PERFOMANCE OF NEW RELEASED UPLAND NERICA RICE VARIETIES UNDER DIFFERENT COMBINED RATES OF NITROGEN AND PHOSPHORUS FERTILIZERS IN ZANZIBAR

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CROP SCIENCE OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

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ABSTRACT

Rice, (*Oryza sativa*) accounts for more than 50% of the staples consumed in Zanzibar. However, only 20% of the annual demand is produced whereas the remaining 80% being imported. Adoption of improved varieties and better soil management practices may increase rice productivity. An experiment was conducted at Mchangamdogo village, Wete district, during the 2012 rice-growing season to test newly released high fertilizer responsive NERICA varieties and different fertilizers rates that can maximize yield. A Randomised Complete Block Design in a factorial arrangement was used to test the varieties and the fertilizer rates in three replications. NERICA 1, 10 and 12 released by Kizimbani Research Institute and Machuwa local variety were used. Urea (46%N) at 0, 40, 80 and 120 kg N ha^{-1} and TSP (46%P_2O_5) at 0, 30 and 50 kg P ha^{-1} were used as Nitrogen and Phosphorus sources respectively. Growth and yield parameters measured were plant height, panicles per square metre, 50% heading, 80% maturity, biomass, harvest index, panicle length, spikelets per panicle, filled grains per panicle, 1000-grain weight and grain yield. Statistical analysis showed NERICA to be significantly ($P \leq 0.001$) superior to Machuwa local variety in all parameters except for plant height. Significant differences were observed among different nitrogen-phosphorus fertility levels. Application of 40 kg N + 30 kg P and 80 kg N + 50 kg P ha^{-1} was the best for grain yield, 1000-grain weight, panicle length and grains per panicle for NERICA varieties. Interaction effects were highly significant ($P \leq 0.001$) at NERICA 12 x 40 kg N + 30 kg P and 80 kg N + 50 kg P ha^{-1}. Therefore, NERICA 12 and 10 can substitute Machuwa local, similarly combination of 40 kg N + 30 kg P ha^{-1} or 80 kg N + 50 kg P ha^{-1} was recommended for NERICA varieties in Zanzibar.

DECLARATION

I, **KHATIB BAKAR HAJI**, 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.

____________________ ___________________

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The above declaration is confirmed by;

________________________ ___________________

Prof. D. G. Msuya. Date

(Supervisor)

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LIST OF ABBREVIATIONS AND SYMBOLS

%	Percentage
<	Less than
ANOVA	Analysis of variance
BC2F1	Back cross 2 Ferial generation 1
BoT	Bank of Tanzania
CEC	Cation Exchange Capacity
Cmol(+)/kg	Centimol (+) per Kilogramme
CV	Coefficient of Variation
DAE	Department of Agriculture and Extension
DAP	Di ammonium phosphate
DAS	Days after sowing
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistics
G.M	Grand Mean
HYV	High yielding variety
JICA	Japan International Co-operation Agency
K	Potasium
LSD	Least Significant Different
MALNR	Ministry of Agriculture, Livestock and Natural Resource
MRP	Muriate Rock Phosphate
N	Nitrogen
NARS	National Agriculture Research System
NASS	National Agriculture Statistics Services
NERICA	New Rice for Africa
NFRA	National Food Reserve Agency

NPF	New plant type
NPK	Nitrogen, Phosphorus and Potasium
NSS	National Soil Survey
O.C	Organic carbon
O.M	Organic Matter
P	Phosphorus
ph	Hydrogen ion concentration
PN	Phosphorus Nitrogen
SSA	Sub-Sahara Africa
SUA	Sokoine University of Agriculture
TDM	Total Dry Matter
TSP	Triple Supper Phosphate
USD	United State Dollar
WARDA	West Africa Rice Development Agency
ZFBS	Zanzibar Food Balance Sheet

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Rice is the seed of the monocot plant *Oryza sativa*, of the grass family. As a cereal grain, it is the most important staple food for a large part of the world especially in tropical Latin America, the West Indies, South Louisiana, East, South and Southeast Asia (FAOSTAT, 2005). Rice ranks second to wheat among the most extensively cultivated cereals in the world (Abodolereza and Racionzer, 2009). In 2009, world rice production was about 680 million tons with a projected record harvest of 710 million tons in 2010 (FAO, 2010), alongside an increase in consumption of about 8 million tons.

In Africa, rice is grown in over 75% of the countries, with a total population close to 800 million people (Sohl, 2005). In the years 2001 – 2005, rice production in Africa expanded at a rate of 6% per annum, with only 30% being attributed to increase in productivity (Fagade, 2008; Africanrice, 2007). Africa cultivated about 9 million hectares of rice in 2006.

In Tanzania rice is the second mostly widely cultivated cereal food crop after maize. The crop is grown in three agro – ecosystems namely rain fed lowland (74%), rain fed upland (20%) and irrigated lowland (6%) (Kanyeka, 1994). Drastic shift of consumers preference in both urban and rural areas from conventional foods to rice coupled with rapid urbanization has resulted into a simultaneous increase in annual per capita consumption of rice in Tanzania of about 25 – 30 kg/year (Kibanda, 2008). This change in consumption habits has led to a growing gap between demand and production of rice which has to be filled by imports. In its effort to increase rice productivity the Rice Research Program in

Tanzania has engaged in the New Rice for Africa (NERICA) research program since 2002. The NERICA paddy varieties which are inter specific hybrids between the local African rice, *Oryza glaberrima* Steud) and the exotic Asian rice (*Oryza sativa. L*) incorporates both the high yielding ability of *Oryza sativa* and resistance of *Oryza glaberrima* to major constrains such as diseases, drought, and low soil fertility (Dzomeku *et al.,* 2007; Kijima *et al.,* 2006). These attributes make them have yield advantage over their *Oryza glaberrima* and *Oryza sativa* parents through superior weed competitiveness, drought tolerance and pest or disease resistance (WARDA, 2004).

Rice is the main staple food in Zanzibar and accounts for more than 50% of staples consumed (ZFBS, 2007). It is estimated that annual consumption per capital is 120 kg, and total annual rice requirement is estimated at 120 000 tons out of which 80% is imported (Mnembuka *et al.,* 2010). Essentially, most rice is cultivated on lowlands under rainfed conditions. In Unguja Island, rice is grown on large plains whereas in Pemba production is mainly in narrow flooded valleys and some on plains (Mnembuka *et al.,* 2010). Literature indicates that about 14180 hectares equivalent to 10.8% of total agricultural land in Zanzibar has been devoted to paddy production out of which 96% is under rainfed system (Mnembuka *et al.,* 2010). Rice farming was long introduced in Zanzibar from South East Asia more than 2000 years ago by Arab traders (Ylievonnen, 1983). Since the introduction of rice in Zanzibar, farmers selected traditional rice varieties which seem to fit Zanzibar conditions. The varieties have long duration of 4 to 6 months, and the common traditionally produced cultivars are Supa, Ringa, Machuwa, Kidunari, Kibawa, Kijicho, Sindano, Majulufa, Kibeuwatwana, Uchuki, Makaniki etc (Ylievonnen, 1983). The study conducted by BoT Department of Economics in 2011 showed that average rice yields increased from 1.5 ton/ha in 2006/07 to 2.3 ton/ha in 2009/10. It was revealed that NERICA, the newly introduced varieties, registered highest yield since its trial in 2008/09. NERICA has recorded yield of about 4.4 ton/ha in 2008/09 and 3.7 ton/ha in 2009/10 (BoT, 2011 unpublished report).

1.2 Problem Statement

In recent years rice consumption in Zanzibar has increased due to increased population and change in food consumption habit from traditional foods. While production of rice has not proportionally increased, this situation leads to increasing rice demand. This necessitates importation of rice from Asian countries to fill the demand gap. Therefore, in order to narrow difference between importation and production, NERICA (New Rice for Africa) varieties, supposedly better yielding, have been introduced to Zanzibar and were tested for the first time by Kizimbani Agricultural Research Station in 2007 and released to farmers in 2009 (Mnembuka *et al.,* 2010). The progeny was developed by West Africa Rice Development Association (WARDA), combining traits from the hardy African rice resistant to pests, weeds and problematic soils with high yielding, good response to mineral fertilization and non shattering characteristics of the Asian rice (Dzomek *et al.,* 2007; Kijima *et al.,* 2006; WARDA, 2001a).

Despite their potentiality, however, NERICA varieties have not been intensively evaluated especially in Zanzibar for adaptability and yield. Genetically, different NERICA varieties may perform differently under Zanzibar conditions. Agricultural production inputs like fertilizers are important determinants of yield, but information on specific fertilizer requirement and recommendations especially nitrogen and phosphorus for NERICA are not known. For these reasons judgment may not be made whether the existing traditional rice varieties cultivated in Zanzibar are more prominent compared to newly introduced NERICA varieties, as well as their production inputs recommendations in terms of fertilizer rates.

1.3 Justification

NERICA varieties are reported to have high yield potential and short growth cycle, and they respond better than traditional varieties to high inputs (Africa Rice, 2008). Experience has shown that potential yield of rainfed upland NERICA depends on various factors, including but not limited to variety, the fertility status of the soil, the rainfall and the management practices of farmers. Average grain yield of 5.2 ton ha^{-1} was recorded in Kenya with NERICA 1 (JICA, 2006). Also, 4.5 ton ha^{-1} in Tanzania with NERICA 2 by applying chemical fertilizer in varying quantity across sites but mostly a basal application of 50 kg ha^{-1} NPK (15:15:15) with 30 kg ha^{-1} N as Urea topdressing (JICA, 2006). In Zanzibar rice production through existing upland varieties yield is 1.2 tons ha^{-1} with blanket recommendation of 40 kg P ha^{-1} and 80 kg N ha^{-1}(MALNR, 2009). This low productivity of rice in Zanzibar justifies the introduction of New Rice for Africa (NERICA) varieties for increasing production per hectare (MALNR, 2009). However, their optimum growth and yield productivity cannot be achieved without assuring appropriate levels of soil nutrients particularly nitrogen and phosphorus, which the proposed study tries to resolve. The data accrued from this study may be used by the Ministry of Agriculture - Zanzibar to specify fertilizer recommendation specifically for NERICA varieties, for increasing rice productivity. This will enable dissemination of a technological package of better performing varieties and fertilizer recommendation to farmers if worthy, through extension agents.

1.4 Objectives

1.4.1 Main objective

To increase rice productivity in Zanzibar through improved varieties and proper soil fertility management.

1.4.2 Specific objectives

i. To determine the soil fertility status at the experiment area.

ii. To find the best performing entry among tested varieties.

iii. To determine the best combination of nitrogen and phosphorus fertilizer rates for maximum grain yield.

iv. To establish the highest interactive effects caused by nitrogen-phosphorus combination and rice varieties.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and Distribution of Rice

Rice (*Oryza sativa* (*L*) is a monocot plant of the genus *Oryzeae*. The genus *Oryzeae* belongs to the species *Oryzeae* of *Poaceae* family. There are 12 genera within the genus *Oryzeae* (Vuaghan, 1994). The genus *Oryzeae* contains approximately 22 species of which 20 are wild species and two (*Oryza sativa* and *Oryza glaberrima*) are cultivated (Vuaghan, 1994). There is some confusion in the literature concerning the current nomenclature of the species most closely related to *Oryza sativa* as they often lack clear distinguishing morphological characteristics (Vuaghan and Morishima, 2003). Recently Vuaghan, 2003) proposed a new nomenclature for cultivated and wild rice in Asia.

Oryza sativa is the most widely grown of the two cultivated species. It is grown worldwide, including in Asia, North and South America, Europe, Middle East and Africa. *Oryza glaberrima* (L), is grown solely in West African countries. *Oryza sativa* and *Glaberrima-sativa* hybrids are replacing *Oryza glaberrima* in many parts of Africa due to higher yield (Linares, 2002). Four *Oryza spiciess* have been reported to grow naturally in Australia. These are *Oryza australiensis, O. mesidonalis, O. officinalis* and *O. rufipogon* (OECD, 1999; LU and Jackson, 2004).

2.2 Importance of Rice and the Development of NERICA Varieties

Rice is a main source of nourishment for over half the world's population (Abodolereza and Racionzer, 2009). In Sub-Sahara Africa (SSA), rice is becoming the most rapidly growing food source for millions of people; and it is an important crop for attaining food security in a number of low-income, food deficit African countries. About 100 million people depend on it for their livelihood (Nwanze *et al.,* 2006). The demand for rice far outstrips the production which in the last 30 years in SSA has increased by 70% due to land expansion and only 30% due to increase in productivity (Fagade, 2000). Its annual production worldwide is approximately 535 million tons. China and India accounting for 50% of total production (Sohl *et al.,* 2005).

In Africa, rice is grown in over 75% of the African countries, with a total population close to 800 million people (Sohl *et al.,* 2005). Although majority of rice varieties cultivated in the continent today belong to *O. sativa* with China as its origin over 10 000 years ago. African continent is the home of *Oryza glaberrima* where it has been domesticated for about 3500 years (Vuaghan, 1994). This species has mainly been confined to West Africa where it had been the most commonly grown rice. The white Asian type, *O. sativa*, was introduced in the continent towards the end of the first millennium via Madagascar (WARDA, 2004). Rice has long been the food staple in many traditional rice growing communities and in major cities in Africa. It is now the fastest-growing food staple in Africa (FAO, 2009). For Africa as whole, annual per capita rice consumption increased from 11 kilograms in the 1970s to 21 kilograms in 2009 (FAO, 2009). In Tanzania, rice is the second widely cultivated cereal after maize, and is consumed by about 60% of the population (IRRI, 1993; Kibanda, 2008). Tanzania is the second largest producer of rice in Eastern, Central, and Southern Africa after Madagascar (Kibanda, 2008). Since the early 1970s, rice has been the number one source of caloric intake in West Africa and the third most important source of calories (after maize and cassava) for the continent as a whole (FAO, 2009).

Domestic rice production grew at the rate of 6 percent a year between 2001 and 2005 but production still falls far short of demand. As a result, Africa imports up to 40 percent of its rice consumption (FAO, 2009). The continent as a whole imports 30 percent of world rice imports, a potentially very risky and unsustainable situation, as shown during the food crisis in 2008 (FAO, 2009).

Rice imports cost Africa almost $4 billion in 2009 (Seck *et al.,* 2010), money that could have been invested in developing the domestic rice sector. Until the early 1990s, rice breeding programs in Africa worked almost exclusively on improving *O. sativa* lines for Africa's diverse rice growth environments.

Some breeders even voted to accelerate the disappearance of *glaberrima* (IRAT, 1967), even though *sativa* varieties are generally much more vulnerable than *glaberrima* to the numerous biotic stresses (rice diseases, insect attacks, weeds etc) and abiotic stresses (soil acidity, drought, salinity, iron toxicity etc) of the African environment.

