SOIL FERTILITY EVALUATION OF THE RICE GROWING AREAS AND RESPONSE OF RICE TO NITROGEN AND PHOSPHORUS IN WEST DISTRICT, ZANZIBAR

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ABSRACT

Studies were conducted at Bumbwi, Mtwango and Kizimbani villages of West District in Zanzibar to evaluate the fertility status of the soils, and their suitability for rice production and the response of rice (*Oryza sativa* L. var. *NERICA* 12) to nitrogen (N), and phosphorus (P). Composite soil samples (0-30cm) were collected from Bumbwi, Mtwango and Kizimbani villages and analyzed to establish their fertility status. Field experiments were conducted at each site at (Bumbwi, Mtwango and Kizimbani) to assess the response of rice to N and P and NxP interaction to establish the optimal economic production of the Rice variety-NERICA No 12 and the residual effects of nitrogen and phosphorus on subsequent rice yields were assessed. The experimental design was a Randomized Complete Block Design (RCBD) with three replications at each site. Phosphorus was applied at the .ates of 0, 20, 40, 80 and 120 kg P ha^{-1} at planting time and nitrogen was applied at the rates of 0, 50, 100, 150 and 200 kg N ha^{-1}, in two equal splits applied at two weeks after seedling emergence. Determination of the residual effects of N and P involved growing of rice during second and third seasons on treated plots without further application of N and P. Data were collected on the response of rice variety NERICA No. 12 to different rates of N and P and their combinations. The nutrient status of the soils at the study areas were low in total nitrogen (0.01 to 0.1 %) and zinc (1.0 mg Zn/kg); medium in phosphorus (7 to 20 mg P/kg). The N and P fertilizer significantly ($P<0.001$) increased grain yield (5.73 t ha^{-1}), with 200 kg N ha^{-1} and 80 kg P ha^{-1}. The residual effects of N and P, significantly ($P<0.001$) increased rice yield during 2012/13, 2.70 to 5.56 t ha^{-1}, 3.26 to 5.73 t ha^{-1} and 2.93 to 5.70 t ha^{-1}, 2013/4 cropping seasons, 2.40 to 4.60 t ha^{-1}, 2.46 to 4.90 t ha^{-1}.and 2.50 to 5.90 t ha^{-1} and 2014/5 cropping seasons and 1.90 to 3,50 t ha^{-1}, 2.26 to 3.53 t ha^{-1} and 2.23 to 3.5 t ha^{-1} at Mtwango, Bumbwi and Kizimbani respectively.

Key words: *Rainfed lowland Rice, Soil fertility evaluation, Rice grain yield*

DECLARATION

I, SOUD NAHODA HASSAN, do hereby declare to the Senate of Sokoine University of Agriculture that this thesis 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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DEDICATION

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LIST OF ABBREVIATION AND SYMBOLS

%	Percentage
$<$	Less than
$>$	Greater than
^{0}C	Degree Celsius
AD	Anderson-Darling test
ANOVA	Analysis of variance
ARC	Africa Rice Centre
BNF	Biological nitrogen fixation
BoT	Bank of Tanzania
CAN	Calcium Ammonia nitrate
CEC	Cation exchangeable capacity
Cmol (+) kg $^{-1}$	Cent mole (+) per kilogram
COSTECH	Tanzania Commission for Science and Technology
CV	Coefficient of variation
Df	Degree of freedom
DTPA	Diethylenetriamine penta acetic acid
EC	Electrical conductivity
FAO	Food and Agricultural Organization of the United Nations
ICRA	International Centre for Research in Agriculture
INM	Integrated nutrient management
INRM	Integrated natural resource management
IPNM	Integrated plant nutrient management
IPPM	Integrated plant pest management

IRRI	International Rice Research Institute
ISFM	Integrated soil fertility management
JICA	Japan International Agency
LISF	Local indicator of soil fertility
MALNRZ	Ministry of Agriculture Livestock and Natural Resource Zanzibar
NERICA12	New Rice Africa No 12
P = 0.05	Probability level at 0.05 (5%)
PLAR	Participatory learning and action research
PTD	Participatory technology development
Q	Quartile
RCBD	Randomized Complete Block Design
RWH	Rain Water Harvest
SSA	Sub Saharan Africa
SUA	Sokoine University of Agriculture
USDA	United State Department of Agriculture
WARDA	West Africa Rice Development Association

