha^{-1})	Panicle length (cm)	Spikelet per panicle (No.)	No.Grain per panicle (No.)	**Spikelets Fertility (%)**
Control	21.9 b	107.7 b	75.8 b	70.0 b
50	23.2 a	165.9 a	140.6 a	81.5 a
100	23.4 a	169.3 a	141.5 a	81.0 a
MEAN	22.8	147.6	119.3	77.5
S.E±	1.29	25.7	32.51	18.93
CV (%)	5.6	17.43	27.3	24.4
$LSD_{0.05}$ (±)	0.7	14.1	17.8	10.4
F-test	***	***	***	*

S.E± - Standard Error, CV(%) – Coefficient of Variation, *** Very highly significant ($P \leq 0.001$) and * = Significant ($P \leq 0.05$).

*** Means within the same column bearing the same letter are not significantly different at ($P \leq 0.05$).**

4.6.4 Effect of potassium application levels on spikelets fertility per panicle

Potassium levels applied to rice plants had significant ($P \leq 0.05$) effects on spikelets fertility per panicle (Appendix 4). The rate of 50 kg K ha^{-1} had the highest spikelet fertility percentage (81.5%) while increasing potassium level to 100 kg K ha^{-1} (81%) had comparable change in spikelets fertility percentage (Table 25). The least spikelet fertility percentage per panicle (70%) was noted in plants without potassium (control). These results showed that potassium nutrition played a vital role in enhancing percentage spikelets fertility. The current results comply with those results reported by Quamph *et al*. (2011) on improving water use efficient by potassium nutrition in various rice genotypes. These results imply that the rate of 50 kg K ha^{-1} to lowland rice varieties grown in soils with medium potassium, high calcium, magnesium and sodium content could be an optimum level in percentage spikelets fertility improvement.

4.7 Interaction between Moisture Levels X Variety, Variety X Potassium Levels and Moisture Levels X Potassium Levels

Interaction of soil moisture levels and potassium levels had significant effect on nitrogen concentration in rice shoot tissues (Appendix 5). Rice plants under saturation (control) without potassium nutrition treatment had higher nitrogen concentration across soil moisture levels (Table 26). Interaction between 50 kg K ha^{-1} and saturation (control) soil moisture levels had the highest nitrogen concentration in shoot tissues (Table 26). Rice plants under drought condition (40 kPa) that was treated with 100 kg K ha^{-1} revealed higher nitrogen concentration in rice shoots tissues. The results indicated that nitrogen concentration in plant tissues varied with soil moisture status and potassium levels.

Table 26: Interaction effects of soil moisture levels and potassium levels on nitrogen concentration in plant tissues.

Treatments	Potassium levels (kg ha^{-1})				
Soil moisture levels (kPa)	Control	50	100	Mean	SE±
Control	1.50	1.72	1.49	1.57	0.06
20 kPa	1.49	1.62	1.49	1.53	
40 kPa)	1.48	1.48	1.59	1.52	
Mean	1.49	1.61	1.52	1.54	
CV (%)	34.67				
SE±	0.03				
LSD$_{0.05}$ (±) within table	0.17				

However, there was no significant difference between potassium levels at drought regime (40 kPa). The interaction between soil moisture levels and potassium levels showed plants with inadequate shoot tissues nitrogen concentration. Hill *et al.* (1998) reported that shoots tissues nitrogen concentration in rice at panicle initiation ranges from 3.3 to 3.8 %. These results imply that adequate potassium nutrition should be supplied to rice varieties to facilitate extraction of key nutrients such as nitrogen from the root zone for better plant performance.

Interaction between soil moisture levels and rice varieties had highly significant ($P \leq 0.01$) effect on number of spikelets per panicle (Appendix 4). The interaction of saturation (control) and rice varieties had higher number of spikelets per panicle (Table 27).

Table 27: Interaction of soil moisture levels and rice varieties on number of spikelets per panicle.

Treatments		Varieties		Mean	SE ±
Moisture levels (kPa)	SARO	NERICA 4	SUPA		
Control	162.0	169.1	160.8	164.0	8.92
20	149.2	162.7	98.4	136.8	
40	142.1	158.1	126.2	142.1	
Mean	151.1	163.3	128.481	147.6	
SE±	5.94				
LSD$_{0.05}$ (±)within table	14.1				

NERICA 4 rice variety had the highest number of spikelets per panicle under saturation followed by SARO variety and lastly SUPA variety. Under drought conditions (40kPa), NERICA 4 had higher number of spikelets per panicle. The results indicated that studied rice varieties varied in number of spikelets under different soil moisture levels which might be due to capability of some varieties to withstand tension in their cells under reduced soil water. The results implied that SARO variety indicated good performance under saturation (control) conditions in terms of number of spikelets per panicle while NERICA 4 had higher number of spikelets per panicle under drought conditions (40 kPa). NERICA 4 variety could mostly be preffered under drought conditions due to its ability to withstand soil moisture tensions.