2.3 Rice Ecology

2.3.1 General

Oryza sativa was first cultivated in South-east Asia, India and China between 8000 and 15 000 year ago (OECD, 1999; Normile, 2004). *Oryza glaberrima* has been cultivated since approximately 1000 BC (Ahn *et al.,* 1992; Murray, 2005). Current cultivation for *Oryza sativa* is worldwide extending from latitude 35°S (New South Wales and Argentina) to 50°N (North China) over 110 countries (Abodolereza and Racionzer, 2009). Rice is grown from sea level to 3000 m and in both temperate and tropical climate. A variety of water regimes are used including submerged upland rice (10% of total cultivation), moderately submerged lowland rice (irrigated 45% or rain fed, 30%) and submerged rice (up to six meter of water, 11% or floating, 4%) (Abodolereza and Racionzer, 2009). Rice can grow in a wide range of soil types as well, including saline, alkaline and acid sulfur soils

(Takawash, 1946; Ahn *et al.,* 1992; OECD, 1999). The chemical properties of the soils do not appear to be as important as the physical ability of the soil to hold flood water (Scott *et al*., 2003).

2.3.2 Rice and soils

Rice is cultivated in a wide range of soils from sandy loam to heavy clay soils. It is well recognized, however, that heavy soil with characteristics of river valley are more preferable than lighter soils. A best soil for rice should have fine fractions of silt and clay, while a difference in yield from one place to another is due to greater variation in soil condition and extension of rice cultivation to unsuitable soils. The optimum soil pH is 5.5 to 6.5 when it is dry and may rise to 7.0 - 7.2 under flooded conditions (Oikeh *et al*., 2008).

2.3.2.1 Soil texture

Texture may be the most important property of rice soils. It affects the moisture status of a soil more than any other property except topography. Texture is particularly important in upland rice fields, which have no bunds to hold moisture. The textural profile includes not only the surface layers but also the layers below. If the sub-soil has sufficient clay content, the importance of the surface soil texture diminishes. In a clayey profile, a surface horizon that is of medium texture may be the most favourable rice soil, possibly because of greater pore space (Grant, 1960).

A surface soil of medium texture can also be easily worked, less water is necessary for initial rice growth because less water is lost through cracks than from a soil with a clayey surface. A study by Shekifu, 1991) in some rice growing regions of Tanzania revealed that the texture of the rice soil ranged from sandy to loam to clay. In general optimum rice production require soils of medium to heavy texture although in practice rice production is carried out in soils ranging from sandy loam to heavy clays (Landon, 1991).

2.3.2.2 Soil pH

Soil pH has profound effect on nutrient availability and hence soil fertility. It influences the rate of plant nutrient release by weathering, the solubility of all material in soil and amount of nutrient ions on the cations exchange site. Oikeh *et al.* (2008) found that the pH range for most agricultural crops is 5.5 – 7.5 and for rice is 6.5 – 7.5.

2.3.1.3 Total nitrogen

The nitrogen regime in aerobic (unflooded) soils is quite different from that in submerged (flooded) soils. Organic nitrogen mineralizes faster in aerobic soils but no nitrogen is released unless the soils have much less nitrogen and yet mineralization occurs. Thus, less total nitrogen is mineralized in aerobic than in anaerobic soils (Borthakur and Mazumder, 1968). This leads to low total nitrogen in upland rice soil

2.3.1.4 Available phosphorus

Phosphorous is an essential element for plant growth, hence an important soil fertility indicator. Based on current soil fertility recommendation a critical P concentration of 7 mg P kg^{-1} is used to separate P deficient soils (NSS, 1990). Phosphorus deficiency is widespread in rainfed rice soils and is particularly prominent in drought-prone environments because its mobility decreases sharply as soil dries.

2.3.1.5 Soil organic matter

The importance of organic matter as described by Tisdale *et al.* (1993), influence physical and chemical soil properties that favourably influence nutrient availability. It acts as conditioner by improving soil structure, moisture content and ion retention, besides being an important source of some nutrient elements. It may as well have negative effect on availability of plant nutrients to plants.

2.3.1.6 Cation exchange capacity (CEC)

Cation exchange capacity of the soil is a measure of the soils ability to retain cation nutrients. It measures the quantities of sites on soil colloidal surface that can retain positively charged ions by electrostatic forces. Therefore, the exchangeable cations determine largely the chemical and physical properties of the soil. Landon (1991) rated CEC levels from less than 6.0 as very low, 6.0 to 12.0 as low, 12.1 to 25 as medium, 25.0 to 40 as high and more than 40 as very high. The author assists that higher the CEC the more the fertile and productive the soil is.

2.3.3 Weather conditions for rice production

Rice tolerates a wide range of climatic conditions, the average rice yield in most rice growing areas range from 1 to 6 t/ha. A number of environmental, biological and socio economic factors contribute the big range of yield. Low yields are related with both lowland rainfed, upland rice and deepwater rice but the low yield in irrigated lowland is related to socio-economic factors (Yoshinda, 1981; WARDA, 2008).

2.3.3.1 Temperature

Temperature largely manipulates not only growth pattern but also has an impact on growth duration of the rice plant. Rice needs moderate to high temperatures during cropping time, while low temperatures during cropping season may extend growth period. Temperature has tremendous impact on crops, it control the physical – chemical processes and evaporation of water from both plant and the soil. The effect may lead to reduction in number of tillers, plant height, number of spikelets, increased percentage of sterility and reduction of grain filling (Ismail *et al*., 2010; Tunde *et al*., 2011).

2.3.3.2 Solar radiation

Radiation is very important energy for photosynthesis reaction in plants, as well as for growth. Plant development and yield are therefore affected by the level of solar radiation. The levels of solar radiation required by rice vary depending on growth stage of the plants. For example, low radiation at vegetative phase may result in yield and its components reduction. Radiation of about 300 cal/cm^2 per day may rise yield to 5 t ha^{-1} from 4.5 t ha^{-1} if other factors are constant (Yoshida, 1981). Yield of rice is directly related to the solar radiation at reproductive and ripening phase (Tunde *et al*., 2011).

2.3.3.3 Relative humidity

High atmospheric humidity is very important for crop development because many plants have the ability to absorb moisture direct from unsaturated air of high humidity. In addition, photosynthesis of the plant leaves may be affected by humidity.

2.3.3.4 Rainfall

Availability of water is more uncertain for upland than for lowland rice because upland fields are not bundled. Because upland rice depends entirely on rainwater, both the amount and the distribution of rainfall are important. Low rainfall during the growing season generally means decreased rice yields. However, the distribution of rainfall is a major influence on yields, even in areas with as high as 2000 mm annual rainfall (De Datta *et al.,* 1974a).

Effects of low rainfall/moisture stress may affect physiological attributes such as days to flowering and maturity. During the grain filling stage moisture stress affects carbohydrate metabolism and therefore low filling of grains (Ahmed *et al.,* 2005).

2.4 NERICA Varieties

2.4.1 Origin

During earlier decades many attempts of crossing *O. sativa* and *O. glaberrima* remained unsuccessful because of sterility barriers (Dingkuhn *et al.,* 1998) in F1 progenies. Indeed, F1 progenies that resulted from this crossing reached almost 100% sterility (Heuer *et al.,* 2003). The strategy used by WARDA to overcome this fertility issue was to backcross the F1 lines with the *O. sativa* parents at least twice. Additionally, embryo rescue technique was also used and the BC2F1 population was subjected to pedigree selection. Doubled haploidy through anther culture was used to shortcut the selection (Africa Rice, 2008).

This process was conducted firstly to the selection of seven upland lines and they were named NERICA (New rice for Africa), followed later by eleven additional upland cultivars. In 2006, the reported population of certified NERICA contained about eighty-eight cultivars and was supposed to be able to cover the major rice ecologies of Africa (Africarice, 2008).

2.4.2 Development of the NERICA

The development of NERICA varieties began in 1991, when Africa Rice initiated an inter specific breeding program for the upland ecosystem. This long-term investment paid off when breeders eventually overcame the obstacles encountered earlier through perseverance and the use of biotechnology tools such as anther culture and embryo rescuing. In 1994 the first inter specific line with promising agronomic performance was obtained (Wopereis *et al.,* 2008; Jones *et al.,* 1997a, b). Several hundred inter specific progenies were generated, opening new gene pools and increasing the biodiversity of rice. The main objective of the breeding work that led to the NERICAs was to combine the high-yielding attribute of *O. sativa* with the resistance of the indigenous *O. glaberrima* to the African environment (Wopereis *et al.,* 2008; Jones *et al.,* 1997a, b).

Another long-sought attribute for a good upland variety is the ability to provide acceptable yields under the low-input use conditions typical of upland rice farming in Africa (Wopereis *et al.,* 2008; Jones *et al.,* 1997a, b). Both objectives have been largely met, as evidenced by the experimental trials data which compare the performance of NERICA progenies with that of their *sativa* and *glaberrima* parents and other *sativa* checks, under high and low input conditions, and under major stresses in upland rice ecologies in Africa (Africa Rice, 2008a, b; Zenna *et al.,* 2008, Atera *et al.,* 2011).

Agronomic trials data show that the NERICA varieties bring to upland farmers the high yield potential of the *sativa* varieties under both low and high input conditions, with what is in essence insurance against the risk of significant yield losses in the face of major upland biotic and abiotic stresses (WARDA, 2001b).

Given that the *sativa* and *glaberrima* parents of these first-generation NERICAs are not the best-performing varieties within the two species, there was reason to expect that the performance of the next generations of NERICAs will be much higher. Through participatory varietal selection, farmers all over Africa have evaluated interspecific lines. The most successful lines have been named NERICA varieties. There are currently 18 NERICA varieties (NERICA1 to NERICA18) suitable for upland conditions (Zenna *et al.,* 2008).

2.4.3 NERICA cultivation area

Surveys conducted by the National Agricultural Research Systems (NARS) of some of African Rice member countries provide estimates on the total area under NERICA varieties in different countries. Diagne *et al.* (2006) and Adegbola *et al.* (2006) estimated the total area under NERICA varieties as 51 000 ha in Guinea in 2004 and 5000 ha in

Benin in 2003. The National Food Reserve Agency (NFRA) of Nigeria, basing its estimates on the quantities of seed produced and distributed to farmers, reported 186 000 hectares under NERICA1 in Nigeria in 2007. The Uganda National Research Institute, citing a report of the Statistics Office of the Ministry of Agriculture in Uganda, estimates 35 000 hectors under NERICA 4. National rice surveys conducted in 2009 by National Agricultural Research Systems (NARS) and National Agricultural Statistical Services (NASS) in 21 Sub-Saharan African countries provide more recent estimates for some of the countries (AfricaRice, 2010). In particular, areas under NERICA were estimated to be about 140 000 hectares in Guinea and 244 000 hectares in Nigeria.

Except in Guinea and Benin where a survey was conducted (in 2003 and 2005 respectively) the estimated areas under NERICA reported by the NARS are based on quantities of seed produced and distributed to farmers. However, there is a need to quantify uptake of NERICA and other improved varieties in a much more reliable manner. Therefore, Africa Rice and partners are currently conducting surveys in many of the countries where NERICA is cultivated to get a better overview of the uptake of NERICA across the African continent (Africa rice, 2008).

2.4.4 Impact of NERICA rice varieties on productivity and livelihoods of farmers

NERICA rice varieties have been developed basically with the aim of improving the rice productivity, raising income and reducing food insecurity of poor upland rice farmers (mostly women) who rarely use fertilizer, which they say they cannot afford (Gebrekidan and Seyoum, 2006).

Empirical evidence from impact assessment studies conducted in West Africa points to a heterogeneous impact of NERICA adoption across and within countries with significantly positive impacts of NERICA adoption on rice yield such as Benin and Gambia. No significant impact was recorded in Ivory Cost and Guinea; and generally higher impacts were recorded for women than for men in almost all countries (Diagne *et al.,* 2009).

In Benin, an additional yield gain of about 1 ton per hectare was attained by farmers adopting NERICA. However, the impact at the national level was very limited because of the presently low diffusion of NERICA varieties in the country (Adegbola *et al*., 2006). Female potential adopters have a surplus of production of 850 kg of paddy per hectare compared to 517 kg for men and an additional gain of 171 978 CFA (337 USD) per hectare for women compared to 141 568 CFA (277 USD) for men (Agboh-Noameshie *et al*., 2007).

In Gambia, results indicate that mostly women rice farmers adopting NERICA varieties achieved an additional rice yield gain of 0.14 ton ha^{-1} (Dibba, 2008). In Ivory Cost, results show that the impact on average rice yield of adopting NERICA varieties is heterogeneous with a sizeable and statistically significant impact found for female farmers (+0.7 tons ha^{-1}) and a non-statistically significant impact found for male farmers (Diagne, 2006; Diagne *et al.,* 2009). Average gain for men in Gambia was not significant. The 0.14 tones (i.e. 140 kilogram) per hectare average gain from adopting NERICA although seemingly small was statistically significant and represented about 15% of the average rice yield obtained by farmers (just under 1 ton ha^{-1}) (Diagne *et al*., 2009).

In Uganda, NERICA was found to have positive effects on productivity and allowed farmers to improve their yield (Kijima *et al.,* 2006). Accordingly, the average yield of NERICA in Uganda was found to be 2.2 tons ha^{-1}, which is twice as large as the average rice yield in sub-Saharan Africa. They found that there is a large difference in yield between experienced and non-experienced households, namely, 2.46 and 1.72 tons ha^{-1}, respectively; indicating that experience does matters in achieving high yields. Other yield determinants included rainfall and this implies that timing of planting NERICA varieties is a crucial determinant of its yield (Kijima *et al.,* 2008). The cropping pattern in the previous season was found to be an important factor affecting rice yield (Kijima *et al.,* 2008). Analysis of impact on income and poverty showed that in Uganda, NERICA has the potential to increase per capita income by 20 USD (12% of actual per capita income) and to decrease the poverty incidence, measured by the head count ratio, by 5 percentage points (from 54.3% to 49.1%) (Kijima *et al.,* 2008). In West-Africa, Glove (2009), Dibba *et al.* (2010) and Dibba, 2010) found NERICA adoption to have positive impact on household rice and total incomes in Gambia. In particular, Dibba, 2010) found that adoption of NERICA increased the rice farmer's daily income by about 10 Dalasi (0.34 USD) on average. For Benin, Sogbossi (2008) identified NERICA adoption as a key determinant in poverty reduction and found it contributed 13% decrease in the probability of being poor. In addition, the gender-based analysis demonstrated that the impact of NERICA adoption is higher on women farmers (reduction of probability of being poor is 19%) than men (reduction of probability of being poor is 6%). Findings from another study conducted in Nigeria indicated that adoption of NERICA increased total farm household income and per capita expenditures by respectively N 63 771.94 (554.5 USD) and N 4 739.96 (41.2 USD), thereby increasing their probability of escaping poverty (Dontsop *et al.,* 2010). The poor was defined using the income poverty line while in Benin it was estimated at CFA 51 413 per year in rural areas and CFA 91 709 per year in urban areas (Sogbossi, 2008).

These results on impact of NERICA adoption in Africa confirm that NERICA can bring hope for millions of small-scale poor farmers in the continent by reducing poverty and income inequality in the population. However, the realization of such hope is conditioned by its wider dissemination that can only take place if the seed bottlenecks and other production constraints are addressed (Dontsop *et al.,* 2010).