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Rice (*Oryza sativa*) is a food and cash crop grown worldwide, and constitutes about 50% of the staple foods consumed in Zanzibar (Mnembuka *et al*., 2010). It has been estimated that the average per capita annual rice consumption in Zanzibar is about 120 kg and the total annual rice demand is 80 000 tons compared to the total annual rice production of only 10 800 tons (Mnembuka *et al*., 2010), hence a deficit of 69 200 tons per year. This deficit has to be met through rice importation, which diverts development funds for the purchase of rice. The rice farming and cropping systems in Zanzibar and in particular West District are characterized by very low rice yields per unit area (1.5 – 2.0 ton ha^{-1}) (Juma, 2010) which are below the FAO (2013) average yield of 5.0 ton ha^{-1}. This problem of low rice yields is wide-spread in Zanzibar, culminating into large rice deficit annually.

1.2 Problem statement

The major causes of low and unstainable rice production in Zanzibar, and in particular West District include low inherent soil fertility status, attributed mostly to low levels of plant nutrients particularly nitrogen and phosphorus in the parent materials of the soils. Losses of nutrients through various processes and transformations of the nitrogen and phosphorus applied to the soils to forms not available to the rice plant, further contribute to the low soil fertility. Imbalanced fertilization and inadequate use of fertilizers, information on the nutrient requirements by the rice crop/plant; cultivation of low yielding rice varieties; continuous sole cultivation of rice on the same fields/areas, and in-appropriate agronomic practices, such as spacing, diseases and pest control have also been identified as contributors to the low rice yields in Zanzibar (Buri *et al*., 2010; Seneyah *et* *al*., 2011; Issak *et al*., 2012; Abe *et al*., 2012). Low rice yield has also been compounded by the farmer's inability to purchase adequate amounts of fertilizers to meet the nutrient requirement by the crop. This has been attributed to the high prices of the fertilizers and other inputs in the production of rice. This has forced most resource poor farmers to rely mostly on the natural soil fertility, which is low and on the decline, for rice production.

1.3 Justification

The current drive by the Zanzibar government is to increase rice production so as to meet the local consumption demand and remain with some excess for the export market (BoT, 2011). The rice production strategy in Zanzibar is to introduce new rice varieties like Nerica 12 to raise the current level of yield from 1.5 - 2.0 t ha^{-1} (Juma, 2010) to the FAO (2013) average of 5 t ha^{-1} for the rain fed rice production system. This strategy involves adoption of integrated soil fertility management (ISFM) in tackling and addressing rice production limitations in Zanzibar. The strategy has to some extent raised rice yields to about 3.5 t ha^{-1} in some areas (Juma, 2010). Therefore, there is still more to be done in Zanzibar in addressing the issues of integrated soil fertility management (ISFM), and integrated natural resource management (INRM) that would positively and significantly contribute to enhanced and sustainable rice production.

The integrated soil fertility management, calls for use of both inorganic and organic soil amendments for rice plant growth, culminating into high yields. There are various organic materials that have the potential to contribute to improvement of soil fertility within Sub Sahara Africa (SSA). The major limitation on the use of organic soil amendments is their low nutrient contents, which are not immediately available to plants as they occur in complex forms.

According to the African Rice Centre (ARC) (2008), NERICA paddy varieties respond better to organic soil amendment compared to the inorganic fertilizers. The organic soil amendments have been reported to improve the physical and biological properties of the soils, like soil moisture retention, soil structure and microbial populations (Buri *et al.*. 2010) and many other physico-chemical and biological properties. The main limitation to the use of organic soil amendments are the very high rates and limited supplies available in the crop production areas.