Interaction of soil moisture levels and lowland rice varieties had significant ($P \leq 0.05$) effect on number of grains per panicle (Appendix 4). Interaction between rice varieties and saturation (control) soil moisture levels had higher number of grains per panicle

Table 28: Interaction between soil moisture levels and rice varieties on number of grains per panicle

Treatments Moisture levels (kPa)	SARO	Varieties NERICA 4	SUPA	Mean	SE (±)
0 (control)	150.2	148.3	127.8	142.1	6.73
20	125.0	129.6	52.0	102.2	
40	114.4	126.3	100.0	113.6	
Mean	129.9	134.7	93.2	119.3	
SE(±)	8.14				
$LSD_{0.05}$ (±)within table	17.8				

(Table 28). SARO variety had the highest number of grains per panicle under saturation soil moisture levels followed by NERICA 4 and lastly SUPA variety. Under drought conditions (40 kPa), NERICA 4 rice plants had higher number of grains per panicle. These results indicated that lowland rice varieties varied in number of grains per panicle under different soil moisture levels which might be due to differences in genetic make up, utilization of mineral nutrients, partitioning of available assimilates and blast infections. SARO variety could be the best choice under saturation soil moisture levels while under drought condition NERICA 4 variety could be the most preferred variety due to its ability to withstand soil moisture tensions.

Interaction of soil moisture levels and rice varieties had significant ($P\leq 0.01$) effect on percentage spikelets fertility (Appendix 4). SARO variety had the highest spikelets fertility under saturation (control) soil moisture levels followed by NERICA 4 and lastly SUPA variety (Table 29).

Table 29: Interaction between soil moisture levels and rice varieties on percentage spikelets fertility

Treatments			Varieties	Mean	SE (±)
Moisture levels (kPa)	SARO	NERICA 4	SUPA		3.74
Control	93.3	86.9	79.8	86.7	
20	81.5	78.8	42.8	67.7	
40	76.4	77.6	80.3	78.1	
Mean	83.7	81.1	67.7	77.5	
SE(±)	6.47				
$LSD_{0.05}$ (±) within table	10.4				

Under drought conditions (40 kPa), SUPA variety indicated higher percentage spikelets fertility although had insignificant difference with the other two varieties. The results implied that studied rice varieties varied in percentage spikelets fertility across soil moisture levels which might be attributed to varietal inherent characteristics.

Interaction of soil moisture levels and potassium had significant effect on number of spikelets per panicle (Appendix 4). Interaction between saturation (control) and 100 kg K ha^{-}1 had highest number of spikelets per panicle. Potassium nutrition at 50 kg K ha^{-1} under saturation soil moisture levels indicated significant change in number of spikelets per panicle (Table 30). Increased potassium nutrition to 100 kg K ha^{-1} under soil moisture levels had insignificant increase in number of spikelets per panicle. Interaction between potassium nutrition at 50 kg K ha^{-1} and (40 kPa) drought condition could be the best combination, under moisture stress regimes. Current results conform to the results reported by Qumpah *et al.* (2011) on rice genotypes that potassium fertilization under lowland conditions significantly increased the spikelet count in Xieyou 9308 by improving water use efficiency. These results imply that potassium nutrition at 50 kg K ha^{-1} could be an optimum and economical level for studied rice varieties in increasing number of spikelets per panicle under saturation and drought conditions.

Table 30: Interaction between soil moisture levels and potassium levels on number of spikelets per panicle

Treatments	Potassium levels (kg K ha^{-1})			Mean	SE ±
Moisture levels (kPa)	(0) Control	50	100		
Control	105.8	189.4	196.7	164.0	8.92
20	113.0	142.0	155.3	136.8	
40	104.2	166.2	156.0	142.1	
Mean	107.7	165.9	169.3	147.6	
SE±	4.58				
$LSD_{0.05}$ (±) within table	14.1				

4.8 Partial Correlation Coefficients among Yield and Yield Components of Rice Varieties

4.8.1 Correlation between variables

Correlation is a statistical technique that shows whether and how strongly pairs of variables are related. Correlation coefficients between variables are helpful in understanding the behaviour of variables and are of value in selecting the desired variable for breeding programmes. Variables that were significant and negatively correlated were between plant height and percentage spikelets fertility; number of grains per panicle and number of unfilled grains per panicle; number of unfilled grains per panicle and percentage spikelets fertility per panicle; number of unfilled grains per panicle and grain yield per hectare; number of tillers per hill and grain yield per hectare.

Table 31: Partial correlations among vegetative and reproductive variables of lowland rice varieties on the study done at Sokoine University of Agriculture Morogoro during 2010/2011 cropping season

Variables	1	2	3	4	5	6	7	8	9	10
1. Plant height	1	0.191	0.261	-0.046	-0.089	-0.274	0.306*	-0.320*	0.216	0.123
2. Tiller number		1	0.040	0.082	0.118	0.018	0.168	-0.024	-0.299*	0.200
3. Shoot dry matter yield per hectare			1	0.010	0.014	-0.089	0.150	-0.118	0.152	0.102
4. Panicle length				1	0.562	0.082	-0.056	0.124	0.110	0.109
5. Spikelet number per panicle					1	0.746 ***	0.068	0.230	-0.006	0.305*
6. No. of grains per panicle						1	-0.614 ***	0.755***	0.477 ***	0.107
7. Unfilled grain per panicle							1	-0.858 ***	-0.721***	0.200
8. Spikelets fertility (%)								1	0.671***	0.038
9. Grain yield per hectare									1	-0.168
10. Unfilled grain per hectare										1

The negative correlations among components of yield are due to intra-plant competition for assimilates and that this is more manifested under more stressful conditions. Significant and positive correlations were observed between plant height and number of unfilled grains per panicle, number of spikelets and number of grains per panicle, number of spikelets per panicle and unfilled grains per hectare, number of grains per panicle and percentage spikelets fertility, number of grains per panicle and grains yield per hectare, percentage spikelets fertility and grain yield per hectare.