2.5 Fertilizers and Rice Production

Chemical fertilizer offers nutrients, which are readily soluble in soil solution and thereby instantly available to plants. Nutrient inputs in crop production systems have come under increased scrutiny in recent years because of the potential for environmental impact from inputs such as Nitrogen and Phosphorus. The average percentage of yield attributable to fertilizers has generally ranged from about 40 to 60% in the USA and England, and has tended to be much higher in the tropics (Ferber, 2001). Recently, calculated budgets for N, P, and K indicate that commercial fertilizers make up the majority of nutrient inputs necessary to sustain current crop yields in the USA (Ferber, 2001).

Modern high yield crop production and its associated inputs have come under intense scrutiny over the past several years. Concerns expressed often involve possible effects of the wide spread application of commercial crop nutrients on the environment (Ferber, 2001; Parry, 1998; Sharpley *et al.,* 1999; Tilman, 2001).

2.5.1 Nitrogen and its influence in rice yield

Nitrogen is one of the major plant nutrients in all agro ecosystems. Large reserves of N are present in soil organic matter, but its availability to plants is influenced by several competing processes including mineralization, immobilization (by microorganisms and plants), nitrification and denitrification (Ferber, 2001). Nitrogen is very essential for the growth and development of crops. Nitrogen absorbed by rice during the vegetative growth stage contributes in growth during reproduction and grain filling through translocation (Bufogle *et al*., 1997; Norman *et al*., 1992). It enhances biomass and seed yield subject to the efficient water supply.

Lack of N results in stunted growth, pale yellow colour, small grain size and poor vegetative as well as reproductive performance. Growth of plants primarily depends on nitrogen availability in soil solution and its utilization by crop plants during growth and development. Dry matter production and its conversion to economic yield is a cumulative effect of various physiological processes occurring during the plant life cycle. Though an increase in yield of crop with increasing rate of nitrogen has been reported by Khan *et al*. (1994). Only few studies have examined the kinetics of gross nitrogen mineralization, immobilization and nitrification rates in soil at temperatures above 15^{o}C (i.e under tropical condition) (Hoyle *et al.,* 2006). Agroecosystem in general and tropical dry land agroecosystems in particular invariably require replenishment of N through exogenous N source. Chemical fertilizers are most widely used as supplemental N. However, questions have been raised about the term sustainability of such system because rate of release of N in soils often does not match crop demand with fertilizer application (Robertson *et al*., 2000). The total N content for most soils ranges from less than 0.02% in sub soil to more than 2.5% in peats. Plow layers of most cultivated soils contain between 0.08% and 0.4% N (Robertson *et al.,* 2000). Levels of N in soils are related to vegetation cover. High content of organic matter and N in some tropical soils have been attributed to their luxuriant vegetation cover of leguminous and non leguminous plants, as well as to the slow rate of humus decomposition in such soils (Robertson *et al.,* 2000).

Previous studies have shown that proper use of fertilizer can increase yield and improve the quality of rice significantly (Awan *et al*., 2003; Ahmed, 2005; Oikeh *et al.,* 2008).

everal studies have shown that application of N fertilizer to rice, leads to increase in plant height, panicle number, leaf size, spikelet number and grain yield (Bala subramanian, 2002; Walker *et al.* (2008).

Nitrogen is an essential nutrient for plants in the soil and lack of it causes chlorosis and less vigor. Application of nitrogen fertilizer produces more vigorous and taller rice plants than those that did not receive any fertilizer. Application of high rates of 70 -130 kg per ha^{-1} of nitrogenous fertilizers gave higher plant height, longer panicles of rice, higher total dry matter and higher grain yield than the lower rate and control according to Saito *et al.* (2006).

Oikeh *et al. (*2008) reported that grain yield of some widely adopted NERICA paddy varieties were depressed at zero nitrogen (N deficiency) over applied N in humid forest ecosystems of Nigeria. Application of 70 kg N and 100 kg N per ha^{-1} resulted in significantly higher total dry matter (TDM) and grain yield of rice than the lowest rate of 40 kg N per ha^{-1} (Fabio *et al*., 2013). In Benin, combination of 60 kg N, 13 kg P and 25 kg K per ha^{-1} (low to moderate inputs) has proved sufficient to produce 4 ton ha^{-1} as compared to zero fertilizer application. Doubling the level of N and P at the same level of K increases grain yield by 25% over a moderate NPK level. Oikeh *et al*. (2006) recommend 60 kg N and 13 kg P for smallholder farmers with basal application of P at sowing and top dressing with one third urea at beginning of tillering and the remaining two third at about panicle initiation. In Uganda, Tsuboi (2006) recommends for the soil that are sufficient in K, the use of 55:23:0 NPK kg ha^{-1} in the form of 55 kg ha^{-1} di-ammonium phosphate DAP, 18:46:0 (NPK) at 15 - 20 days after germination and 50 kg ha^{-1} urea (46%N) each at 15 days after sowing and 55-65 days after sowing. Kamara *et al*. (2011) concluded that Nitrogen application increased rice grain yield and yield components with the highest grain yield obtained at 100 kg N ha^{-1}. N application at even lower rates significantly increased grain yield of the rice varieties suggesting that N is a major limiting nutrient in rice production.

2.5.2 Phosphate and rice production

Phosphorus, P, is the second important nutrient for plant growth and promotes root development, tillering, early flowering; and performs other functions like metabolic activities, particularly in synthesis of protein (Panhawar *et al.,* 2011). P fertilization is important to sustain crop production, maintain soil fertility and enhancing fertility of degraded soils under intensified agricultural production systems. P is essential for high N_2 fixation rates as it is required for all energy transformation processes in plants and hence has stimulatory effect on very energy-demanding N_2 fixation process (McLauglin *et al.,* 1990; Somado *et al.,* 2003).

A large proportion of the existing P in the soil is generally in forms not accessible to the plant roots (Kirk *et al.* 1998). P application reportedly promotes root and shoot growth and increases grain yield (Sahrawat *et al.,* 2001). P plays an important role in early vegetative growth stages, because it promotes tillering and root development (Slaton *et al*., 2002); Sainio *et al.,* 2006). P is important for plant growth, promotes root development, tillering and early flowering, and performs other functions like metabolic activities, particularly in synthesis of protein (Panhawar *et al.,* 2011). Yosefi *et al.,* 2011) reported that P fertilizer significantly influenced grain number per panicle. In addition, Panhawar *et al.* (2011) found that P increased upland rice yield. Li *et al.* (2010) argued that application of P fertilizer is one of the most important practices for rice crop yield. P deficiency is widespread in rain-fed rice soils and is particularly prominent in drought-prone environments because the nutrient mobility decreases sharply as soil dries. P is also critical for crop establishment under dry-seeded conditions (Kirk *et al.,* 1998). Increasing P availability to the plant has been found to increase yield in drought-prone rain fed rice, and P fertilizer can also be applied to compensate for stem borer injury in rice by increasing tillering (Boling *et al.,* 2004).

P applied as bands close to the seeds is the most effective method, and deep banding can increase P use efficiency, as well as early plant growth and grain yield (Borges and Mallarino, 2001). The rate of development of the root system in zones containing P is particularly important in rain-fed environments where root growth must be rapid at the onset of rains if subsequent dry periods are to be survived (Kirk *et al.,* 1998).

Rice yield increased significantly when rate of P application increased from 0 - 35 kg ha^{-1} as diammonium phosphate (DAP) and from 0 - 52.5 kg ha^{-1} as Muriate Rock Phosphate (MRP) while the grain yield was maximized by application of 60 kg P ha^{-1} (Suchan *et al.,* 2012). Yosef Tabar (2012) stated that, fertile tillers, number of field grains per panicle, 1000 grain weight and grain yield increased by application of 90 kg P ha^{-1} with Torim Hashemi rice caltivar. In Ivory Coast, the of 60 kg P ha $^{-1}$ as water soluble P source (triple superphosphate - TSP) has been proposed in the acid soils of the humid agroecosystem (Sahrawat *et al.,* 1995; Somado *et al.,* 2006). P deficiency further accentuated on many of the soils, especially Ultisols and Oxisols, because of fast reversion of soluble forms into insoluble forms through reactions with iron and aluminium oxides (P-fixation). Low concentration of P combined with low P solubility limits the productivity of soils. Lack of adequate P not only limits the response to other major nutrients including N, but also affects the overall fertility and productivity of soils (Sahrawat *et al.,* 2001). In addition, the soil infertility problem is accentuated under intensified agricultural production systems.

For this reason, the application of inorganic P fertilizers is a major requirement for sustained crop production in rice as well as for enhancing soil fertility (Sahrawat *et al.,* 2001).

2.6 Growth in 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 for up to 20 years (IRRI, 2008). 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. Small wind pollinated flowers are produced within a branched panicle ermeged from the flag leaf sheath and consist of a central rachis with up to four primary branches at each node. Primary and secondary branches bear the flower spikelets. Each spikelet has a single floret and two glumes. It is enclosed by a rigid, keeled lemma that is sometimes extended to form an awn and partially envelops the small palea (McDonald, 1979; OECD, 1999).

2.6.1 Root system

The roots of rice plant originate from the node and its number is governed by the number of nodes. It is distributed shallowly and horizontally in the surface layer of the soil within a depth of 20cm during the period from rooting to tillering. The roots grow downward rapidly attaining the maximum length of 60 - 80cm at the heading stage. Roots of rice plants increases markedly in number at the tillering stage and elongate down ward at the internode elongation stage (Matsushima, 1980).

2.6.2 Plant height

Singh and Sharma (1987) reported that application of 180 kg N ha^{-1} resulted in higher plant height of rice. Meena *et al*. (2003) also reported similar results. The increase in plant height with increased N application irrespective of spacing might be primarily due to enhanced vegetative growth with more nitrogen supply to the plant. Okeleye *et al.* (2006) and Oikeh *et al. (*2009) reported that enhanced tiller and panicle production was mentioned as one of the reasons given by farmers in Western Nigeria for their preference for NERICA varieties compared to the other improved upland varieties. Several studies have shown that application of N fertilizer to rice leads to increase in plant height, panicle number, leaf size, spikelet number, and grain yield.

2.6.3 Date to maturity

NERICA generally have much shorter growing cycle (about 90 -110 days) compared to local varieties (about 110 – 120 days, it is possible to have a double cropping under sufficient rainfall. Their early maturing gives a comparative advantage with respect to demand for labour (Defoer *et al.,* 2002). NERICAs are stress resistant and respond well to both low and high input conditions (Defoer *et al.,* 2002). Under optimum growing conditions the number of days to 50% heading of a rice crop can alternatively be used to estimate the number of days to attain maturity. Maturity of rice varieties can be classified as very early (less than 105 days), early (105-120), medium (121-135 days), late (136-160 days) and very late (over 160 days) (IRRI, 1992). Unlike ripening phase, which takes 35 days after 50% heading to reach complete maturity, the vegetative phase, irrespective of the variety is the only growing phase that varies to give differences in maturity periods

2.6.4 Biomass

Kato *et al.* (2006) reported that the increasing rates of nitrogen and phosphorus have significantly increased the straw dry matter yield of rice. Moreover, that if water supply is adequate and frequent, it was possible to produce a large amount of top dry matter under upland condition, which is comparable to that in-irrigated lowland condition. The increase in biological and grain yield could be due to the increase in yield attributes (plant height, number of productive tillers/hill, panicle weight and 1000-grain weight) (Ebaid *et al.*, 2007).

2.7 Yield and Yield Components

Rice yield is determined by yield components, while yield components are influenced by genetic and environmental factors (climate, nutrient/soil, and water) (Matsushima, 1995). Yield components of rice varieties include number of panicles per plant, number of grains per panicle, percentage of empty grains and 1000-grain weight. New plant type (NPT) of high yielding rice variety Fatmawati, for example, has an advantage in the number of grains per panicle (sinks) which almost reaches 400, twice as the common high yielding varieties (HYVs). However, the number of panicles per hill and percentage of filled grains are low (Makarim *et al.,* 2004). In contrast, HYVs have high numbers of panicles per hill, but grain numbers per panicle are low to medium so that the actual yields are similar or slightly lower than the NPT (Makarim *et al.,* 2005).

Environmental conditions affect the rice yield components. Ismail *et al*. (2003) reported that the 1000-grain weight of rice is correlated with rainfall and soil moisture content. The number of filled grains per panicle and panicles per hill were correlated with water stress and water status of the soil. Percentage of empty grains is determined by air temperature during the critical growing stage, namely the time of meiosis (9 - 12 days before flowering) and flowering (Shihua *et al*.,1991). Cold temperature during meiosis or hot or cold temperature at flowering caused high sterility.

2.7.1 Number of panicle per square meter

Abdulrachman *et al*. (2004) reported that application of N, P, K fertilizers and their combinations on IR64 variety influenced the number of panicles per hill and grains per panicle, but did not affect 1000 grain weight. Koyama *et al*. (1973) stated that N application at the initial plant growth stage tended to increase seedling number per hill, while N fertilization at primordial stage increased panicle number per hill and grain number per panicle.

2.7.2 Panicle length

Syafruddin *et al*. (2003) reported that N fertilization consistently increased panicle length and decreased percentage of empty grains on Kapuas rice varieties grown on new opening rice fields and on swampland.

2.7.3 Spikelet per panicle

Number of spikelets increasing with increasing nitrogen rates has been reported by Mauad *et al.* (2003) in Brazil and Ahmed *et al.* (2005) in Bangladesh. Application of 100 kg N ha^{-1} increased spikelet number per panicle by 19 to 22% over the number obtained at 30 kg N ha^{-1}, and 70 to 88% compared with when nitrogen was not applied. It is generally recognized that the number of spikelets per panicle or number of panicles per unit area determines rice yield depending on the cultivar. Grain yield increased in most cultivars with increased number of spikelets per panicle. Kato *et al*. (2008) made similar observations that in upland conditions where drought occurs sporadically, spikelets number per unit area contributes immensely to yield.

2.7.4 Grains per panicle

Number of grains per panicle contribute a lot to grain yield than other yield components. It is often suggested that improvement of grains per panicle would lead to increase in rice grain yield. Mustafa and Elsheikh (2007) and Sadeghi (2011) noted that grains per panicle are one of the yield components that frequently making the greatest contribution to rice grain yield. Samonte *et al.* (1998) reported significant association between number of grains per panicle and grain yield. They concluded that the number of grains per panicle could be used as a selection index in early generations of rice.

2.7.5 1000 grain weight

Grain weight is an important yield component in rice production. It is determined by the supply of assimilates during the ripening period and the capacity of the developing grain to accumulate the translocated assimilates (Ntanos and Koutroubas, 2002). Bhowmick and Nayak (2000) reported that increase in grain weight at higher nitrogen rates might be primarily due to increase in chlorophyll content of leaves that led to higher photosynthetic rate and ultimately plenty of photosynthates available during grain development. On the other hand, Fageria and Baligar (2001) reported that the weight of 1000-grains increased significantly and quadratically with increasing nitrogen rates in Brazil. Other studies reported that the weight of 1000-grain decreased with increasing nitrogen rates (Mauad *et al*. (2003). Surekha *et al.* (2006) reported that the weight of 1000-grains was not affected significantly by crop management practices. Mauad *et al*. (2003) and Surekha *et al*. (2006) considered grain weight as a genetic trait that could possibly explain the inconsistent response to nitrogen fertilization and crop management practices. Wilson *et al.* (1996) found that 1000-grain weight is not significantly affected by fertilizer treatment, it is a genetical character fixed by an individual variety. In addition, Mauad *et al*. (2003) reported that increments in N rates reduced the mass of 1000-grains in rice probably because the amount of carbohydrates was not sufficient to fill the greater number of spikelets produced. A significant difference in 1000-grain weight of rice as affected by variation in fertilizer packages was also observed by Mirza *et al*. (2010).