The strategy of using soil amendments in crop production must take on board; the problems of oversupply or undersupply of the plant nutrients to crop plants which can have negative consequences hence. non-attainment of the expected increases in yield/biomass. The principle of balanced fertilizer use takes care of the dynamics of the nutrients in the soil ecosystem which including uptake by the respective plants, losses through leaching and erosion, transformations of the added nutrients into forms not extractable by the plants and the applied nutrient-soil-plant interactions.

Experience has shown that potential yield of rainfed upland NERICA is the product of the interaction of various plant growth factors, like the plant variety, fertility status of the soil, rainfall and plant management practices adopted by farmers. For example an average grain yield of 5.2 t ha^{-1} was recorded in Kenya with NERICA 1 (JICA, 2006) and 4.5 t ha^{-1} in Tanzania with NERICA 2 according to African Rice Centre (2008) by applying inorganic fertilizers in varying quantities. Zanzibar rice production level of 2 t ha^{-1} for upland local rice varieties where the blanket recommendation of 40 kg P ha^{-1} and 80 kg N ha^{-1} were adopted have been reported (MALNRZ, 2009). The low yields of the local rice varieties in Zanzibar justified the introduction of the New Rice for Africa (NERICA) varieties. However assessment of the fertility status of soils; hence adoption of appropriate soil fertility management practices as a strategy to increase yields (MALNRZ, 2009) is mandatory.

Fertilizers and other soil amendments are used in crop production to supplement plant nutrients in the soil that occur in quantities that are below the amounts needed by plants. With introduction of new and high yielding rice varieties, soil nutrient mining has been on the increase hence the need to re-assess fertilizer and manure rates so as to attain high and sustained yields. Sarfo *et al.* (2014) noted that, for most crops, the best fertilizer types, rates and times of application are not known to the small scale farmers, thus constituting a constraint to fertilizer and nutrient use efficiency.

During 2009/2010 season, NERICA 1, 10, and 12, varieties were distributed to some farmers for the first time by the Kizimbani Agricultural Research Station (Juma, 2010). The progeny was developed by the West Africa Rice Development Association (WARDA) by combining traits from the hardy African rice varieties resistant to pests, weeds, and problematic soils with high yielding, high responsive to mineral fertilization and non shattering characteristics of Asian rice varieties (Dzomeku *et al.*, 2013; Kijima *et al.*, 2012; WARDA, 2001). Despite their high yield potentials, the NERICA varieties have not been intensively evaluated, especially in Zanzibar, for their adaptability and yield performance. It is no wonder that NERICA rice varieties might perform differently under Zanzibar conditions. It is assumed that agricultural production inputs like fertilizers are important determinants of yields, but information on specific fertilizer requirements and recommendations, especially nitrogen and phosphorus for NERICA have not yet been established for Zanzibar. In order to increase and sustain high yield potentials of the NERICA rice varieties, adoption of the appropriate ISFM and IPNM strategies, should be given due consideration for rice production in Zanzibar.

What remains to be done is to assess the strategies in place, like establishment of fertility status of the soils with respect to rice production, establish the N and P levels for optimal rice production, and design/develop the right approaches and strategies, for enhanced and sustainable rice production in Zanzibar. Fertilizer application times (regime), improvement of the irrigation structures, so as to improve water use efficiency, and adoption of appropriate planting/sowing time, so as to coincide with the rain seasons and adoption of integrated plant pest management (IPPM) (Juma, 2010), should also be addressed.

This study, therefore, aimed at providing comprehensive information on the fertility status of rice growing soils in Zanzibar, and rice response to soil fertility amendment in West District in Zanzibar, as an attempt in charting out the appropriate strategies and approaches, for increased and sustained rice production, hence attainment of food security and increased farmers income and their livelihoods.