The results confirmed the use of percentage spikelets fertility per panicle and number of grains per panicle as indicators of high grain yield due to their positive correlations with yield. Aris *et al.* (2010) reported similar observations. This signifies that percentage spikelets fertility and number of grains per panicle are important components which contribute to the final grain yield. Therefore, the highly significant and positive correlations among percentage spikelets fertility, number of grains per panicle and grain yield per hectare indicated that improving of any one of these components will likely improve yield without compensation effects operating. These yield components could also be used as a selection criterion for breeding high yielding rice varieties. Plant height was significant ($P \leq 0.05$) and positively correlated with unfilled grain per panicle. The positive correlation between plant height and unfilled grains per panicle imply that improving stem elongation puts emphasis on vegetative growth at the expense of grain production. Increased height could be at the expense of grain filling from intraplant competition. The positive correlation between number of spikelets and number of grains per panicle imply that improving number of spikelets per panicle will increase number of grains per panicle, as spikelet formation is important prerequisite for grain formation.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study showed that soil moisture levels had effects on yield and yield components of the lowland rice varieties. On the basis of these results, the following conclusions were made:

i. To achieve high grains yield in lowland rice moisture level must be maintained at saturation throughout the reproductive period.

ii. Rice varieties with high grain yield should have high percentage spikelets fertility and number of grains per panicle. The study revealed that grain yield was significantly and positively correlated with grains per panicle and spikelets fertility percentage.

iii. Potassium nutrition should be supplied to rice varieties under lowland rainfed ecosystem for drought stress alleviation and improvement of yield and yield components.

5.2 Recommendations

The following recommendations should be given consideration in improving rice grain yield.

i. Saturation soil moisture level is recommended for high rice grain yield under lowland rice ecosystem.

ii. NERICA 4 and SARO varieties are recommended for lowland rice ecosystem due to their high yielding ability under saturation and stressed soil moisture level.

iii. Potassium nutrition at 50 kg K ha^{-1} should be supplied to rice varieties grown in soils with medium potassium content for drought stress alleviation and yield components enhancement.

Since these results were based on single season experiment, more detailed studies on the response of lowland rice varieties to moisture stress at different levels of potassium are recommended. Similarly, the studies should be repeated in other lowland rice growing parts of Tanzania in different seasons and more varieties should be included in the experiment.

REFFERENCE

Abdallah, A. A., Shimaa, A. B., Zayed, B. A. and El Gohary, A. A. (2010). *The Role of Root System Traits in the Drought Tolerance of Rice* (*Oryza sativa* L.). World academy of science, engineering and technology, Egypt. 1382pp.

Abdus, S. K., Imran, M. and Ashfaq, M. (2010). Estimation of genetic variability and correlation for grain yield component in rice (*Oryza sativa* L.). *American Eurasian Journal of Agricultural and Environmental Science* 6(5): 585 – 590.

Aris, H., Kustianto, B., Supartopo, K. and Suwarno, D. (2010). Correlation analysis of agronomic characters and grain yield of rice for tidal swamp areas. *Indonesian Journal of Agricultural Science* 11(1): 11 – 15.

Athar, H. and Ashraf, M. (2005). *Photosynthesis Under Drought Stress*. In: Hand book Photosynthesis. (Edited by Pessarakli, M.), CRC Press, New York, USA. 810pp.

Babu, R. C. (2010). Breeding for drought resistance in rice: an integrated view from physiology to genomics. *Journal of Plant Breeding* 1(4): 1133 – 1141.

Bahmanaiar, M. A. and Ranjbar, G.A. (2007**.** Response of rice cultivars to rates of nitrogen and potassium application in field and pot conditions. *Pakistan Journal of Biological Sciences* 10(9): 1430 – 1437.

Bakul, M. R. A., Akter, M. S., Islam, M. N., Chowdhury, M. M. A. A. and Amin, M. H. A. (2009).Water stress effect on morphological characters and yield attributes in some mutants T- Aman rice lines. *Bangladesh Research Publication Journal* 3(2): 934 – 944.

Balotf, S. and Kavoosi, G. (2011). Differential nitrate accumulation, nitrate reduction, nitrate reductase activity, protein production and carbohydrate biosynthesis in response to potassium and sodium nitrate. Biotechnology Institute, Shiraz University, Shiraz, Iran. *African Journal of Biotechnology* 10 (78): 17973 – 17980.

Balotf, S., Niazi, A ., Kavoosi, G. and Ramezani, A. (2012). Differential expression of nitrate reductase in response to potassium and sodium nitrate. *Australian Journal of Agricultural Science* 6: 130 – 134.

Baque, M. A., Karim, A. M., Hamid, A. and Tetsushi, H. (2006). Effects of fertilizer potassium on growth, yield and nutrient uptake of Wheat (*Triticum aestivum*) under water stress. *South Pacific Studies* 27(1): 25 – 35.

Baset Mia, M.A. and Shamsuddin, Z. H. (2011). Physio-morphological Appraisal of Aromatic Fine Rice (*Oryza sativa* L.) in Relation to yield potential. *International Journal of Botany* 7: 223 – 229.

Bationo, A., Kihara, J., Vanlauwe, B., Kimetu, J., Waswa, B. S. and Sahrawat, K.L. (2008). *Integrated Nutrient Management: Concepts and Experience from Sub-Saharan Africa. (*Edited by Aulakh, M.S. and Grant, C.A.), Integrated Nutrient Management for Sustainable Crop Production. New York, USA pp. 467 – 521.