2.7.6 Grain yield

Grain yield in rice is a function of panicles per unit area, number of spikelets per panicle, 1000-grain weight and spikelet sterility (Fageria and Baligar, 2001). Grain yield has been found to increase in most cultivars with increased number of spikelets per panicle. Kato *et al.* (2008) made similar observations that in upland conditions where drought occurs sporadically, spikelets number per unit area contributes immensely to yield. Increasing the rate of NPK at balanced levels leads to increase in rice grain yield and its yield components.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Site Description

The research, which involved an experiment in the field, was conducted at Mchangamdogo village, Wete district, Nothern region of Pemba Island, Zanzibar – Tanzania (05° 09'S and 39°49'E), during the long rains season (*masika*) from March to July 2012. The experimental site is characterized by bimodal rainfall distribution, with long-term averages of about 1 284.91 mm per year (TMA, 2011). Total annual rainfall was 1622.01 mm in 2011. Daily rainfall distribution during the research period is presented in Table 2. The soil at the site was sand-clay loam, with 36.8% organic carbon kg^{-1} soil, total nitrogen was 1.6% kg^{-1} soil; 2.8 mg available P kg^{-1} soil (Mehlich III), electrical conductivity 0.03 ms/cm and pH (in water 1:2.5), 5.4. Cation exchange capacity (CEC) of the soil was 20.3 $cmol^{+}kg^{-1)}$ (Table 3). Prior to the trial, the site, owned by Mchangamdogo Primary School, was under continuous cultivation of local rice varieties.

3.2 Experimental Design and Field Layout

The experiment was set up as Randomized Complete Block Design in Factorial arrangement with three replications (Appendix 2a, b, and c). Each replicate was 29.5 m x 9.5 m = 280.25 m^2 subdivided into four sub replicates with 2 m x 29.5 m separated from each other by 0.5 m and then each sub replicate divided into 2 m x 2 m subplots separated from each other by 0.5 m. This formed a total experimental area of about 899.75 m^2.

3.3 Treatments

Three NERICA rice varieties i.e NERICA 1, NERICA 10, NERICA 12 from Kizimbani Agricultural Research Institute (KARI) and ''Machuwa'' local variety collected from farmers were used as the first factor. Fertilizer rate combinations using Triple supper phosphate (TSP 46% P_20_5) and Urea (46% N) were used as the second factor.

3.3.1 Characteristics of rice varieties used in experiment

Table 1: Characteristics of rice varieties used in experiment

Variety	Ecology	Days to 50% heading	Days to 80% maturity	Potential yield (kg/ha)	1000 grain weight (g)	Average plant height (cm)
NERICA 1	Upland rice	70–75	95-100	4500	26.0	100
NERICA 10	Upland rice	65–70	90–95	4000	26.0	100
NERICA 12	Upland rice	65-70	90-100	5500	36.8	115
Machuwa	Upland rice	80-85	105-110	1000	25.0	120

Source. WARDA (2001) and DAE

3.3.2 Fertilizer combinations

There were four levels of nitrogen (0, 40, 80 and 120 kg N ha^{-1}) and three levels of phosphorus (0, 30, and 50 kg P ha^{-1}). These levels were combined to form twelve fertilizer combinations (Appendix 1). The combinations were (N 0, P 0), (N 0, P 30), (N 0, P 50), (N 40, P 50), (N 40, P 30), (N 40, P 0), (N 80, P 0), (N 80, P 30), (N 80, P 50), (N 120, P 50), (N 120, P 30) and (N 120, P 0) for 0, 30, 50 kg P ha^{-1} and 0, 40, 80, 120 kg N ha^{-1} respectively.

3.4 Procedures

3.4.1 Land preparation

Prior to experimental layout, the area was ploughed and harrowed by tractor and levelling was done manually by hand hoe. Plots were then demarcated and labelled according to experimental design.

3.4.2 Sowing/dibbling

Three to five dry seeds were dibbled in dry soil on 24 and 25 April 2012 at a spacing of 20 cm x 20 cm, 10 rows per plot with ten plant stands per row forming 100 plant stands per plot. A seed rate of 50 – 60 kg ha^{-1}, equivalent to 22 g per plot was used and the seedlings were thinned 14 – 18 days after sowing (DAS) remaining with two seedlings per stand. Spacing and seed rate per hector is as recommended by Oikeh *et al*. (2006) for NERICA varieties.

3.4.3 Fertilizer application

Prior to seeding/dibbling, basal application of 0, 30, and 50 kg P ha^{-1} as Triple super phosphate (TSP 18%P) equivalent to 60 g/4m^2 in 30 kg P ha^{-1} and 100 g/4m^2 in 50 kg P ha^{-1} was applied in respective plots, by broadcasting uniformly on the plots. Nitrogen in the form of Urea (46% N) at a rate of 0, 40, 80 and 120 kg N ha^{-1} equivalent to 0 g, 35 g, 70 g and 105 g urea $plot^{-1}$ respectively was measured using electronic measuring balance and applied into two splits. One third was applied at 21 days after seed germination and the first weeding and thinning, the rest two third applied at panicle initiation stage (45-50 days after seeding) following the recommendation by Oikeh *et al.* (2008).

3.4.4 Weed control

Two weeding operations were conducted. The first practice was application of SATUNIL herbicide 600 cc at the rate of 4 – 5 lt ha^{-1} two weeks after emergence when seedlings had attained 3 – 4 true leaves. The second weed control practice was hand weeding four weeks after the first operation. Wild rice (Oryza *spp*), nut sedges (Cyperus *spp*) and Brachiaria *spp* were the most dominant weed species in the experimental area.

3.4.5 Pest and Diseases control

During the experimental period, no disease problems emerged to warrant control measures, however, there was a minor problem of birds (pest) after panicle emergence, which were controlled using farmer's practice of scaring.

3.5 Data Collection

3.5.1 Rainfall data

Rainfall data were collected from Tanzania Meteorological Agency (Mchangamdogo Secondary School Rainfall recording station) during the research period January to July 2012 and recorded in Table 1.

3.5.2 Soil analysis

Soil samples were collected from the experimental site between 0 – 20 cm deep by using soil auger. Three composite samples of 1 kg each sent for analyses at Kizimbani Research Station Soil Laboratory using standard procedures for soil analysis. The composite soil was air dried and grounded to pass through 8 mm sieve. A small sub sample of the composite soil was grounded and sieved to pass through 2 mm sieve for physical and chemical analysis. The description of data was done according to Landon, (1991), NSS, (1990) and Loveland and Webb (2003). Summary of the procedures and subsequent soil analysis data presented in Table 3.

3.5.3 Growth parameters

3.5.3.1 Plant height

At physiological maturity, ten randomly selected plants from each plot were measured from the ground surface to the tip of longest panicle by using measuring ruler and the mean plant height computed and recorded in centimetres (cm).

3.5.3.2 Days to 50% heading

Days to 50% heading was recorded by counting the number of days from sowing to when 50% of the plants in each plot had flowered. Average was computed for three replicates.

3.5.3.3 Days to 80% grain maturity

Days to 80%, maturity was recorded by counting the number of days from sowing to when 80% of grains on the panicle in each plot were fully mature and ripened to golden shine.

3.5.3.4 Biomass yield

One square meter quadrant (1 m^2) from each plot was harvested at physiological maturity from the ground surface and all materials were sun dried to constant weight and then weighed using an electronic measuring balance. Weight for each plot was recorded in grams (g).

3.5.3.5 Harvest index (HI)

The harvest index in percentage was determined by dividing the grain yield (Economic yield) over Total dry mass (TDM) yield (Biomass yield) multiplied by one hundred for each plot. HI (%) = (Grain yield per meter square/Total dry mass yield per meter square) x 100.

3.5.4 Yield parameters

3.5.4.1 Number of panicles per meter square

Number of panicles per square meter was counted after harvesting the one meter quadrant from each plot and the total number of panicles for the quadrant recorded.

3.5.4.2 Panicle length

Ten panicles were randomly selected to measure panicle length. The panicle lengths were measured using measuring ruler from the panicle neck to the tip and the mean computed and recorded in (cm).

3.5.4.3 Number of spikelets per panicle

Number of spikelets per panicle was counted from ten randomly selected panicles used to measure panicle length, and their mean was recorded.

3.5.4.4 Number of grains per panicle

Five panicles from each plot were selected randomly from the harvested panicles and threshed individually and their grains counted. Only fully filled grains were counted and recorded for each plot.

3.5.4.5 1000 grain weight

Three samples of 1000 fully filled grains was collected and weighed using electronic measuring balance in grams after harvesting, threshing, winnowing and sun drying to 14% moisture content. Mean weight was recorded for each plot.

3.5.4.6 Grain yield

This was determined for grains from one meter harvested area of each plot, which was threshed, winnowed, and sun dried to 14% moisture content and weighed in grams.

3.6 Data Analysis

The data collected were subjected to analysis of variance (ANOVA) using GenStat (Fourteenth Edition) computer program. Mean separation was performed using LSD and Turkey Test at 95% confidence intervals. The basic assumption for the two factors experiment for each observation was

Xijk where i = 1,2……,1 level of factor A, j = 1, 2……, j of factor B and k =1,2 ……, k experiment units.

The stastical model is:

Xijk = u + Ai + Bj + (AB)ij + eijk ……………………………………….…………..(1)

Where:

u = general mean common to all observations

Ai = effect of ith level of factor A

Bj = effect of jth level of factor B

(AB)ij = interaction effect of ith level of factor A and jth level of factor B

Eijk = random error or random effect specific to each experimental unit in the experiment.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results Description

The results of the experimental site soil analysis, description and meteorological data are presented Table 2 and 3. It show that weather parameters especially rainfall (Table 2) influenced the experiment at least slightly, and that the soil was deficient in both nutrients tested (nitrogen and phosphorus) which warrants fertilizer use as shown in Table 3.

Table 2: Rainfall data (mm) from the nearby station recorded from January 2012-July 2012 for the experimental site

	1st week	2rd week	3rd week	4th week	Total	Mean/wk
January	0	0	0	0	0	0
February	0	0	0	10.5	10.5	2.62
March	18	0	50.2	35.7	103.91	25.97
April	76.6	0	225.2	34.8	336.6	84.15
May	58.2	72.9	84.3	32.8	248.2	62.05
June	47.8	0	17.3	33.5	98.6	24.65
July	32.3	14.7	0	27.2	74.2	18.55

Source: TMA (Mchangamdogo Secondary School Rainfall recording station)

Table 3: Soil analysis results and rating of different soil analysis attributes for the experimental site

1.Soil attribute Physical soil Properties	Value	Method	Remark	Reference
Soil particle analysis				
Sand	27%	Bouyoucos hydrometer	Sand ClayLoam	Landon (1991)
Silt	32%			
Clay	41%			
Chemical characteristics				
Soil pH	5.4	1:2.5 Soil:H_20	Slightly acidic	Landon, (1991)
Total Nitrogen	1.6% kg^{-1} soil	Kjeldahl	Very low	NSS (1990)
Extractable Phosphorus	2.8 (mgP/kg^{-1})	Kurtz-Bray 1	Very low	Landon (1991)
CEC	20.3cmol$^{(+)}$/kg	1M Ammonia acetate	Medium	
EC	0.03mS/cm	1:5 Soil:H_20	Salinity effect negligible	
OM	36.8% kg^{-1}soil	Walkley- Black	Medium	Loveland and Webb (2003)

Results of performance of rice crop in terms of growth and yield parameters in relation to varieties, nutrients levels and their interactions are presented in Tables 4, 5, 6 7a and 7b. Table 4 shows analysis of variance (ANOVA) for the effect of treatments, which includes fertility levels, varieties and their interactions. Table 5 shows the mean effects of varieties on growth and yield parameters. Table 6 shows the mean effects of fertility levels (nutrient combinations) on growth and yield parameters of rice crop. Tables 7a and 7b present the interaction effects between varieties and fertilizer levels on growth and yield parameters, respectively. Generally, there were highly significant differences ($P \leq 0.001$) among varieties and between fertility levels for growth, yield and yield parameters evaluated in this experiment (Table 4). In addition, significant differences ($P \leq 0.05$) occurred due to varieties x fertility levels interaction except for plant height, panicle length and spikelets per panicle.

Table 4: Analysis of Variance (ANOVA) results of mean sum of squares for growth, yield and yield parameters of rice under various levels of N and P nutrition

Source of variation	Degree of freedom	Plant height (cm)	Days 50% flowering	Days 80% maturity	Biomass yield. (g)	Harvest Index%	Number of panile/m^2	Panicle length (cm)	Spikelets /panicle (n)	Grains/panicle(n)	1000 grain weight(g)	Grain yield/m^2
Blocks	2	209.2**	17.68^{ns}	83.52**	122.8^{ns}	26.36^{ns}	42.36^{ns}	0.42*	60.91^{ns}	13.57^{ns}	4.16**	867.0^{ns}
Fertility Levels	11	382.65***	384.12***	303.27***	178180.9***	377.65***	35737.38***	8.05***	23.00***	785.49***	19.74***	32985.2***
Varieties	3	594.59***	830.71***	952.57***	312593.1***	3837.71***	119437.05***	76.27***	51.8***	13167.01*	57.59***	271859.4***
Interaction	33	38.27 ^{ns}	30.22***	32.00***	8133.3***	31.18***	4031.10***	1.34 ^{ns}	2.36 ^{ns}	241.43***	2.96***	3743.9***
Error	94	4.96	2.05	2.44	9.83	1.86	4.71	0.98	1.87	6.09	0.78	22.64
TOTAL	143											

* Significant at $P \leq 0.05$
** Significant at $P \leq 0.01$
*** Significant at $P \leq 0.001$
ns not significant at $P \leq 0.05$

4.2 Mean Effects of Rice Varieties on Growth and Yield Parameters

The mean effects of varieties or genotype and yield parameters are presented in Table 5. Machuwa local variety was significantly the tallest than others. It was significantly ($P \leq 0.001$) the latest to reach 50% flowering and to attain 80% physiological maturity than all other varieties. However, the performance of this variety in other attributes was significantly poorer than the other varieties except in 1000 grain weight where difference were not significant from NERICA10 Table 5. In addition, it accumulated significantly less biomass (dry matter) than the NERICA varieties while NERICA 1 also accumulated significantly less biomass than the other two NERICA varieties.

Results on harvest index show that NERICA 12 was the best converter of dry matter into grain yield, with harvest index value of 43.2% (Table 5). This value was significantly higher than all the rest of the varieties, while each of the rest of the varieties was also significantly different from the others. The local variety (Machuwa) had the lowest harvest index (21.2%) followed by NERICA 1.