1.4 Objectives

The overall objective of the study was, therefore, to increase and sustain rice production in West District through appropriate N and P fertilization. The above overall objective was addressed through the following specific objectives;

i. To determine physical and chemical properties of soils in the study areas.
ii. To evaluate the response of NERICA NO 12 rice variety to different rates and combinations of N and P.
iii. To determine the residual effect of nitrogen and phosphorus on the subsequent rice yields.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction of Rice to Tanzania

According to Carpenter (1978) the first appearance on the East Africa Coast of *Oryza sativa* type of rice might have been brought by traders from Sri Lanka and India sailing via Oman to Somalia, Zanzibar and Kilwa, some 200 years ago. Introduction of *Oryza sativa* into the hinterlands of Africa was along the slave trade routes from the East Africa Coast and Zanzibar to Zaire during the 19th century. The area inhabited by Wanyamwezi in west central Tanzania (Tanganyika) became the inland base of the traders from 1852 onwards (Iliffe, 1979). From the headquarter at Tabora one route led to neighboring Sukumaland, the area inhabited by *Wasukuma* bordering Lake Victoria in Northwestern Tanzania, and the other route, Morogoro and Mbeya. Formally unknown crops such as maize, cassava and rice were also introduced along the caravan routes to supplement the local diets, of millet, sorghum and banana (Meertens *et al*., 1995). The cultivation of rice was mostly by Arab traders who settled in these areas. The local farmers were not initially interested in rice production because its production turned out to be less reliable in terms of yield and high labour demand in comparison with millet and sorghum (Meertens *et al*., 1999). The low yields of rice then were attributed to inadequate soil moisture and inherent low fertility status of the soils.

The cultivation of rainfed rice in Sukumaland was not that pronounced between 1960s to 1980s, as a consequence of the Tanzania Government categorizing the Sukumaland as a semi arid environment suitable only for drought resistant crops such as cassava, sorghum and cotton (Meertens *et al*., 1995). Therefore, rice cultivation was not among the priority crops in Sukumaland. As on attempt to cultivate rice in the semi-arid areas, construction of bunds surrounding the rice plots to conserve water that would have been lost through surface run off were adopted. This was a strategy to conserve water (rain water harvesting) in semi-arid areas with unreliable and relatively low rainfall (700 - 900 mm) (Meertens, 2011). This technology led to interest in rice cultivation in the semi- arid areas of Tanzania by the indigenous people in the respective arid and semi- arid areas. In Tanzania this was done in some parts in Mwanza and Shinyanga in Tanzania Mainland, and Kilombero. Cheju, Chaani and Muyuni in Zanzibar (Meertens *et al*., 1995). The size of plots varied from 10-100 m^2.

2.2 Factors that Influence Growth and Establishment of Rice in Zanzibar

Rice growth is controlled both by the physical and chemical properties and behavior of the soils under rice cultivation as well as climate and other environmental attributes, like diseases and pests.

2.2.1 Physical properties of the soils

Among the soil physical properties related to soil fertility in rice production include soil water retention capacity, water and air permeability, heat conductivity, texture and structure of the soils (Kirk, 2004; Jaillard *et al*., 2005). The physical properties of surface soils are very important in determining its productivity potential. These properties determine the extent of biological activities in the soil, influence genesis of soil structure and control infiltration of water which are important in germination and growth of young rice seedlings (Asmar, 2011; Ingram, 1997). However, for lowland rice cultivation, soil physical properties are relatively not that crucial as long as sufficient water is available (Landon, 1991).

2.2.2 Soil fertility status

It has been reported that low fertility status, nitrogen and phosphorus as being the major limiting plant nutrients, where total nitrogen contents are very low (0.01%N) as well as phosphorus (<8 mg/kg) as reported by (Uleid, 2007).

Soil pH hence soil reaction is probably the most important chemical parameter that influence the growth performance of rice (Bloom, 2000). It reflects the overall chemical status of the soil and influence a whole range of chemical and biological processes occurring in the soil. Because of its implications in most chemical reactions in the soil, knowing the actual value of soil pH and monitoring its changes is critical for the understanding of the physico-chemical functioning of the soil (Jaillard *et al.*, 2005). Under very acidic as well as alkaline soil conditions, phosphorus is less available. The occurrence of the relatively insoluble iron and aluminum phosphates in acidic soils, and less soluble calcium phosphates in soil with high pH is the main constraints/limitation contributing to low plant extractable phosphorus levels in such soils. Phosphorous availability is optimal between pH 6.0 and 7.0 (Carvalhais, 2015).