Bhiah, K. M., Guppy, C., Lockwood, P. and Jesson, R. (2010). Effect of potassium on rice lodging under high nitrogen nutrition. *Environmental and Rural Science* 8: 1 – 2.

Bouman, B. A. M. and Toung, T. P. (2001). Field water management to save water and increase its productivity in irrigated lowland rice. *Agricultural Water Management* 49: 11 – 30.

Bray, R. H. and Kurtz, L. T. (1945). Determination of total, organic and available forms of phosphorus in soils. *Soil Science* 58: 39 – 45.

Bremner, J. M. and Mulvaney, C. S. (1982). Total nitrogen. In: *Method of Soil Analysis.* Edited by Page, L. A., Miller, R.H. and Keeney, D.R. American Society of Agronomy, Madison Wisconsin. pp. 595 – 624.

Buri, M. M., Nuhu, I. R. and Toshiyuki, W. (2008). Determining Optimum Rates of Mineral Fertilizers for Economic Rice Grain Yields under the “Sawah” System in Ghana. *West African Journal of Applied Ecology* 12: 1 – 12.

Cakmak, I. (2005). The role of potassium in alleviating detrimental effects of abiotic stresses in plants. *Journal of Plant Nutrition Soil Science* 168: 521 – 530.

Cakmak, I. (2007). Role of potassium in alleviating abiotic stress. *International Fertilizer Society* 611: 45 – 89.

Chapman, H. D. (1965). *Cation Exchange Capacity*. In: Methods of soil analysis (Edited by Black, C. A.). Agronomy No 9. American Society of Agronomy. Madison, Wisconsin. 901pp.

Cui, K., Peng, S., Ying, Y., Yu, S. and Xu, C. (2004). Molecular dissection of the relationships among tiller, number plant height and heading data in rice. *Plant Production Science* 7(3): 309 – 318.

Dobermann, A., Cassman, K. G., Mamaril, C. P. and Sheehy, J. E. (1998). Management of phosphorus, potassium and sulfur in intensive, irrigated lowland rice. *Field Crops Research* 56: 113 – 138.

Elliot, T. M. (2009). Potassium fertilization influence on rice growth, yield and stem rot index. Dissertation for Award of MSc Degree at University of Arkansas, Southeast Missouri State, 24pp.

Fageria, N. K. (2011). *Plant Tissue Test for Determination of Optimum Concentration and Uptake of Nitrogen at Different Growth Stages in Lowland Rice*. National Rice and Bean Research Center, Brazil. 270pp.

Fageria, N. K., Santos, A. B. and Cutrim V. A. (2008). Dry matter and yield of lowland rice genotypes as influenced by Nitrogen fertilization. *Journal of Plant Nutrition* 31: 788 – 795.

FAO (2006). Statistical. Yearbook [http://faostat.fao.org/yearbook]. site visited on 12/04/2009.

FAO (2009). Statistical yearbook. Country profiles-WEB edition, statistics division food and agriculture. [http://www.fao.org/statistics/yearbook] site visited on 08/04/2009.

Gomez, K. A. and Gomez, A. A. (1984). *Statistical Procedures for Agricultural Research*. Edited by John Willy and Sons, New York. 140pp.

Gowda, V. R. P., Henrya, A. O., Yamauchic, A., Shashidharb, H. E. and Serraj, R. (2011). Root biology and genetic improvement for drought avoidance in rice. *Field Crops Research* 122: 1 – 13.

Grist, D. H. (1986). *Rice*. (6th Edition.), Publisher Wiley, J. and Sons, Singapore. 599pp.

He, Q. I., Zhang, K. I., Xu, C., Xing, Y. (2010). Additive interactions make important contributions to spikelets per panicle in rice near isogenic (*Oryza sativa* L.) lines. *Journal of Genetics and Genomics* 37: 795 – 803.

Hill, J. E., Roberts, S. R., Brandon, D. M., Scardaci, S. C., Williams, J. F. and Mutters R. G. (1998). Rice production in California. [www.plantsciencesucdavis.edu/uccerice] site visited on 19/01/2012.

IRRI (1985). *A Report of an IRRI Mission on Rice Research and Production in Malawi and Tanzania.* IRRI, Manila, Philippines. 125pp.

IRRI (1985). *The Flowering Response of the Rice Plant to Photoperiod*. Los Baños, Laguna, Philippines. 66pp.

IRRI (1993). *Rice Almanac 1993 - 1995.* International Rice Research Institute, Los Banos, Philippines. 320pp.

IRRI (2007). Nutrient functions and deficiency symptoms. Philipine international rice research institute [www.Philirice.gov.ph] site visited on 02/03/2010.

IRRI (2010). Phil Rice bares new developments in rice research. [http://www.prc.gov.ph] site visited on 16/04/2011.

Islam, M. S. H., Bhuiya, M. S. U., Gomosta, A. R., Sarkar, A. R. and Hussain, M.M. (2009). Evaluation of growth and yield of selected hybrid and inbred rice varieties grown in net-house during transplanted aman season. *Bangladesh Journal of Agricultural Research* 34(1): 67 – 73.

Jia, Y., Yang, X., Feng, Y. and Jilani, G. (2008). Differential response of root morphology to potassium deficient stress among rice genotypes varying in potassium efficiency. *Zhejiang Univiversity. Journal of Biological Science* 9(5): 427 – 434.

Joseph, L. P. (1995). Soil sampling and sample preparation. International institute of tropical agriculture. *Research Guideline* 2: 1 – 11.