Yield parameters (number of panicles [productive tillers], panicles length, spikelets per panicle, grains per panicle, 1000-grain weight and grain yield) showed that Machuwa was consistently inferior to the NERICA varieties as shown in Table 5 ($P \leq 0.05$). Also, NERICA 12 had higher grain yield (2 966 kg ha^{-1}) and 1000 grain weight (23.64 g) compared to other NERICA varieties. The local variety (Machuwa) had statistically lower yield parameters.

Table 5: Mean effects of rice varieties on growth, yield and yield parameters of the crop

Treatment	Plant height (cm)	Days to 50% Flowering	Days to 80% Maturity	Biomass (g)	Harvest Index (%)	Number of Panicle/m2	Panicle Length (cm)	Spikelets/ Panicle(no)	Number of grains/panicle	1000 grain Weight(g)	Grain Yield/m^2 (g)
NERICA 10	82.84a	65.78a	96.64a	666.9c	41.61c	200.9b	22.39b	11.38b	91.51b	21.27a	266.5c
NERICA 12	84.95a	67.31ab	97.25a	688.3d	43.19d	198.5b	22.80b	11.81b	94.70b	23.64c	296.6d
NERICA 1	82.83a	68.25b	98.39a	621.9b	40.20b	208.2c	22.26b	11.43b	91.43b	22.22b	243.4b
MACHUWA	91.42b	76.50c	107.61b	481.1a	21.16a	87.6a	19.61a	9.17a	54.42a	20.76a	100.6a
Mean	**85.51**	**69.46**	**99.97**	**614.6**	**36.54**	**173.82**	**21.76**	**10.95**	**83.02**	**21.97**	**226.8**
C.V%	**7.1%**	**3.6%**	**3.0%**	**2.0%**	**6.3%**	**3.3%**	**5.5%**	**21.0%**	**9.0%**	**4.4%**	**12.2%**
S.E	**4.96**	**4.71**	**2.44**	**9.83**	**1.8**	**4.71**	**0.98**	**1.87**	**6.09**	**0.78**	**22.64**
LSD $_{0.05}$	**1.8**	**0.6**	**0.8**	**27.8**	**0.9**	**2.7**	**0.4**	**0.4**	**3.7**	**0.4**	**6.2**

Means in column followed by the same letter are not significant at LSD $_{0.05}$

4.3 Mean Effects of Fertilizer Nutrients Combinations over the Control

Generally, all fertilizer levels had significant influence on most of the growth, yield and yield components of the genotypes. The varying levels of N and P caused significant differences in plant height (Table 6). The tallest plants were observed at 40 kg N + 30 kg P ha^{-1} (93.04cm), followed by 120 kg N + 0 kg P ha^{-1} (93.02cm) and 120 kg N + 30 kg P ha^{-1} (91.42cm). These three combinations had statistically similar effect on plant height ($P \leq 0.001$). The shortest were from the control (73.92 cm) followed by the application of 30 kg P ha^{-1} without N (79.64 cm).

On number of days to flower, application of 120 kg N without P significantly delayed the plants to attain 50 % flowering (79.17 days) compared to the control (58.78 days). On the other hand, significant differences among fertilizer combinations 120 kg N + 50 kg P ha^{-1} (106.17); 120 kg N + 30 kg P ha^{-1} (107.0); 120 kgN + 0 kg P ha^{-1} (107.58) and control were observed in days to crop to maturity. Under control, plants matured earlier (96.67 days) compared to those different rates of fertilizers were applied. Results on biomass yield showed highly significant difference among different fertilizer combination. However, the effect of fertilizer rates on biomass was similar in the following combination: 40 kgN + 50 kg P ha^{-1} and 80 kg N + 0 kg P ha^{-1}; between 40 kg N + 30 kg P ha^{-1} and 80 kg N + 0 kg P ha^{-1}; between 80 kg N + 30 kg P ha^{-1} and 80 kg N + 50 kg P ha^{-1}; and between 80 kg N + 30 kg P ha^{-1} and 120 kg N + 50 kg P ha^{-1}. At 120 kg N + 0 kg P ha^{-1} the plants were enhanced to accumulate more biomass (8 225 kg/ha) than any other combination whereas the control (4 660 kg ha^{-1}) and 0 kg N + 30 kg P/ha (4 458 kg ha^{-1}) were very poor combinations in driving the plants to accumulate dry matter. On harvest index, 120 kg N + 0 kg P ha^{-1} resulted into the smallest value than all the other combinations except 0 kg N + 30 kg P ha^{-1} where differences were not significant. The crop was best in photoassimilate conversion at the nutrient level of 40 kg N + 30 kg P ha^{-1}

(45.54%) followed by 40 kg N + 50 kg P ha^{-1} (42.92%), 40 kg N + 0 kg P ha^{-1} (41.08%) and 80 kg N + 50 kg P ha^{-1} (40.27%). The rest of combinations moderately affected this growth parameter.

Similar to growth parameters, yield parameters showed significant differences among nutrient combinations ($P \leq 0.001$). The highest mean number of panicles per square meter was obtained at the combination of 120 kg N + 30 kg P ha^{-1}. However, other highest N levels (120 kg N + 0 kg P ha^{-1} and 120 kg N + 50 kg P ha^{-1}) had statistically similar effect on the number of panicles per meter square. The lowest number of this yield attribute was observed in the control plot (98.7) and combinations of 0 kg N + 30 kg P ha^{-1} (97.1) and 0 kg N + 50 kg P ha^{-1} (98.3). In the remaining combinations, plants produced moderate number of panicles. On the other hand, the panicle length was not much affected by nutrient combinations whereas the control resulted into significant shortest panicle length (19.67 cm) than all other combinations (Table 6). These lengths ranged from 21.29 cm to only 22.93 cm.

The results on number of spikelets per panicles showed significant differences in 0 kg N + 30 kg P ha^{-1} (8.9), 0 kg N + 50 kg P ha^{-1} (8.3) and 120 kg N + 0 kg P ha^{-1}, whereas other combinations and the control had similar effect in this parameter. Application of 120 kg N + 0 kg P ha^{-1} enhanced the plants to produce more spikelets per panicle (14.08). Similarly, significant differences were observed on grains per panicle in varying rates of nitrogen and phosphorus combinations and the control. Application of 80 kg N + 50 kg P ha^{-1} produced the highest number of grains per panicle (95.9) while the control gave the lowest mean number of grains per panicle (73.13) followed by 0 kg N + 30 kg P ha^{-1} (74.32). The rest of the combinations favoured the plants for an average number of grains per panicle.

Results on the 1000 grain weight indicate that grain-filling process was significantly affected by varying levels of nutrients. Application of 40 kg N + 30 kg P ha^{-1} produced the highest 1000-grain weight (23.80 g) compared to the control which gave lowest grain weight (19.34 g). Increasing rates of N and P did not necessarily increase 1000-grain weight; however, application of N generally influenced grain weight over the control.

The result on grain yield indicate that, the control (0 kg N + 0 kg P ha^{-1}) and increasing level of P to 50 kg ha^{-1} without N application had similar effect on the grain yield. At these nutrient combinations, the plants could not express their yield potential due to nitrogen deficiency which resulted into significantly lower yields (1474 kg ha^{-1}, 1363 kg ha^{-1} and 1574 kg ha^{-1} respectively) as compared to 2 918 kg ha^{-1} and 2 850 kg ha^{-1} observed with the application of intermediate levels of N (80 kg + 50 kg P ha^{-1} and 40 kg ha^{-1} + 30 kg P ha^{-1}) respectively. Land productivity and expression of the plants yield potential was found to be moderate under application of intermediate to high N rate (40 kg and 120 kg) with moderate application of P (30 kg) which were still significantly better than the control group.

Table 6: Mean effects of fertilizer nutrients (nutrient combinations) levels on growth, yield and yield parameters of rice.

Fertilizer treatment	Plant height (cm)	Days to 50% Flowering	Days to 80% Maturity	Biomass (g/m^2)	Harvest Index(%)	No. of Panicle/ m^2	Panicle Length (cm)	Spikelets/ Panicle (number)	No. of Grains/ panicle	1000 rain Weight (g)	Grain Yield (g/m^2)
0kgN+0kgP	73.92[a]	58.33[a]	90.67[a]	466.0[b]	30.92[bc]	98.7[a]	19.67[a]	11.30[abc]	72.13[a]	19.34[a]	147.4[a]
0kgN+30kgP	79.64[a]	65.17[b]	96.25[b]	445.8[a]	29.98[ab]	97.1[a]	21.29[b]	8.97[a]	74.32[ab]	20.64[ab]	136.3[a]
0kgN+50kgP	80.24[abc]	66.25[bc]	95.83[b]	483.4[c]	33.24[c]	98.3[a]	21.50[b]	8.83[a]	77.77[abc]	20.64[ab]	157.4[a]
40kgN+0kgP	81.89[abc]	66.25[bc]	96.67[b]	517.5[d]	41.08[ef]	149.2[b]	21.72[b]	10.52[ab]	85.61[cde]	21.21[ad]	221.0[b]
80kgN+0kgP	85.39[bcd]	67.83[bcd]	98.92[bc]	593.9[ef]	38.14[de]	163.2[b]	21.86[b]	10.64[ab]	77.73[abc]	22.41[cd]	244.9[bc]
120kgN+0kgP	93.02[e]	79.17[f]	107.58[d]	822.5[j]	27.30[a]	229.6[ef]	21.43[b]	14.08[c]	84.23[bcd]	22.33[cd]	226.7[bc]
40kgN+30kgP	93.02[e]	68.17[bcd]	99.42[bc]	607.0[f]	45.54[g]	221.8[d]	22.62[b]	11.96[abc]	77.96[abc]	23.80[e]	285.0[d]
80kgN+30kgP	87.78[bcd]	70.50[d]	99.92b[c]	704.6[gh]	38.11[de]	205.9[d]	22.23[b]	11.17[abc]	86.88[cdef]	22.41[cd]	255.5[bcd]
120kgN+30kgP	91.42[e]	77.08[e]	107.00[d]	742.5[i]	33.07[bc]	230.8[f]	22.07[b]	10.40[ab]	94.46[ef]	22.96[de]	238.4[bc]
40kgN+50kgP	88.03[cd]	68.92[cd]	99.75[bc]	581.6[e]	42.92[fg]	150.0[b]	21.71[b]	11.98[bc]	76.88[abc]	21.74[ab]	260.3[cd]
80kgN+50kgP	84.98[bcde]	71.00[d]	101.50[c]	692.6[g]	40.27[def]	222.3[e]	22.93[b]	10.83[ab]	95.90[f]	22.86[de]	291.8[d]
120kgN+50kgP	89.77[de]	74.83[e]	106.17[d]	712.2[h]	37.92[d]	229.0[ef]	22.15[b]	10.72[ab]	92.33[def]	22.88[de]	256.6[bcd]
Mean	**85.52**	**69.17**	**99.97**	**614.6**	**36.54**	**173.82**	**21.76**	**10.95**	**83.02**	**21.97**	**226.8**
C.V%	**7.1%**	**3.3%**	**1.3%**	**2.0%**	**6.3%**	**3.3%**	**5.5%**	**2.29%**	**9.0%**	**4.4%**	**12.2%**
S.E ±	**6.07**	**5.77**	**2.99**	**12.04**	**2.28**	**5.77**	**1.2**	**21.0**	**7.46**	**0.96**	**27.73**
Prob.	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**

Means followed by the same letter in a column are not significantly different according to Turkey Test at 95% confidence intervals

4.4 Interactive Effects of Varieties and Fertility Levels

4.4.1 Vegetative response

Analysis of variance (ANOVA) results (Table 4) for growth, yield and yield parameters did not show significant differences on mean interactive effects of varieties and fertility levels for plant height, panicle length and spikelets per panicles ($P \leq 0.05$). However, partitioning of variety x fertilizer interaction effect (Table 7a and 7b) indicates that they were significant differences probably because certain varieties were more influenced by fertilizer rates than the others.

Interaction of fertilizer rates with Machuwa variety was such that for days to 50% flowering, 120 kg N + 0 kg P ha^{-1} led to latest flowering (95.33 days) which was also latest overall. For Machuwa variety days to flowering at 120 kg N + 0 kg P ha^{-1} was statistically similar with days to flowering at 120 kg N + 30 kg P ha^{-1} but not with any other levels ($p \leq 0.05$). Earliest flowering was recorded by NERICA 1 variety (55 days) when no fertilizer was used. At all levels of fertility, Machuwa was generally the latest in flowering though not consistently significant. When no fertilizer was used, NERICA 1 was the earliest but only significantly when compared with Machuwa. When no N fertilizer applied, Machuwa was still latest to flower with increasing levels of P application. At these levels, NERICA 1 began to lose in earliness. When no P was applied but with intermediate levels of N (40 and 80 kg N ha^{-1}) days to flowering was not significantly influenced whatever the variety. Even Machuwa was statistically the same as others.

Similar to 50% flowering, interaction of fertilizer rates with Machuwa was such that for days to 80% maturity, 120 kg N + 50 kg P ha^{-1} and 120 kg N + 30 kg P ha^{-1} led to latest maturity (114.67 days) which was also the latest overall. When fertilizers were not applied, NERICA 1 was the earliest to reach maturity but only significantly when compared with Machuwa. When increasing N fertility, Machuwa was still latest to maturity when compared to other varieties.

Interaction of NERICA varieties with fertilizer rates for biomass yield was such that, application of 120 kg N ha^{-1} without P influenced NERICA 12 to accumulate highest biomass yield (8 770 kg ha^{-1}) that was the highest overall. For Machuwa variety biomass yield at 120 kg N ha^{-1} without P application was statistically similar with biomass at 80 kg N + 50kg P ha^{-1} and 80 kg N + 30 kg P ha^{-1} with NERICA 1. The increasing level of N and P to highest levels (120 kg N and 50 kg P ha^{-1}) significantly influenced biomass yield especially for NERICA 1 and Machuwa local variety when compared to control. Harvest index results was such that, interaction of fertilizer levels with NERICA varieties at 40 kg N + 30 kg P ha^{-1} led to NERICA 1 producing the highest harvest index (50.97%) compared to Machuwa at the same level of fertilizer. When fertilizers were not applied, NERICA 1 was exceeded by NERICA 12 for harvest index but not statistically different. However, it was significantly different when compared with Machuwa variety. With increasing N fertility, Machuwa variety consistently differed significantly from NERICA 1 in harvest index and was observed to have the lowest harvest index at 120 kg N/ha (13.90%) though comparable with the control ($P \leq 0.05$).