2.2.3 Climate

There are many climatic attributes influencing plant growth and subsequently yields. These include, soil and air temperature, photoperiod, solar radiation and precipitation. Climate influences rice yield through many interrelated and often diverse environmental and biological factors and their interactions making it difficult to separate their effects on rice growth (Wilson *et al.*, 2014).

High day temperatures and solar radiation and low night temperatures are apparently conducive to the production of more rice panicles without much reduction in spikelet numbers (Smith *et al.*, 2001). The filled spikelet percentage was about the same for the dry and wet season. Thus, grain yield can be integrated as: Yield (t ha^{-1}) = spikelet's/ m^2 x grain weight (g/ 1000 grains) x filled spikelet's % x 10^5 (Wilson *et al.*, 2014). A major portion of grain carbohydrate comes from photosynthesis, during the ripening period (Wilson *et al.*, 2014). During the reproductive stage solar radiation, affects spikelet number per square meter, and during ripening it affects the filled spikelet's grain percentage (Park *et al.*, 2009; Shepherd and Soule, 2012). Dekamedhi and De Datta (1995) correlated yield with cumulative radiation for various periods working forwarded from the date of planting or backward from the date of maturity and observed that high radiation at any stage after panicle initiation was associated with higher yields in both traditional and improved rice varieties.

Temperature during the ripening period is an important factor in rice production (Mustafa and Elsheikh, 2011). The term climatic productivity index to express the effects of radiation and temperature on rice grain yield has been proposed by Yoshida (1987) who found high correlation coefficients of grain yield index with actual rice yields suggested that spikelets number per square meter was the most important factor limiting yield of IR747-B2-6 rice at Los Banos, Philippines.

From the same series of experiments, Parker *et al.* (2012) contended that a yield of 4 t ha^{-1} could be obtained with 200 cal/ cm^2 of solar radiation per day during the reproductive stage, other growth factors being optimal. Several studies in Japan by Mutert and Fairhurst (2013), Michael (2011) and Muruli and Paulsen (2014), reported close correlations between climatic parameters like solar radiation, temperature, and rice yields.

Soil temperatures, > 45 °C influence germination of rice seeds, function of roots, rate and duration of plant growth, and occurrence and severity of plant diseases and nutrient uptake (Shimazaki and Sugahara, 2010). Extremely high soil temperatures also have harmful effect on roots like absorption of nutrient from the soil and may cause destructive lesion on stems of rice plants. On the other hand, low temperature impedes plant mineral nutrient uptake or absorption (Zhang *et al.*, 2014) by limiting the movement of nutrient ions in the soil ecosystem.

2.2.4 Soil moisture

Soil moisture is a crucial factor influencing root growth, nutrient uptake and total biomass production. Rice plants are sensitive to low soil moisture. Low soil moisture in early spring negatively affects shoot elongation as well as the formation of flowers, consequently affecting yields (Britzke, 2014). Low soil moisture in summer reduces shoot thickening, rather than shoot elongation (Zhang *et al.*, 2014).

2.2.5 Air temperature

Air temperature directly influences photosynthesis, which is the most important physiological process in rice production. The optimum temperature for photosynthesis depends on rice plant's species and also cultivar for the same species (Meena *et al.*, 2013). The temperature regime greatly influences not only the growth duration but also the growth pattern of the rice plant (Meena *et al.*, 2013). The critical temperatures for germination, tillering, inflorescence initiation and development, dehiscence, and ripening for rice have been identified (Table 1).

Table 1: Response of rice plants to varying temperature at different growth stages (Adapted from Yoshida, 1987)

	Critical temperature (^{0}C)		
Growth stage	**Low**	**High**	**Optimum**
Germination	16-19	45	18-40
Seeding emergence and establishment	12-23	35	25-30
Rooting	16	35	25-28
Leaf elongation	7-12	45	31
Tillering	9-16	33	25-31
Primodia	15	-	-
Panicle differentiation	15-20	30	-
Anthesis	22	35-36	30-33
Ripening	12-18	>30	20-29

2.2.6 Rainfall

The effects of rainfall on rice growth performance are determined by amount, intensity; distribution and duration of rainfall. The amount and distribution of rainfall are important rainfall factors limiting yields of rainfed rice, which constitutes about 80% of rice grown in South and Southeast Asia (De Datta, 1985). The optimum rainfall for rice production ranges from 1500 mm to 2000 mm per year (Yoshida, 1987).