Kandil, A. A., Sultan, M. S., Badawi, M. A., Abd El-Rahman, A. A. and Zayed, B. A. (2010). Performance of rice cultivars as affected by irrigation and potassium fertilizer under saline soil conditions. Yield and yield components. *Crop and Environment* 1(1): 18 – 21.

Kant, S. and Kafkafi, U. (2002). *Potassium and Abiotic Stresses in Plants*. (Edited by Pasricha, N. S. and Bansal, S. K.), Role of potassium in nutrient management for sustainable crop production in India. Potash Research Institute, India. 251pp.

Kanyeka, Z. L., Msomba, S. W., Kihupi, A. N. and Penza, M. S. F. (1994). Rice ecosystems in Tanzania: characterization and classification. *Research Training, Newsletter* 9(2): 13 – 15.

Kim, H. E., Park, H. S. and Kim, K. J. (2009). Methyl jasmonate triggers loss of grain yield under drought stress. *Plant Signal Behavior* 4(4): 348 – 349.

Lindsay, W. L. and Norvell, W. A. (1978). Development of a DTPA soil test for zinc, iron, manganese, and copper. *Soil Science Society American Journal* 42: 421 – 428.

Luzi-Kihupi A., Zakayo J A , Tusekelege H , Mkuya, M., Kibanda, N. J. M., Khatib K. J. and Maerere A. (2009). *Mutation Breeding for Rice Improvement in Tanzania. (*Edited by Shu, Q.Y.), Food and Agriculture Organization of the United Nations, Rome, Italy. 387pp.

Luzi-Kihupi, A. and Zakayo, J. A. (2001). Performance of early maturing mutants derived from Supa rice (*Oryza sativa* L.) cultivar. *Journal of Agricultural Science* 4: 37 – 44.

Malvi, R.U. (2011). Interaction of micronutrients with major nutrients with special reference to potassium. *Journal of Agricultural Science* 24(1): 106 – 109.

Manneh, B., Kiepe, P., Sie, M., Ndjiondjop, M., Drame, N. K., Traore, K., Rodenburg, J., Somado, E. A., Narteh, L., Youm, O., Diagne, A. and Futakuchi, K. (2007). *Exploiting Partnerships in Research and Development to help African Rice Farmers cope with Climate Variability.* Africa Rice Center, Benin. 10pp.

Mayra, R., Canales, E., Carlos, J. B., Carmona, E., López, J. and Borrás, P. M. Hidalgo, O. (2005). Identification of genes induced upon water-deficit stress in a drought-tolerant rice cultivar. *Journal of Plant Physiology* 163(5): 577 – 584.

McLean, E. O. (1982). *Soil pH and Lime Requirement, American Society of Agronomy.* Branch of agriculture dealing with various physical and biological factors. In: Methods of Soil Analysis. 224pp.

Meertens, H. C. C., Ndege, L. J. and Lupeja, P. M. (1999). The cultivation of rainfed, lowland rice in Sukumaland, Tanzania. *Agriculture Ecosystems and Environment* 76: 31 – 45.

Mghase, J. J., Shiwachi, H., Nakasone, K. and Takahashi, H. (2010). Agronomic and socio-economic constraints to high yield of upland rice in Tanzania. *African Journal of Agricultural Research* 5(2): 150 – 158.

Mghogho, R. M. K. (1992). A review of rice production in Southern highland of Tanzania from 1980s to 1990s. In: *Proceeding of International Conference on Agricultural Research, Training and Technology Transfer in the Southern Highlands of Tanzania* (Edited by Ekpere, A. J. *et al.*), Mbeya, Tanzania. pp. 163 – 173.

Mostajeran, A. and Rahimi Eichi, V. (2009). Effects of drought stress on growth and yield of rice (Oryza sativa L.) cultivars and accumulation of proline and soluble sugars in sheath and blades of their different ages leaves. *American Eurasian Journal Agricultural and Environment Science* 5 (2): 264 – 272.

Mzee, O. M. (2001). Effectiveness of Minjingu Phosphate Rock as a source of phosphorus for lowland rice production in selected soils of Tanzania. Dissertation for Award of MSc Degree at Sokoine University of Agriculture, Morogoro, Tanzania, 120pp.

Naoki, M. and Tushihiro, M. (2009). Growth and yield of six rice cultivars under three water saving cultivations. *Plant Production Science* 12(4): 514 – 525.

Narciso, J. and Hossain, M. (2002). *World Rice Statistics, Total Carbon, Organic Carbon and Organic Matter.* Methods of soil analysis. (Edited by Page A. L.), International Rice Research Institute, American Society of Agronomy, Wisconsin. pp. 539 – 579.

Ndaeyo, N. U., Iboko, K. U., Harry1, G. I. and Edem, S. O. (2008). Growth and yield performances of some upland rice (*Oryza sativa* l.) cultivars as influenced by varied rates of NPK fertilizer on an Ultisol. *Journal of Tropical Agriculture, Food, Environment and Extension* 7: 249 – 255.

Nelson, D. W. and Sommers, L. E. (1982). *Total Carbon, Organic Carbon and Organic.* In: Methods of soil analysis. (Edited by Page, A. L.), Chemical and Microbiological Properties, Wisconsin. 579pp.

Ngailo, J. A., Abiud, L. K. and Catherine, J. S. (2007). *Rice Production in the Maswa District, Tanzania and its Contribution to Poverty Alleviation.* Research on Poverty Alleviation, Shinyanga, Tanzania. 63pp.