Table 7a: Mean interactive effects of varieties and soil fertility levels on growth parameters of rice

TREATMENT	Plant height (cm)	Days to 50% Heading	Days to 80% Maturity	**Biomass (g/m^2)**	**Harvest Index(%)**
0N+0P+NERICA 10	73.87^{ab}	56.67^{ab}	86.67^{abc}	473.6^{cd}	33.70^{efghi}
0N+0P+NERICA 12	76.20^{abc}	57.67^{abc}	86.00^{ab}	496.1^{de}	$36.87^{efghijk}$
0N+0P+NERICA 1	73.87^{ab}	55.00^{a}	85.00^{a}	497.8^{de}	35.30^{efghij}
0N+0P+MACHUWA	71.77^{a}	64.00^{bcdef}	$105.00^{fghijklm}$	396.8 a	17.80^{ab}
0N+30P+NERICA 10	78.07^{abcd}	60.00^{abcd}	90.00^{abcd}	479.3^{cde}	30.93^{efg}
0N+30P+NERICA 12	81.87^{abcdef}	65.00^{bcdefg}	95.00^{abcdef}	443.6^{bc}	30.70^{efg}
0N+30P+NERICA 1	76.60^{abc}	65.00^{bcdefg}	95.00^{abcdef}	467.3^{cd}	$38.10^{ghijklm}$
0N+30P+MACHUWA	82.03^{abcdef}	$70.67^{efghijk}$	$105.00^{fghijklm}$	393.0^{a}	20.17^{ab}
0N+50P+ NERICA 10	78.90^{abcd}	60.00^{abcd}	90.00^{abcd}	470.6^{cd}	$37.87^{fghijkl}$
0N+50P+ NERICA 12	81.53^{abcde}	65.00^{bcdefg}	95.00^{abcdef}	496.8^{de}	$39.30^{hijklmno}$
0N+50P+ NERICA 1	78.90^{abcd}	65.00^{bcdefg}	95.00^{abcdef}	489.8^{de}	32.87^{efgh}
0N+50P+ MACHUWA	81.63^{abcde}	75.00^{hijklm}	$103.33^{efghijkl}$	476.6^{cde}	22.93^{bcd}
40N+50P+ NERICA 10	$88.60^{abcdefg}$	$70.00^{efghijk}$	$101.67^{efghijk}$	653.9^{jk}	$45.70^{mnopqrs}$
40N+50P+ NERICA 12	$86.90^{abcdefg}$	62.33^{abcde}	94.00^{abcde}	693.4^{kl}	49.80^{qrs}
40N+50P+ NERICA 1	$84.23^{abcdefg}$	63.33^{abcdef}	93.33^{abcde}	577.1^{gh}	46.13^{nopqrs}
40N+50P+ MACHUWA	92.40^{bcdefg}	80.00^{lmn}	110.00^{klm}	401.9^{a}	30.03^{de}
40N+30P+NERICA 10	$90.27^{abcdefg}$	65.67^{cdefg}	95.00^{abcdef}	712.3^{lm}	50.27^{rs}
40N+30P+NERICA 12	$89.40^{abcdefg}$	65.67^{cdefg}	95.67^{bcdefg}	736.9^{mn}	50.77 s
40N+30P+NERICA 1	$90.27^{abcdefg}$	67.00^{defghi}	97.00^{defghi}	556.6^{g}	50.93^{s}
40N+30P+MACHUWA	102.13^{fg}	75.00^{hijklm}	110.00^{klm}	422.3^{ab}	30.20^{def}
40N+0P+NERICA 10	75.73^{ab}	$70.00^{efghijk}$	$100.00^{defghijk}$	573.7^{gh}	46.23^{nopqrs}
40N+0P+NERICA 12	$88.47^{abcdefg}$	$70.00^{efghijk}$	90.00^{abcd}	573.6^{gh}	$42.20^{jklmnopr}$
40N+0P+NERICA 1	75.73^{ab}	65.00^{bcdefg}	95.00^{abcdef}	515.5^{ef}	$45.03^{lmnopqrs}$
40N+0P+MACHUWA	$87.63^{abcdefg}$	$70.00^{efghijk}$	$101.67^{efghijk}$	407.2^{ab}	22.17^{bc}
80N+0P+NERICA 10	82.83^{abcdef}	66.67^{defgh}	$101.67^{efghijk}$	609.5^{hi}	48.10^{pqrs}
80N+0P+NERICA 12	82.00^{abcdef}	66.67^{defgh}	$98.33^{defghij}$	653.9^{jk}	47.27^{pqrs}
80N+0P+NERICA 1	$86.17^{abcdefg}$	68.00^{defghi}	$98.00^{defghij}$	625.7^{ij}	$38.03^{ghijklm}$
80N+0P+MACHUWA	$90.57^{abcdefg}$	$70.00^{efghijk}$	$101.00^{efghijk}$	486.7^{de}	19.17^{ab}
80N+30P+NERICA 10	$84.90^{abcdefg}$	66.67^{defgh}	$98.33^{defghij}$	779.3^{op}	$44.93^{lmnopqrs}$
80N+30P+NERICA 12	83.83^{abcdef}	$70.00^{efghijk}$	96.67^{cdefgh}	795.5^{opq}	48.27^{pqrs}
80N+30P+NERICA 1	$84.90^{abcdefg}$	$70.00^{efghijk}$	$97.67^{defghij}$	693.7^{kl}	$40.67^{ijklmnop}$
80N+30P+MACHUWA	97.50^{defg}	75.33^{ijklm}	107.00^{ijklm}	549.9^{fg}	18.57^{ab}
80N+50P+NERICA 10	80.00^{abcde}	64.67^{bcdef}	97.00^{defghi}	779.4^{op}	47.70^{pqrs}
80N+50P+NERICA 12	$86.43^{abcdefg}$	$70.00^{efghijk}$	$100.00^{defghijk}$	813.2^{pqrs}	47.67^{pqrs}
80N+50P+NERICA 1	80.00^{abcde}	71.33^{fghijk}	$102.00^{efghijkl}$	685.8^{kl}	$42.87^{jklmnopqr}$
80N+50P+MACHUWA	$91.17^{abcdefg}$	78.00^{klmn}	107.00^{ijklm}	491.8^{de}	22.83^{bcd}
120N+50P+NERICA 10	$89.27^{abcdefg}$	69.00^{efghij}	$100.67^{efghijk}$	789.6^{opq}	$42.47^{jklmnopq}$
120N+50P+NERICA 12	$84.37^{abcdefg}$	73.33^{ghijkl}	$103.33^{efghijkl}$	826.8 qrs	46.90^{opqrs}
120N+50P+NERICA 1	$89.27^{abcdefg}$	74.33^{hijklm}	106.00^{hijklm}	737.8^{mn}	$43.37^{klmnopqrs}$
120N+50P+MACHUWA	96.17^{cdefg}	82.67^{mn}	114.67^{m}	494.6^{de}	18.93^{ab}
120N+30P+NERICA 10	$86.07^{abcdefg}$	$70.00^{efghijk}$	$100.67^{efghijk}$	807.8^{opqr}	$38.93^{hijklmn}$
120N+30P+NERICA 12	$89.17^{abcdefg}$	77.00^{jklmn}	$103.33^{efghijkl}$	853.2^{st}	$36.80^{efghijk}$
120N+30P+NERICA 1	$86.07^{abcdefg}$	78.33^{klmn}	107.33^{jklm}	769.0^{no}	$39.30^{hijklmno}$
120N+30P+MACHUWA	104.37^{g}	85.00^{no}	114.67^{m}	560.0^{g}	17.23^{ab}
120N+0P + NERICA 10	$85.57^{abcdefg}$	$70.67^{efghijk}$	$101.33^{efghijk}$	874.1^{t}	32.50^{efgh}
120N+0P + NERICA 12	$89.20^{abcdefg}$	77.00^{jklmn}	107.67^{jklm}	877.0^{t}	33.03^{efghi}
120N+0P + NERICA 1	$85.57^{abcdefg}$	76.67^{jklmn}	109.33^{klm}	846.3^{rst}	29.77^{cde}
120N+0P + MACHUWA	99.63 efg	92.33 o	112.00lm	692.5 kl	13.90a
Mean	85.52	69.17	99.97	614.6	36.5
S.E ±	6.07	35.77	2.44	9.83	2.28
C.V (%)	7.1	3.3	3.0	2.0	6.3
P value	0.433	0.001	0.001	0.001	0.001

Means followed by the same letter in a column are not significantly different according to Turkeys Test at 95% confidence intervals

4.4.2 Reproductive and yield response

Results presented in Table 7b indicate that significant differences were observed in number of panicles per square meter due to interaction of rice varieties and fertility level ($p \leq 0.001$). The highest number of panicles (298) was observed in NERICA 1 at 80 kg N + 30 kg P ha^{-1} whereas variety Machuwa (local) produced the lowest number (68.0). Increasing N rate to 120 kg N ha^{-1} significantly influenced the number of panicles per meter square in Machuwa variety (105.3) compared to the control (74.3). In addition, increasing N rates to 120 kg ha^{-1} without P significantly influenced the number of panicles in NERICA 1 (292.7) which was statistically different to other N rates with NERICA. Application of 120 kg N ha^{-1} to NERICA 1 gave highest mean panicle (292.7) significantly differed compared to other rates. When P rate was increased it influenced the number of panicles in Machuwa variety but not statistically different from other rates. In NERICA 1, the number of panicles decreased with increasing P rate although differences were not significant.

Interaction of fertilizer rates with rice varieties for number of grains per panicle was 80 kg N + 50 kg P ha^{-1} led NERICA 1 and NERICA 10 to produce highest mean number of grains per panicle (114.40 grains) compared to Machuwa (58.47 grains). When fertilizer was not applied, NERICA 1 (72.23 grains) was exceeded Machuwa (59.30) but not statistically different. In addition, when P was not applied but with highest level of N (120 kg ha^{-1}), number of grains per panicle decreased in Machuwa variety (48.80 grains) compared to other rates but increased in NERICA 1 (98.87). When N fertilizer was not applied, NERICA 1 was significantly differed from Machuwa in mean number of grains number per panicle at 50 kg P ha^{-1}. Data on 1000 grain weight was such that, the interaction of 120 kg N + 30 kg P ha^{-1} with NERICA 12 produced the highest mean value (25.43 g) while variety Machuwa produced the lowest value (16.8g) when no fertilizer was applied (control). Significant difference was observed in 1000 grain weight from the control and the increasing N rates to 120 kg ha^{-1} in Machuwa variety. However, no statistically significant differences were observed between 40 kg, 80 kg and 120 kg N ha^{-1} for the mean 1000-grain weight in this variety. When N was not applied, variety Machuwa did not show significant difference in 1000-grain weight between means at 30 kg P, 50 kg P ha^{-1} and control. Similarly, there was no significant difference in 1000 grain weight when 0 kg P, 30 kg P and 50 kg P + 120 kg N ha^{-1} was applied to NERICA 12.

As of grain yield, the highest mean interactive effect was observed at 80 kg N + 50 kg P ha^{-1} with NERICA 12 (3 881 kg ha^{-1}) while at the same level the lowest was Machuwa variety (1 125 kg ha^{-1}). No statistically significant difference was observed in Machuwa grain yield at the control and any other fertilizer rate. When N fertilizer was applied in varying level, Machuwa still had the lowest grain yield. Grain yield of NERICA 12 was influenced by varying levels of N from 0 kg ha^{-1} to 80 kg ha^{-1} but not significantly different from the highest level (120 kg ha^{-1}). In addition, NERICA 1 and NERICA 12 (1 831kg ha^{-1}) differed significantly in grain yield when compared to Machuwa (708 kg ha^{-1}) at control.

Table 7b: Interactive effects of varieties and nutrients levels on yield parameters of rice