Most of tropical Southeast Asian countries, such as parts of Burma, Kampuchea, Indonesia, Philippines, Thailand, and Vietnam, receive about 2000 mm of rain annually (Zarate, 2015). This should be adequate for the rice crop provided the rainfall is uniformly distributed during the active vegetative and reproductive stages of the rice plant. Even in areas in Asia where the annual rainfall is 1200-1500 mm, if the rainfall is concentrated in the monsoon season, it is adequate for a single rice crop (Matsubayashi *et al*.. 2014).

2.2.7 Plant factors

Plant factors that directly influence the physiological processes that effect the rice plants growth, development, and grain formation include stunted growth of the rice plant (Witt and Haefele, 2005). Indirect influences include the incidence of crop insect, diseases, rooting systems, plant height, tillering, and variety hence grain yield (Witt and Haefele, 2005).

To obtain high grain yields, balanced growth at all stages must be achieved, that is soil, plant and climatic factors are optimal. Balanced growth is reflected in the high ratio of the weight of the panicles to that of the total dry matter produced. This ratio is known as the harvest index (HI). Low solar energy and high temperature are detrimental to low harvest index (Murata *et al*., 1980). For the same reason, grain production in temperate areas will be more efficient for a given rice variety (Murata *et al*., 1980). The physiological causes for variation in HI within a variety and among varieties of rice are not well understood (Yoshida. 1987) Investigation on the HI index.

2.2.8 Agronomic factors

The agronomic factors that affect rice production include such activities like for examples sowing, plant spacing, weed and pest control, application of fertilizers, manures and other soil amendments. The common rice pests include armyworms, heteronychus beetle. strippled stem borer and pink stem borer (Mnembuka *et al.*, 2010). The strippled stem borer and pink stem borer cause damage to the plant at tillering stage (dead hearts) and flowering stages.

Methods and time of application of soil amendments for traditional rainfed varieties, is crucial in rice production. Response to nitrogen fertilizers at high rates may cause crop lodging and high disease incidences (Mnembuka *et al.*, 2010). The common fertilizers used in rice production in Zanzibar include sulphate of ammonia (S.A), $(NH_4)_2SO_4$ triple super phosphate ($Ca(H_2PO_4)_2$, sulphate of potash (K_2SO_4) and muriate of potash (Kcl), (Juma, 2010). About 80 kg N ha^{-1} could be applied once at 30 days after transplanting where split application is done, one (40 kg N ha^{-1}) at tillering stage, and the second split applied (40 kg N ha^{-1}) applied at the booting stage (MALNRZ, 2009).

2.2.9 Constraints to rainfed rice production system

Bolling and Nayak (2014) reported that moisture deficit, nutrient deficiencies (N and K) and pest infestations are the major determinants of yield levels of rice in Central Java and Philippines. Supplying adequate amounts of nutrients in the form of fertilizers and manures and good pest control are equally important as moisture deficit management for increased productivity of rainfed rice (Boling and Nayak, 2014). The relative importance of moisture deficit, nutrient and pest management may vary from place to place in the cultivation of rice. Therefore yield constraint analysis should be systematically carried out to identify appropriate soil and crop management strategies to be adopted.

In semi arid areas of Tanzania, the constraints to rainfed lowland rice production have been documented by Meertens *et al.* (1999). Rice farmers in the Maswa hardpan plains regarded weed infestation as the most important constraints to rice production. Weed problem in rainfed rice is directly related to water availability in the excavated banded fields and the method of crop establishment (Williams *et al.*, 2014). Weed control is difficult in rainfed rice partly because of erratic and unpredictable rainfall. The types of weeds that emerge are closely related to moisture contents of the soils and water depth (William *et al.*, 2014). It is important, then, to determine the safe limit for water depth that would maximize suppression of weeds without unacceptable risk to rice plants, growth performance. However, the problems of water availability, stem borer infestation, low soil fertility and low availabilities of agricultural inputs like improved seed and fertilizers, are among the major constraints to increased rice production.