NSS (1990). *Laboratory Procedures for Routine Analysis*. (3rd Edition.), Agricultural Research Institute, Mlingano, Tanga, Tanzania. 212pp.

Nwanze, F. K., Justin, K. P. and Jones, M. P. (2001). *South-South Cooperation on Food Security Rice*. West Africa. 331pp.

Oikeh, S. O., Nwilene, F., Diatta, S., Osiname, O., Touré, A. and Okeleye, K. A. (2008). Responses of upland NERICA rice to nitrogen and phosphorus in forest agroecosystems. *Agronomy Journal* 100(3): 735 – 741.

Prajapati, K. and Modi, H. A. (2012). The importance of potassium in plant growth. *Indian Journal of Plant Science* 1(3): 177 – 186.

Price, A. H., Jill, E. G., Horton, P., Jones, H. G. and Grifiths, H. G. (2001). Linking drought resistance Mechanisms to drought avoidance in upland rice using QTL approach. Progress and new opportunities to integrate stomatal and mesophyll responses. *Journal of Experimental Botany* 53(371): 989 – 1004.

Quampah, A., Wang, R. M., Shamsi, I. H., Jilani, G., Zhang, Q., Hua, S. and Xu, H. (2011). Improving water productivity by potassium application in various rice genotypes. *International Journal of Agricultural Biology* 13: 9 – 17.

Rachelle, M. W. (2007). Potential impact of temperature and carbon dioxide levels on rice quality. Thesis for Award of PhD Degree at Seydney University, 106pp.

Rahman, M. T., Islam, M.T. and Islam, M. O. (2002). Effect of water stress at different growth stages on yield and yield contributing characters of transplanted Aman rice. *Pakistan Journal of Biological Science* 5(2): 169 – 172.

Rockstrom, J., Hatibu, N., Oweis, T. Y., Wani, S.,Barron, J., Bruggeman, A., Farahani, J., Karlberg, L., Qiang, Z. (2007). Managing water in rainfed agriculture. In Molden, D. (Ed.). *Water for Food, Water for Life:* A Comprehensive Assessment of Water Management in Agriculture, London, UK. 352.

Sarvestaini, Z. T., Hemmatellah, P., Seyed, A. M. M. S. and Hamidreza, B. (2008). Study of water stress effects in different growth stages on yield and yield components of different rice (*Oryza sativa* L.) caltivars. *Pakistan Journal of Biological Science Iran* 11(10):1303 – 1309.

Savage, S. (1979). *Undergraduate Laboratory Manual.* Introduction to soil science. McGill University, Montreal. 133pp.

Selvaraj, K. I., Pothiraj, N., Thiyagarajan, K. and Bharathi, M. (2011). Genetic parameters of variability, correlation and path coefficient studies for grain yield and other yield attributes among rice blast disease resistant genotypes. *African Journal of Biotechnology* 10(17): 3322 – 3334.

Shahidullah, S. M., Hanafi, M. M., Ashrafuzzaman, M., Razi Ismail, M., Salam, M.A. and Khair, A. (2010). Biomass accumulation and energy conversion efficiency. *Aromatic Rice Genotypes* 333(1): 61 – 67.

Shayo, N. B., Mamiro, P., Nyaruhucha, C. N. M. and Mamboleo, T. (2006). Physico-chemical and and grain cooking characteristics of selected rice cultivars grown in Morogoro, Tanzania. *Journal of Science* 32(2): 30 – 33.

Sikuku, P. A., Netondo, G. W., Onyango, J. C. and Musyimi, D. M. (2010). Effects of water deficit on physiology and morphology of three varieties of NERICA rainfed rice (*Oryza sativa* L.). *Journal of Agricultural and Biological Science* 5(1): 23 – 28.

Tanguilig, V. C. and De Datta, S. K. (1988). International research institute, Los Banos, Laguna. *Philippines Journal of Crop Science* 13: 33.

Umar, S. (2006). Alleviating adverse effects of water stress on yield of sorghum, mustard and groundnut by potassium application. New Delhi, India. *Pakistan Journal of Botany* 38(5): 1373 – 1380**.**

Umar, S. and Moinuddin, (2002). Genotypic differences in yield and quality of groundnut as affected by potassium nutrition under erratic rainfall conditions. *Journal of Plant Nutrition* 25: 1549 – 1562.

Vaghefi, N., Nasir, S. M., Makmom, A. and Bagheri, M. (2011). The economic impact of climate change on rice production in Malaysia. *International Journal of Agricultural Research* 6(1): 67 – 71.

Waraich, E. A., Rashid, A., Yeseen, A., Saifullah, M. and Mohamed, A. (2011). Improving agricultural water use efficiency by nutrient management in crop plants. *Soil and Plant Science* 61: 291 – 304.

WARDA (2008). *NERICA, the New Rice for Africa.* A Compendium. (Edited by Somado, E. A., Guei, R. G. and Keya, S. O.), Africa Rice Center WARDA. Africa Association, Sasakawa Tokyo, Japan. 210pp.

Watanabe, F. S. and Olsen, S. R. (1965). Test of an ascorbic acid method for determining phosphorus in Central Illinois. *Geological Survey Guidebook* 13: 129 – 134.

Wopereis, M. C. S., Kropff, M. J., Maligaya, A. R. and Tuong, T. P. (1996). Drought-stress responses of two lowland rice cultivars to soil water status. *Field Crops Research* 46: 21 – 39.