TREATMENT	Number of Panicles	Panicle Length (cm)	Spikelet /Panicle	Grains /panicle^{-1}	1000 grain /weight (g)	Grain yield (g/m^{2})
0N+0P+NERICA 10	104.3 ^{e}	20.33 ^{abcdefg}	99.63 ^{efg}	72.23 ^{abcdef}	18.53^{ab}	159.6^{abcdefg}
0N+0P+NERICA 12	106.7 ^{e}	20.6 ^{abcdefg}	13.37 ^{ab}	84.73 ^{fgh}	21.60^{bcdefgh}	183.1^{cdefghi}
0N+0P+NERICA 1	109.3 ^{e}	20.33 ^{abcdefg}	12.43 ^{ab}	72.23 ^{abcdef}	20.43^{bcdef}	176.2^{bcdefgh}
0N+0P+MACHUWA	74.3 ^{ab}	17.40 ^{a}	10.77 ^{ab}	59.30 ^{abcde}	16.80^{a}	70.8^{a}
0N+30P+NERICA 10	102.7 ^{de}	21.50 ^{bcdefg}	13.37 ^{ab}	76.10 ^{bcdefg}	19.90 ^{abcde}	148.9^{abcdef}
0N+30P+NERICA 12	101.0 ^{de}	23.23 ^{efg}	9.10 ^{ab}	92.67 ^{fghij}	21.40^{bcdef}	138.1^{abcd}
0N+30P+NERICA 1	107.3 ^{e}	21.50^{bcdefg}	9.40 ^{ab}	76.10 ^{bcdefg}	21.77^{cdefghi}	176.1^{cdefgh}
0N+30P+MACHUWA	77.3 ^{abc}	18.93 ^{abcd}	7.70 ^{a}	52.40 ^{ab}	19.50^{abcd}	82.3^{a}
0N+50P+ NERICA 10	108.0 ^{e}	22.00 ^{bcdefg}	9.70 ab	79.73 ^{cdefgh}	19.90^{abcde}	179.8^{bcdefgh}
0N+50P+ NERICA 12	104.7 e	22.97^{defg}	9.30 ^{ab}	100.33 ^{ghi}j	21.40^{cdefgh}	195.3^{defghi}j
0N+50P+ NERICA 1	103.7 $_{e}$	20.80 ^{abcdefg}	9.00 ^{ab}	79.73 ^{cdefgh}	21.77^{cdefghi}	161.3^{abcdefg}
0N+50P+ MACHUWA	76.7 ^{abc}	20.23 ^{acdefgb}	7.3 ^{a}	51.27 ^{ab}	19.50^{abcd}	93.1^{abc}
40N+50P+ NERICA 10	205.3 ^{hi}	22.10 ^{bcdefg}	13.07 ^{ab}	81.40 ^{defgh}	19.93^{abcde}	309.7^{klmnop}
40N+50P+ NERICA 12	195.0 ^{gh}	22.80^{defg}	13.07 ^{a}b	95.10 ^{fghij}	25.00^{jk}	345.7^{lmnop}
40N+50P+ NERICA 1	103.7 ^{e}	22.10 ^{bcdefg}	9.70 ^{ab}	79.73 ^{cdefgh}	21.23^{bcdefgh}	264.7^{hijkl}
40N+50P+ MACHUWA	96.0 ^{cde}	19.83 ^{abcdef}	12.87 ^{ab}	51.27 ^{ab}	20.80^{bcdefg}	120.9^{abcd}
40N+30P+NERICA 10	220.7 ^{ij}	23.13 ^{efg}	12.87 ^{ab}	81.40 ^{defgh}	23.40^{fghijk}	358.3^{mnop}
40N+30P+NERICA 12	232.7 ^{j}	23.40 ^{efg}	12.53 ^{ab}	95.10 ^{fghij}	24.77^{ijk}	376.4^{op}
40N+30P+NERICA 1	292.3 ^{op}	23.13 ^{efg}	12.13 ^{ab}	81.40 ^{defgh}	24.17^{hijk}	283.6^{jklmno}
40N+30P+MACHUWA	101.3^{de}	20.80 ^{abcdefg}	10.30 ^{ab}	53.93 ^{ab}	22.87^{efghijk}	121.5^{abcd}
40N+0P+NERICA 10	182.3 ^{fg}	22.40 ^{cdefg}	11.33 ^{ab}	90.27 ^{fghij}	22.63^{defghijk}	295.1^{klmnop}
40N+0P+NERICA 12	172.3 ^{f}	23.13 ^{efg}	11.33 ^{ab}	104.63 ^{hij}	20.80^{bcdef}	266.2^{hijklm}
40N+0P+NERICA 1	172.3^{f}	23.13 ^{efg}	10.00 ^{ab}	90.27 ^{fghij}	22.57^{defghijk}	232.3^{efghijk}
40N+0P+MACHUWA	68.0 ^{a}	18.20 ^{ab}	9.40 ^{ab}	57.27 ^{abcd}	1923^{bcdef}	90.6^{abc}
80N+0P+NERICA 10	194 ^{gh}	22.90 ^{defg}	11.80 ^{ab}	82.37 ^{efgh}	21.20^{bcdefgh}	293.6^{klmno}
80N+0P+NERICA 12	191.0 ^{fgh}	22.90 ^{defg}	11.17 ^{ab}	94.43 ^{fghij}	22.83^{efghijk}	311.5^{klmnop}
80N+0P+NERICA 1	184.3 ^{fg}	23.13 ^{efg}	10.97 ^{ab}	82.37 ^{efgh}	22.80^{efghijk}	234.7^{fghijk}
80N+0P+MACHUWA	83.3 ^{abcd}	23.13 ^{efg}	8.63 ^{ab}	51.73 ^{ab}	22.80^{efghijk}	139.5^{abcde}
80N+30P+NERICA 10	228.3 ^{j}	22.63 ^{cdefg}	11.40 ^{ab}	96.33 ^{fghij}	23.50^{fghijk}	266.1^{hijklm}
80N+30P+NERICA 12	226.7 ^{j}	23.37 ^{efg}	11.87 ^{ab}	98.77 ^{ghij}	23.83^{ghijk}	369.1^{nop}
80N+30P+NERICA 1	298.0 ^{p}	22.63 ^{cdefg}	12.80 ^{ab}	96.33 ^{fghij}	22.40^{cdfghijk}	283.7^{jklmno}
80N+30P+MACHUWA	70.7 ^{a}	20.30 ^{abcdefg}	8.60 ^{ab}	51.73 ^{ab}	21.70^{bcdefghijk}	103.7^{abcd}
80N+50P+NERICA 10	274.3 ^{lmno}	24.23 ^{g}	11.33 ^{ab}	114.40 ^{j}	23.20^{fghijk}	372.2^{op}
80N+50P+NERICA 12	258.0 ^{kl}	23.50 ^{fg}	12.33 ^{ab}	96.33 ^{fghij}	24.70^{ijk}	388.1^{p}
80N+50P+NERICA 1	265.0 ^{klm}	24.23 ^{g}	12.03 ^{ab}	114.40 ^{j}	23.10^{fghijk}	294.3^{klmno}
80N+50P+MACHUWA	92.0 ^{bcde}	19.77 ^{abcdef}	7.60 ^{a}	58.47 ^{abcde}	23.37^{bcdef}	112.5^{abcd}
120N+50P+NERICA 10	265.3 ^{klm}	22.07 ^{bcdefg}	11.13 ^{ab}	112.10 ^{ij}	23.23^{fghijk}	290.1^{klmno}
120N+50P+NERICA 12	263.7 ^{kl}	22.90^{defg}	11.80 ^{ab}	88.93 ^{fghi}	24.70^{ijk}	370.8^{op}
120N+50P+NERICA 1	285 ^{nop}	22.07 ^{bcdefg}	10.53 ^{ab}	112.73 ij	21.27^{bcdefghijk}	276.9^{jklmn}
120N+50P+MACHUWA	102.^{d}	21.57 ^{bcdefg}	9.40 ^{ab}	55.57 ^{abc}	23.37^{cdefghijk}	88.4^{ab}
120N+30P+NERICA 10	268.3^{klmn}	22.57 ^{cdefg}	10.33 ^{ab}	112.97 ij	21.73^{bcdefghi}	276.0^{ijklmn}
120N+30P+NERICA 12	266.0 ^{klmn}	23.03^{efg}	11.47 ^{ab}	94.97 ^{fghij}	25.43^{k}	294.2^{klmno}
120N+30P+NERICA 1	284.3 ^{mnop}	22.57 ^{cdefg}	11.47 ^{ab}	112.97 ij	22.77^{efghijk}	191.8^{klmno}
120N+30P+MACHUWA	104.7 ^{e}	20.13 ^{abcdef}	8.33 ^{ab}	56.93 ^{abcd}	21.90^{cdefghijk}	91.4^{abc}
120N+0P + NERICA 10	265.7 ^{klmn}	20.13^{abcdef}	14.10 ^{ab}	98.87 ^{ghij}	20.33^{abcdef}	277.5^{jklmn}
120N+0P + NERICA 12	254.7 ^{k}	22.47^{cdefg}	15.57 ^{b}	90.40 ^{fghij}	25.33^{k}	292.1^{klmno}
120N+0P + NERICA 1	292.7 ^{op}	21.70^{bcdefg}	14.33 ^{ab}	98.87 ^{ghij}	22.37 ^{cdefghijk}	244.9^{ghijk}
120N+0P + MACHUWA	105.3 ^{e}	19.40^{abcde}	12.30 ^{ab}	48.80 ^{a}	21.27^{bcdefgh}	92.4^{abc}
Mean	173.82	21.76	10.95	83.2	21.97	226.8
S.E±	5.77	1.2	21.0	7.4	0.96	27.73
C.V (%)	3.3	5.5	2.3	9.0	4.4	12.2
P value	0.001	0.582	0.995	0.001	0.001	0.001

Means followed by the same letter in a column are not significantly different according to Turkeys Test at 95% confidence interval

4.5 Discussion

4.5.1 Weather and soil parameters

4.5.1.1 Weather parameters - rainfall

Weather data showed that there was a sharp increase in rainfall from 103.9 mm in March to 436.6 mm in April, thereafter decreased to 248.2 mm, 98.6 mm and 74.2 mm in May, June and July respectively. Even though the total amount of precipitation appeared to be high (873.4mm), distribution was uneven during the experiment period. There was high rainfall during the vegetative growth of the crop that favoured tillering of NERICA variety. Tillers that developed at early stage grew profusely producing panicles contributed to yield, as most of them were productive tillers. Rainfall decreased during grain filling and at maturity in June and July. According to Africa Rice (2008), NERICA rice performs well even at relatively low rainfall. A minimum of 20 mm per week is required which should be well distributed throughout the growing period. Results showed that the month of July received 74.2 mm (18.5mm/week) of rainfall lower than the minimum required for NERICA, which might have affected yield of these varieties. Such situation must have reduced at least slightly the assimilate partitioning from the source to sink hence increasing the number of unfilled grains. It may also have affected physiological attributes such as days to flowering subsequently delaying crop maturity and harvesting as stated by Ahmed *et al*. (2005).

4.5.2 Soil parameters

4.5.2.1 Soil texture

Texture is the most important property of rice soils. It affects the moisture status of a soil more than any other property except topography. The soil texture of sand clay loam at the experimental site suits production of the released upland NERICA varieties. Texture is particularly important in upland rice fields that have no bunds to hold moisture. For upland rice cultivation, fine to sandy texture soils are often considered (De Datta, 1991). A study by Shekifu (1991) in some rice growing regions of Tanzania revealed that the texture of the rice soil ranged from sandy to loam to clay. In general, optimum rice production requires soils of medium to heavy texture although in practice rice production is carried out in soils ranging from sandy loam to heavy clays (Landon, 1991).

4.5.2.2 Soil pH

Result of soil analysis showed that the soil of the experimental site was moderately acidic (pH 5.4). Soil pH has profound effect on nutrient availability and hence soil fertility. Hailes *et al.* (1997) found pH range for most agricultural crops to be 5.5 – 7.5. For rice production in upland condition, the favourable pH is 6.5 – 7.0. Below this range manganese and aluminium toxicity can occur in strongly acidic soils and iron deficiency in alkaline soils (Yoshida, 1981). From the soil analysis result of this study the soil of the experimental site was in need of pH improvement practices to 6.5 like increasing the organic matter.

4.5.2.3 Total nitrogen

According to NSS (1990) guidelines, the proposed nitrogen value for most crops in Tanzania is 2% kg^{-1} soil. Soil of the experimental site was 1.6% N kg^{-1} soil. Less total nitrogen is a general characteristic of aerobic rather than anaerobic soils due to low mineralization process in aerobic soils (Borthakur and Mazumder, 1968).

4.5.2.4 Available phosphorus

According to Landon (1991), the experimental site soil's available phosphorus level of 2.8ppm was very low. Phosphorus deficiency is widespread in rain-fed rice soil and is particularly prominent in drought-prone environments because its mobility decreases sharply as soil dries. The availability of phosphorus is lower in upland soils than in submerged soils because upland soils are aerobic and tend to be acidic. Furthermore, some upland soils fix phosphate more readily than do alluvial lowland soils, so they require more phosphate fertilizer (Landon, 1991).

4.5.2.5 Soil organic matter

Results indicated that the soil at the experimental site was medium in organic matter content (36.8g kg^{-1} soil) and is above the threshold level (34g kg^{-1}soil) according to Loveland and Webb, (2003). The importance of organic matter as described by Tisdale *et al.* (1993) is improvement of physical and chemical soil properties that favourably influence nutrient availability to the plant. Therefore, the soil at the experimental site favours the growth and yield of upland rice production as shown in this study.

4.5.2.6 Cations exchange capacity (CEC)

The soil analysis results indicated that the CEC of the experimental site was 20.3 cmol kg^{-1} soil, ranked as medium according to EUROCONSULT (1989). According to Landon (1991) the higher the CEC the more the fertile and productive the soil.

4.5.3 Significance of NERICA varieties

4.5.3.1 General Growth of the plants

Generally, during the vegetative growth rice plants were good, but there were some differences among the varieties. Plants of NERICA appeared more vigorous and greener while Machuwa local variety was the least especially in vigor and intensity of green colour, obviously because of genetic differences. In addition, NERICA varieties plots harboured low density of weeds compared to the check variety. These observations agreed with report by Kaneda (2007a) that NERICA varieties have desirable agronomic traits that are potentially useful for weed competitiveness including:- good vigor at seedling and vegetative stages for weed suppression, intermediate to tall stature and moderate tillering ability, making them superior to local landraces. In addition, they have characteristic wide, droopy leaves that are able to suppress weeds (Dzomeku *et al.,* 2007).

Machuwa variety, the most common local grown by farmers in Pemba has already been replaced by the released upland New Rice for Africa (NERICA) like NERICA1, NERICA10 and NERICA 12. These new varieties have several superiorities, especially their yield potential which is higher than that of the local land race except for height. In generally, the study results have exhibited differences in the genetic makeup of the rice varieties used and their differences in nitrogen-phosphorus fertility responses. These findings are in agreement with those by Surek and Baser (2003, 2005) who found that rice genotypes differed significantly for grain yield and yield component traits.

The results indicate that Machuwa variety was significantly taller than all the NERICA varieties, which is in agreement with Africa Rice report (2008) that NERICA varieties are short, and have short growth cycle. Maturity period of rice is classified as very early (less than 105days), early (l05-120 days), medium (121-135 days) (IRRI, 1992). According to this classification, NERICA varieties (98.39 days to maturity) can be categorised as very early maturing while Machuwa (107 days) as early maturing. This is in agreement with the report of Defoer *et al.* (2002) that, NERICA generally have much shorter growing cycle (about 90-110 days) compared to local varieties and that it is possible to have a double cropping under sufficient rainfall.

Biomass yield in rice varieties influenced by leaf area index, plant height, number of tillers per unit area, 1000-grain weight and grain yield. The result of this study showed that

NERICA varieties out yielded Machuwa in number of productive tillers, panicle length, grains per panicle, 1000-grain weight and grain yield hence biomass yield. These results are similar to those by Ebaid *et al.* (2007) who found that the increase in biological and grain yield could be due to the increase in yield attributes (plant height, number of productive tillers/hill, panicle weight and 1000-grain weight).

Results indicated that NERICA varieties have higher harvest index probably because of high potential for panicle production and high ability to partition photosynthates more efficiently to the grains compared to the local variety. Also high harvest index observed in NERICA varieties has been associated with enhanced grain yield as evident from the results of this study.

4.5.3.2 Yield and yield components

The results indicated that NERICA varieties had high number of productive tillers (panicles) per meter square compared to local check. These results are in agreement with report by Okeleye *et al.* (2006) and Oikeh *et al.* (2008) that NERICA varieties were preferred by the South Western Nigerian farmers because of their good tillering (panicles) ability.

NERICA varieties outperformed Machuwa in panicle length as the main characteristic of all high yielding varieties. This result confirms the report of Abdul Karim (2010) that high yielding rice varieties have higher panicle length. It is generally recognized that the number of spikelets per panicle or number of panicles per unit area determine rice yield depending on the cultivar. Grain yield increased in most cultivars with increased number of spikelets per panicle. Results of this study revealed that the released upland NERICA varieties are superior for number of spikelets per panicle compared to Machuwa, which influences high grain yield. This is in agreement with finding of Matsunami *et al.* (2009). Also, Dingkuhn (1998) reported local land races having limited number of spikelets per panicle because of lack of secondary branches. Results indicated that NERICA varieties recorded highest 1000-grain weight compared to Machuwa. This agreed with report by Dingkuhn *et al.* (1998) who found the superiority of NERICA cultivars on seed weight compared to CG 14 land race cultivar. It also agrees with Kamara *et al.* (2009) that rice cultivars significantly influenced 1000-grain weight due to differences in seed sizes**.** On the attribute of grain yield NERICA varieties out yielded the Machuwa local variety. This is in agreement with JICA (2006) that NERICA has surpassed the local landraces in grain yield with a potential to revolutionize the rice industry in Africa.

4.5.4 Significance of fertilizer combinations

4.5.4.1 Significance of nutrient rates over the control

It is evident from the results that plant height increased from the control plot with the increasing level of nutrients fertility. This is in line with report by Saito *et al.* (2006) who found that application of higher rate of nitrogen-phosphorus gave higher rice plant height than lower rate because the supply of nutrients were not enough to meet the growth requirements. The results also showed that nitrogen-phosphorus fertilizers influences flowering and maturity periods. Nitrogen increases chlorophyll content of the leaves hence influences photosynthesis process. Phosphorus influences all energy processes that take place in plants. Therefore, increasing nitrogen phosphorus fertility stimulates vegetative growth resulting to delaying flowering and maturity. It is evident from this experiment that days to flowering and maturity increased from 58.3 and 90.67 at control plots to 89.77 and 106.17 respectively at 80 kg N + 50 kg P ha^{-1} a significant delay in reproductive growth attributes. The results support the findings by Kaneda (2006) that low fertility level appeared as a good alternative to reduce days required to heading and maturity.