Water management can therefore partly substitute weeding in rice fields. Grassy weeds such as *Hydrophila spinosa* may be completely eliminated if a flooding depth of 15 cm is maintained throughout the rice crop growth cycle (Bhan, 1983). Based on the above, it could be concluded that water availability is the primary constraint to rainfed lowland rice production as it influence the availability and uptake of nutrients and weed proliferation. Soil moisture stress is one of the major problems that affect crop growth worldwide. The problem is complex in rain fed crops, as it may occur early in the growing season or from flowering to grain filling, and may follow a period in which soils are flooded and become anaerobic (Wade *et al.*, 2013). Soil moisture stress affects almost all growth processes;

however, the stress response depends upon the intensity, rate and duration of exposure and the growth stages of the rice plants (Kronzucker *et al.*, 1999; Barre *et al.*, 2013). The reduction of growth due to moisture stress is mainly through its influence on leaf expansion, which determines the potential photosynthetic productivity of plants (Chen *et al.*, 2014).

IRRI (2005) reported that response of the rice plants to water stress varied with the growth stage and other agronomic practice. It was noted that direct sown rice is less prone to moisture stress than transplanted rice at early stage of rice growth due to competition for nutrients (De Datta, 1981). During the growing season, rainfall amounts of at least 100 mm per month are required by the rice crop (De Datta, 1981). Water requirement by rice plants is low at seedling stage (De Datta, 1981). However, if there is severe water stresses that occur at seedling stage of the rice plants, recovery of the rice seedlings is possible. However soil moisture stress at any growth development phase of rice plants has a negative effect on the rice growth performance and consequently yields (De Datta, 1981; Rahman *et al.*, 2013; Pirdashti *et al.*, 2014; Hemmatollah *et al.*, 2004). Soil moisture stress during the vegetative growth stages was found to reduce plant height, number of tillers and leaf area (IRRI, 2005). However, effects during this stage vary with the severity of soil moisture stress and age of the rice crop. Long duration rice varieties suffer less damage than short duration varieties because long vegetative growth period could help plant recovery when stress is relieved (IRRI, 2005).

Furthermore, it was observed that soil moisture stress at or before panicle initiation reduces panicle numbers significantly, where anthesis and ripening stages are the most sensitive to water stress (IRRI, 2005). Soil moisture stress during anthesis increases the likelihood of unfilled spikelet's (Pirdashti *et al.*, 2014). Hemmatollah *et al.* (2004)

reported that yield reduction as a result of soil moisture stress were 21%, 50% and 21% at vegetative, flowering and grain filling stages, respectively.

Alleviation of moisture constraints can be achieved through rainwater harvesting techniques (Hatibu, 2002: Gould and Neuman, 1999; Pennamperuma, 1999; Johnson *et al.*, 2014; Rerkasem and Jamjod 2010; Parsadeh, 2011; Corrales *et al.*, 2007). Rain water harvesting (RWH) is commonly practiced in semi arid areas for rainfed lowland rice production through in-situ, micro and macro rainwater harvesting techniques (Pezeshki, 1994). Rainwater harvesting basically involves all conventional approaches to soil and water conservation and management designed to enhance rain water intake into the soil, prolonged storage and consequently availability to plants (Oikeh *et al.*, 2013; Otsyina *et al.*, 1995).

2.3 Nutrient Transformations and Dynamics in Rice Soils

Plant nutrients found or added to soils can be transformed into forms not available to plants. Such transformation processes include fixation, adsorption, precipitation, complexion, ion exchange and immobilization (Bell and Seng, 2004). These transformations, determine the dynamics of nutrients in the soil, and the quantity-capacity-intensity relationships of the plant nutrients in the soil ecosystem. The nutrient uptake by plants, leaching and erosion processes also contribute to nutrient dynamics in soils, hence contributing to the magnitude of rice response to nutrients inherently occurring in soil and those added to it as soil amendments. Fluctuation in the redox-potentials of the soil ecosystem has profound and enormous consequences on nutrient dynamics and availability to rice plants, other crops inclusive (Bell and Seng, 2004).