Xueyong, L., Qian, Q., Zhiming, F., Yonghong, W., Guosheng, X., Dali, Z., Xiaoqun, W., Xinfang, L., Sheng, T., Fujimoto, H., Ming, Y., Da, L., Bin, H. and Jiayang, L. (2003). Control of tillering in rice. *Chinese Academy of Sciences* 422: 617 – 621.

Yan-bo, J. X. Y., Ying, F. and Ghulam, J. (2008). *Differential Response of Root Morphology to Potassium Deficient Stress Among Rice Genotypes Varying in Potassium Efficiency.* Zhejiang University, Hangzhou, China. 7pp.

Yang, J. and Zhang, J. (2006). Grain filling of cereals under soil drying. *New Phytologistic* 169(2): 223 – 236.

Zayed, B. A., Elkhoby, W. M., Shehata, S. M. and Ammar, M. H. (2007). Role of potassium application on the productivity of some inbred and hybrid rice varieties under newly reclaimed saline soils. *African Crop Science* 8: 53 – 60.

Zheng, B., De-an, J., Ping W., Xiao-yan, W., Qing, L. and Ni-yan, W. (2006). Relation of root growth of rice seedling with nutrition and water use efficiency under different water supply conditions. *Rice Science* 13(4): 291 – 298.

Zubaer, M. A., Chowdhury, A. K. M. M. B., Islam, M. Z. Ahmed, T. and. Hasan, M. A. (2007). Effects of water stress on growth and yield attributes of Aman rice genotypes. *International Journal of Sustainable Crop Production* 2(6): 25 – 30.

Zulkarnain, W. M., Ismail, M. R., Ashrafuzzaman, M., Saud, H. M. and Haroun, I. C. (2009). Rice growth and yield under rain shelter house as influenced by different water regimes. *International Journal of Agriculture and* Biology 11(5): 566 – 570.

APPENDICES

POT EXPERIMENT

Appendix 1: Temperature Data (Screen House)

Temperature

Date 1	^{0}C	Date 2	^{0}C	Date 3	^{0}C	Date 4	^{0}C	Date 5	^{0}C	Date 6	^{0}C	Date 7	^{0}C	Date 8	^{0}C	Date 9	^{0}C	Date 10	^{0}C
28/01	0	4-Feb	36	11-Feb	43	18-Feb	37	25-Feb	33	4-Mar	30	11-Mar		18-Mar	38	25-Mar	26	1-Apr	32
29/01		5-Jan	45	12-Feb	34	19-Feb	36	26-Feb	34	5-Mar	32	12-Mar	36.50	19-Mar	31	26-Mar	43	2-Apr	27
30/01		6-Feb	45	13-Feb	32	20-Feb	26	27-Feb	31	6-Mar	31	13-Mar	23.50	20-Mar	32	27-Mar	42	3-Apr	31
31/01		7-Feb	33	14-Feb	33	21-Feb	28	28-Feb	33	7-Mar	33	14-Mar	35.00	21-Mar	32	28-Mar	30	4-Apr	35
1/2/2011		8-Feb	36	15-Feb	35	22-Feb	36	1-Mar	30	8-Mar	32	15-Mar	40.00	22-Mar	33	29-Mar	42	5-Apr	37
2/2/2011		9-Feb	35	16-Feb	38	23-Feb	34	2-Mar	33	9-Mar	34	16-Mar	35.00	23-Mar	33	30-Mar	26	6-Apr	32
3/2/2011	0	10Feb	39	17-Feb	**35**	24-Feb	30	3-Mar	33	10-Mar	31	17-Mar	43.00	24-Mar	**43**	31-Mar	29	7-Apr	34

Appendix 2: ANOVA Table for mean squares on yield and yield components for study done in the screen house at Sokoine University of Agriculture Morogoro November 2010 to May 2011

			MEAN	SUM	SQUARE		
S.V	Df	Plant height	Tiller number	Shoot dry matter	Panicle length	Grain yield Pot^{-1}	Unfilled grain pot^{-1}
Replication	2	21.0	0.9	5.8	0.6	4.6	0.04
Moisture level	2	1602.6 ***	3.3 ns	17.9 ns	19.9***	290.8 ***	2.68 **
Variety	2	20260.4***	407.5 ***	1604.5 ***	0.8 ns	673.1 ***	18.49 ***
Moisture *Variety	4	65.4 ns	4.6 ns	26.0 ns	2.5 **	85.6 ***	1.30 *
Klevel	2	148.6 **	10.4 *	10.9 ns	23.9 ***	26.8 ns	0.85 ns
Moisture*Klevel	8	444.6 ***	7.7 **	22.8 ns	13.2 ***	33.1 ns	0.96 ns
Variety*Klevel	6	6777.6 ***	136.0 ***	540.1 ***	0.3 ns	232.9 ***	6.31***
Moisture*Variety*Klevel	12	30.9 ns	4.7 *	16.3 ns	0.9 **	40.7 *	0.54 ns
Error	68	68	68	68	68	68	68
Total	106						

Appendix 2: cont……..