The results also indicated that, increasing fertility level to 120 kg N ha^{-1} without P application increases biomass yield, which must be due to increasing vegetative growth of the rice plant. The available nutrients might have helped in enhancing leaf area and increasing photosynthesis rate that resulted in higher photo-assimilates production and more dry matter production. Elsewhere, application of 70 kg N to 100 kg N ha^{-1} resulted in significantly higher total dry matter than the lower rate or control (Mirza *et al.* 2010). Harvest index was reduced from 45.54% at (40 kg N + 30 kg P ha^{-1}) to 27.30% by increasing fertility levels (120 kg N + 0 kg P ha^{-1}) due to increasing vegetative growth, reduced panicle length, grains per panicle and grain yield due to low accumulation of dry matter to the grains. In addition, it was observed that fertility level tend to increase number of panicles (productive tillers) per unit area in rice. Different nitrogen and phosphorus fertilizer combinations influence number of productive tillers in rice and the two nutrients play a vital role in cell division, Mirza *et al.* (2010); Fabio *et al*. (2013). Positive effects of nitrogen phosphorus fertility level was observed on panicle length, which increased from 19.67cm at control to 22.93cm at 80 kg N + 50 kg P ha^{-1}. Beyond that level, however, nitrogen phosphorus fertility seemed to stimulate vegetative growth and caused panicle length reduction. These results support findings of Shen *et al.* (2003) that higher levels of nitrogen phosphorus lead to increase in vegetative growth and reduce the panicle length. The result implied that nitrogen fertilizer have high influences on increasing number of spikelets per panicle. Number of spikelets increased from 8.9 at the control plot to 14.08 at 120 kg N + 0 kg P ha^{-1}. Maud *et al.* (2003) in Brazil and Ahmed *et al.* (2005) in Bangladesh found the similar results. In addition, similar finding was observed in 1000-grain weight. A 1000-grain weight increased from (19.34 g) at control plots to (23.80 g) at 40 kg N + 30 kg P ha^{-1}. Other fertility levels produced lower 1000-grain weight. This finding is consistent with Mauad *et al*. (2003) observations that increments in nitrogen phosphorus rates reduced the mass of 1000-grain weight probably because the amount of carbohydrates produced was not sufficient to fill the greater number of spikelets. Obviously, rice grain yield increased as the level of nitrogen-phosphorus increased. Oikeh *et al*. (2006) found that doubling the level of Nitrogen and Phosphorus at the same levels of potasium increased grain yield by 25% over a moderate nitrogen-phosphorus. Further, Kamara *et al*. (2011) concluded that Nitrogen application increased rice grain yield and yield components with the highest grain yield obtained at 100 kg N ha^{-1}. In this study, the highest grain yield was recorded at 80 kg N + 50 kg P ha^{-1}.

4.5.4.2 Significance of different nutrients - Nitrogen

(a) Vegetative growth

Nitrogen as one of the major plant nutrients is very essential for growth and yield of rice (Ahmed *et al*., 2005). It has been observed in this experiment that plant height increased as the rate of nitrogen increased from 73.92cm at the control plot to 93.02cm at 120 kg N. Similar findings were reported by Lee (1998) that application of nitrogen fertilizer produced more vigorous and taller plants than those that did not receive any nitrogen. The increase in plant height with increased nitrogen application might be primarily due to enhanced vegetative growth with more nitrogen supply to plant. Similar to plant height, nitrogen has great influence on days to flowering and maturity in rice. Results of this study indicated that number of days to flowering and maturity increased as the rate of nitrogen increased. This is because nitrogen increases chlorophyll on the leaves hence influences the rate of photosynthesis and photosynthates production hence promoting vegetative growth resulting to delay in flowering and maturity.

It is obvious from the result that biological yield increased as the rate of nitrogen increased due to increase in vegetative growth. Nitrogen increased straw yield with effect on plant vegetative growth by increasing tiller number and plant height. The results confirm findings of Saito (2006) that application of higher rate of nitrogen (70 -130 kg ha^{-1}) was responsible for higher total dry matter accumulation. In addition, harvest index was also affected by increasing N-level, perhaps due to increasing straw yield, reducing panicle length and lowering grains per panicles due to low dry matter accumulation in the grains that ultimately gave the lower harvest indices.

(b) Yield and yield components

Nitrogen levels significantly affected number of tillers (panicles) per meter square. Maximum number of panicles was produced at 120 kg N ha^{-1} and other levels were statistically at par with each other. These results are in line with those reported by Nawaz (2002) and Meena *et al.* (2003) that enhanced tillering (panicle) by increased nitrogen application might be attributed to more nitrogen supply to plant at active tillering stage. On panicle length, increasing nitrogen fertilizers caused an increase in panicle length from 19.67cm at control to 21.43cm at 120 kg N ha^{-1}.

This result disagreed with that of Shen *et al.* (2003) that panicle length decreased with higher rates of nitrogen but agreed with Syafrudin *et al.* (2003) that nitrogen fertilization consistently increased panicle length probably because the second dose of nitrogen at panicle initiation stage might influence panicle elongation. In addition, the results have indicated that as we go from higher level of nitrogen to lower level, number of grains per panicle was reduced. Similar findings have been reported by Bhowmick and Nayak (2000) and Nawaz (2002) that more number of grains per panicle obtained in treatments receiving higher nitrogen levels were probably due to better nitrogen status of plants during panicle growth and grain filling period. A 1000-grain weight was significantly influenced by nitrogen levels, such that maximum 1000-grain weight (22.41 g) was obtained at 80 kg N ha^{-1}. Similar findings have been reported by Bhowmick and Nayak

(2000). Increase in 1000-grain weight at higher nitrogen rates might be primarily due to increase in chlorophyll content of leaves which led to higher photosynthetic rate and ultimately plenty of photosynthates available during grain development. Results of this experiment also indicated that paddy grain yield increased with increasing nitrogen levels upto 80 kg N ha^{-1}. This finding isagrees with Bhowmick and Nayak (2000) and Boling *et al*. (2004), that paddy yield increases with the increasing level of nitrogen from 110 to 156 kg ha^{-1}.

(c) Significance of Phosphorus

P is the second important nutrient for plant growth, promotes root development, tillering, and early flowering, and is involved in metabolic activities, particularly in synthesis of proteins (Panhawar *et al.,* 2011). Plant height increased slightly (but not significantly) from the control (73.92 cm) to 50 kg P ha^{-1} (80.24 cm). This suggests that phosphorus has an effect on plant growth. It promotes root growth responsible for nutrients absorption from the soil that enhances plant development as stated by Panhawar *et al.,* 2011. In addition, it is evident from the results that phosphorus had some effect on number of filled grains in rice, which increased as the rate of phosphorus increased from the control to 50 k P ha^{-1}. The results agree with those of Yosefi *et al.* (2011). Results of this study also indicated that phosphorus fertilizer rate had some effect on rice grain yield where maximum grain yield was obtained by applying 50 kg P ha^{-1}. The results are consistent with those of Panhawar *et al*. (2011) and Yosef Tabar (2009) who observed the highest grain yield by applying 90 kg P ha^{-1} with Torim Hashem rice cultivar.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study revealed the suitability of released upland NERICA varieties for upland conditions of Zanzibar. The NERICA varieties showed significant improvement over Machuwa local variety on number of panicles per square meter, panicle length, earliness to flowering and maturity, biomass accumulation efficiency (total biomass) harvest index, number of filled grains per panicle, 1000 grain weight and grain yield. The local variety also exceeded NERICA varieties in plant height. For maximum panicle length, spikelets per panicle, 1000-grain weight, grain yield and harvest index, NERICA 12 was best overall. NERICA 1 was more superior in number of filled grains per panicle, early flowering and maturity.

Different combination rates of nitrogen-phosphorus application had significant influence on growth and productivity of rice. Application of 80 kg N $_+$ 50 kg P ha^{-1} resulted in highest harvest index, 1000-grain weight, grain yield and plant height while maximum number of filled grains, and panicle length were recorded at 40 kg N + 30 kg P ha^{-1}. Large quantity of biomass was achieved by application of 120 kg N, whereas early flowering and maturity was influenced by not applying any fertilizer (0 kg N + 0 kg P ha^{-1}).

Interaction of NERICA 12 x 80 kg N + 50 kg P ha^{-1} produced highest grain yield (388.1g/m^2 or 3881kg/ha) followed by NERICA 12 x 40 kg N + 30 kg P ha^{-1} (376.4 g/m^2 or 3 764 kg ha^{-1}). The difference between the two yields was not statistically different. One can conclude that NERICA varieties are more interactive at low and high fertility levels and produce significantly higher grain yield compared to Machuwa local variety.

Nitrogen application increased rice grain yield and yield components with the highest grain yield obtained at 80 kg N/ha (2 449 kg/ha) in absence of P application. Nitrogen application at even lower rates significantly increased grain yield of the rice suggesting that nitrogen is a major limiting nutrient in the study area. It has been observed that rice plant need nitrogen almost throughout the vegetative phase but in particular at tillering and panicle initiation phase as recommended to apply nitrogen in two splits (at tillering and panicle initiation stage). Effect of phosphorus was not as visible as it is for nitrogen in this experiment but it plays an important role in physiological development of rice plant. Even though the highest grain yield was observed when 50, kg P ha^{-1} applied without nitrogen.

5.2 Recommendations

These recommendations are made in respect to the results obtained from the experiment.

i. Based on the rice responses to applied nitrogen phosphorous combinations, application of 40 kg N + 30 kg P /ha for resource limited smallholder production systems and 80 kg N + 50 kg P /ha for moderate to higher resource farmers, may be adopted for production of released upland NERICA in Zanzibar.

ii. For improving rice productivity in Zanzibar NERICA 12, NERICA 10 and NERICA 1 may substitute Machuwa local variety.

iii. More research should be performed to evaluate response of upland rice varieties and make very specific recommendations depending on soil characteristics and response of the varieties.

iv. Agronomical and Socio-economical evaluation trials at farmers field should be encouraged to seek more information and farmers opinions on suitability of the

NERICA varieties compared to existing local and improved upland Indica varieties.

v. Farmers should be encouraged to grasp the importance of maintaining soil fertility status for sustainable soil productivity and encouraging farmer to split nitrogen fertilizer into two, at tillering and panicle initiation stage.

vi. It is recommended to confirm these findings in more experimental trials in different cropping seasons and different locations because the results reported were obtained from a single cropping season.

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APPENDICES

Appendix 1: Fertilizer combinations

kgN/ha kgP/ha	0	40	80	120
0	0,0	0,40	0,80	0,120
30	30,0	30,40	30,80	30,120
50	50,0	50,40	50,80	50,120

Appendix 2a: Experimental layout Replication 1

VARIETY 1	VARIETY 2	VARIETY 3	VARIETY 4
50,0 x NERICA 1	0,0 x NERICA 12	50,120 x MACHUWA	30,40 x NERICA 10
30,40 x NERICA 1	30,0 x NERICA 12	30,80 x MACHUWA	0,40 x NERICA 10
0,40 x NERICA 1	50,0 x NERICA 12	0,40 x MACHUWA	50,80 x NERICA 10
50,120 x NERICA 1	0,40 x NERICA 12	0,0 x MACHUWA	30,120 x NERICA 10
30,80 x NERICA 1	50,120 x NERICA 12	30,40 x MACHUWA	50,40 x NERICA 10
0,0 x NERICA 1	50,40 x NERICA 12	50,40 x MACHUWA	30,0 x NERICA 10
0,120 x NERICA 1	0,80 x NERICA 12	30,120 x MACHUWA	0,0 x NERICA 10
50,80 x NERICA 1	30,80 x NERICA 12	0,80 x MACHUWA	50,120 x NERICA 10
0,80 x NERICA 1	50,80 x NERICA 12	30,0 x MACHUWA	30,80 x NERICA 10
30,120 x NERICA 1	0,120 x NERICA 12	0,120 x MACHUWA	50,0 x NERICA 10
30,0 x NERICA 1	30,120 x NERICA 12	50,0 x MACHUWA	0,120 x NERICA 10
50,120 x NERICA 1	30,40 x NERICA 12	50,80 x MACHUWA	0,80 x NERICA 10

Appendix 2b: Experimental layout Replication 2

VARIETY 3	VARIETY 1	VARIETY 4	VARIETY 2
50,120 x MACHUWA	50,0 x NERICA 1	30,40 x NERICA 10	0,0 x NERICA 12
30,80 x MACHUWA	30,40 x NERICA 1	0,40 x NERICA 10	30,0 x NERICA 12
0,40 x MACHUWA	0,40 x NERICA 1	50,80 x NERICA 10	50,0 x NERICA 12
0,0 x MACHUWA	50,120 x NERICA 1	30,120 x NERICA 10	0,40 x NERICA 12
30,40 x MACHUWA	30,80 x NERICA 1	50,40 x NERICA 10	50,120 x NERICA 12
50,40 x MACHUWA	0,0 x NERICA 1	30,0 x NERICA 10	50,40 x NERICA 12
30,120 x MACHUWA	0,120 x NERICA 1	0,0 x NERICA 10	0,80 x NERICA 12
0,80 x MACHUWA	50,80 x NERICA 1	50,120 x NERICA 10	30,80 x NERICA 12
30,0 x MACHUWA	0,80 x NERICA 1	30,80 x NERICA 10	50,80 x NERICA 12
0,120 x MACHUWA	30,120 x NERICA 1	50,0 x NERICA 10	0,120 x NERICA 12
50,0 x MACHUWA	30,0 x NERICA 1	0,120 x NERICA 10	30,120 x NERICA 12
50,80 x MACHUWA	50,120 X NERICA 1	0,80 x NERICA 10	30,40 x NERICA 12

Appendix 2c: Experimental layout Replication 3

VARIETY 4	VARIETY 2	VARIETY 1	VARIETY 3
30,40 x NERICA 10	0,0 x NERICA 12	50,0 x NERICA 1	50,120 x MACHUWA
0,40 x NERICA 10	30,0 x NERICA 12	30,40 x NERICA 1	30,80 x MACHUWA
50,80 x NERICA 10	50,0 x NERICA 12	0,40 x NERICA 1	0,40 x MACHUWA
30,120 x NERICA 10	0,40 x NERICA 12	50,120 x NERICA 1	0,0 x MACHUWA
50,40 x NERICA 10	50,120 x NERICA 12	30,80 x NERICA 1	30,40 x MACHUWA
30,0 x NERICA 10	50,40 x NERICA 12	0,0 x NERICA 1	50,40 x MACHUWA
0,0 x NERICA 10	0,80 x NERICA 12	0,120 x NERICA 1	30,120 x MACHUWA
50,120 x NERICA 10	30,80 x NERICA 12	50,80 x NERICA 1	0,80 x MACHUWA
30,80 x NERICA 10	50,80 x NERICA 12	0,80 x NERICA 1	30,0 x MACHUWA
50,0 x NERICA 10	0,120 x NERICA 12	30,120 x NERICA 1	0,120 x MACHUWA
0,120 x NERICA 10	30,120 x NERICA 12	30,0 x NERICA 1	50,0 x MACHUWA
0,80 x NERICA 10	30,40 x NERICA 12	50,120 X NERICA 1	50,80 x MACHUWA

N.B

Each subplot measure 2m x 2m = 4m^2

Between subplot = 0.5m

Each sub replicate measure 2m x 29.5m = 280.25m^2

Between sub replicate = 0.5m

Total experimental area = 899.75m^2