S.V	Df	MEAN Root dry matter pot^{-1}	SUM Straw dry matter pot^{-1}	Total dry matter pot^{-1}
Replication	2	14.7	36.8	17.7
Moisture level	2	42.8 *	440.2 ***	1702.4***
Variety	2	4105.5 ***	12605.8 ***	24602.8 ***
Moisture *Variety	4	64.4 ***	247.2 ***	264.7 **
Klevel	2	119.3 ***	20.3 ns	72.3 ns
Moisture*Klevel	8	46.9**	17.2 ns	481.3 ***
Variety*Klevel	6	1378.3 ***	4214.6 ***	8256.1***
Moisture*Variety*Klevel	12	25.7 *	89.5***	103.2 ns
Error	68	68	68	68
Total	106			

Appendix 3: Rainfall Data (field experiment)

RAINFALL DATA (mm)

Oct.	TOTAL
4.2	

Appendix 4: ANOVA Table for mean squares for various vegetative and reproductive variables on study done in the field (Crop museum) at Sokoine University of Agriculture Morogoro November 2010 to May 2011

S.V	Df	Plant height	Tiller number	Shoot dry matter	Shoot dry matter per hactre	Panicle length	Spikelet per panicle	Grain per panicle	Unfilled grain per panicle	Spikelets Fertility (%)	*Unfilled grain per hactre*	**Yield (ton/ha)**
Replication	2	268.6	26.3	437.4	3.1	0.1	1987.1	4297.0	512.5	885.4	0.015	3.8
Moisture level	2	4.1 ns	19.5 ns	343.1 ns	2.4 ns	6.7*	5596.9 ***	11424.5 ***	1096.9 ns	2439.6 **	0.007 ns	17.4 ***
Variety	2	17171.7 ***	3261.8***	5582.3***	39.7***	4.1 ns	8426.9 ***	13913.0***	1330.9 ns	2009.4**	0.022*	65.4 ***
Moisture *Variety	4	115.6 ns	20.3 ns	342.3 ns	2.4 ns	3.0 ns	2184.4 **	3053.8 *	444.3 ns	1324.0**	0.001 ns	1.1 ns
Klevel	2	169.6 ns	20.1 ns	113.8ns	0.8 ns	19.1 ***	32420.1***	38269.5 ***	291.8 ns	1146.7 *	0.004 ns	0.9 ns
Moisture*Klevel	4	108.6 ns	5.5 ns	155.6 ns	1.1 ns	2.6 ns	2355.0**	2116.9 ns	496.6 ns	463.8ns	0.005 ns	0.8 ns
Variety *Klevel	4	76.9 ns	8.5 ns	416.2 ns	3.0 ns	2.8 ns	739.4 ns	1539.0 ns	594.8 ns	318.9 ns	0.005 ns	0.3 ns
Moisture*Variety*Klevel	12	1396.1 ***	261.1 ***	629.9 ***	4.5 ***	4.2**	4462.1 ***	6161.7 ***	551.0 ns	814.2 **	0.004 ns	6.9 ***
Error	46	60.1	10.5	196.7	1.4	1.7	662.0	1056.9	471.3	358.3	0.006	1.0
Total	80											

Appendix 5: ANOVA table for mean square for Nitrogen and Potassium nutrients concentration in plant tissues.

Source of Variation	**Degree of freedom**	**%Nitrogen**	**%Potassium**
Replication	2	0.192	0.161
Moisture levels	2	0.016 ns	0.032 ns
Lowland rice varieties	2	1.358***	0.307 *
Soil moisture levels*Varieties	4	0.026 ns	0.146 ns
Potassium levels	2	0.098 **	0.412*
Lowland rice varieties*Potassium levels	4	0.006 ns	0.186 ns
Moisture levels *Potassium	4	0.071**	0.057 ns
Soil moisture levels*Lowland rice varieties* Potassium levels	12	0.044*	0.073 ns
Error	48	0.019	0.103

Appendix 6: Calculation of amount of water required to moisten soil to field capacity by savage method (1979)

- Bulky Density of the soil sample (disturbed soils)

$$\text{BD} = \frac{\text{Weight of the soil (W1)}}{\text{Volume of the soil (100 cm}^3\text{)}}$$

- The amount of water required to moisten the soil with volume of 100cm^3 (V2).

$$\text{V2 cm}^3 = \frac{\text{100 cm}^3\text{ of soils x15cm}^3\text{of water}}{\text{V1 cm}^3}$$

- The amount of water required to moisten 1000 g(1kg) ………(.V3)

$$\text{V3 Cm} = \frac{\text{1000 g x V2 cm}^3}{\text{W1 g}}$$

- Volume of 1 kg (1000g) of soil is labeled Vs.

$$\text{Where Vs} = \frac{\text{Weight of Soil (g)}}{\text{Bulky Density of Soil}}$$

Therefore percentage of water required to moisten the soil of 1 kg (1000g) to Field Capacity is calculated as follows.

$$\text{\% of water at the Field Capacity} = \frac{\text{V3}}{\text{Vs}} \text{ x 100}$$

If volume of 1 kg (1000g) of soil "Vs" is already known then calculate the volume of 4 kg of soil (1 pot). % water required to moisten 4 kg of soil will be equal to the volume of 4 kg of soil x percentage water required to moisten 1 kg of soils to field capacity.

The amount of water to apply in a pot of 4 kg will be 90 % of obtained water at field capacity.

Appendix 7: Conversion of total produce to required storage % moisture content

$$\text{Weight of sample } \frac{(100 - \text{MC\%})}{100} \times \frac{(100 + \text{MC storage})}{100} = \text{Y g} 1.6\ \text{m}^{-2}$$

$$\text{If, } 1.6\ \text{m}^2 = \text{Yg}$$

$$10{,}000\text{m}^2 = \text{x}$$

$$\text{X} = \frac{10{,}000\text{m}^2\ \text{Yg}}{1.6\text{m}^2}$$

$$\text{X} = \frac{10{,}000\text{m}^2\ \text{Yg}}{1.6\text{m}^2 \times 1000} = \text{X kg ha}^{-1}$$