2.4 Effects of Redox Conditions on Rice-growth Performance

Plant nutrient availability is influenced by flooding and processes associated with reducing soil conditions and Eh. Many factors, including soil physic-chemical characteristics, nutrient pools, plant development and physiological status and flood-tolerance capabilities are important (Pezeshki, 1999; Kozlowski, 2013; Bhonsle, 2013). Despite the adaptations reported for wetland plants, various nutritional deficiencies and toxicities may occur (Armstrong *et al*., 2014). Reduced soil conditions may lead to inhibition of nutrient uptake and transport due to root dysfunction and death (Kogawara *et al*., 2006); Delaune *et al*., 1998; Dechassa and Schenk, 2014), and blockages in the vascular and parenchyma systems resulting from phototoxic damages (Armstrong and Drew, 2002). Oxygen supplies to rice roots are critical for nutrient uptake and ion transport. Flood - induced stress include reduced water uptake due to root dysfunction that results from soil O_2-deficiency including altered cation and anion concentrations in the xylem sap and decreased hydraulic conductance of roots as has been reported in the literature for various rice species (Else *at al*., 2013).

There are reports of reduction of water and nutrient uptake, disturbance of hormonal balance such as a decrease in gibberellins and cytokine and an increase in abscise acid and ethylene in response to flooding (Jackson, 2014; Hattori, 2009). Under reduced soil conditions, some wetland plants, rice inclusive, plant nutrient still persisted partly because of the internal oxygen supply system but partial anoxia in roots can reduce solute intake (Armstrong and Drew, 2002; Kogawara *et al*., 2006; Gibbs *et al*., 2013).

Nutrient concentrations at toxic levels may accumulate in tissue under reduced conditions due to higher availability of certain nutrients and root dysfunction (Reed and Martens, 2008, Hook, 1983; Pezeshki *et al*., 1988). During prolonged flooding, as soil Eh Jecline continues, pH decreases while zinc availability increases leading to high tissue zinc concentrations (Pavanasasivam and Axley, 2012) and reduced ferric and manganese forms that are soluble (Pennamperuma, 1999). Thus, tissue Mn and Fe concentration are high in plants under aerated condition (Good and Patrick, 1997; Gries *et al.*, 1990). Leaf discoloration (bronzing) due to high soluble ferrous iron has been reported in some rice plant species (Tanaka *et al.*, 1988).

Although sulphide is phototoxic, in most cases wetland plants have the capability to oxidize sulfide in the rhizosphere thus, avoiding or minimizing injury to roots (Tanaka *et al.*, 1985). However, there are several reports confirming that excess soil sulfide may inhibit plant growth (Armstrong *et al.*, 2014) since the soil soluble sulfide species including H_2S are toxic to plant roots (Tanaka *et al.*, 1988; Allam and Hollis, 2009).

Sulphate uptake, translocation and accumulation in foliage have been documented for several plant species (Carlson and Forrest, 2013; Pearson and Havil, 2014). The inhibitory effect of H_2S on cytochrome oxidase is disruptive for aerobic respiration and excess cytosolic, and Fe and Mn are harmful to enzymatic structures (Drew, 2000). The inhibitory effects of elevated sulfide concentrations on leaf photosynthetic capacity have been demonstrated in several wetland species including *Panicum hemitomom* and *Spartina alterniflora* (Drew, 2000). Such photosynthetic response has been attributed to light reactions (Shimazaki and Sugahara, 2010) and/or photophosphorylation (Wellburn *et al.*, 2013), and alterations in the activity of photosynthetic enzymes (Garsed, 2011; Dropff, 2011). Sulfide utilization and injuries have been reported in hypoxic roots and rhizomes of *Phragmite saustralis* (Furtig *et al.*, 2013). Sulfide has been implicated as a factor responsible for decreased plant growth and productivity in several wetland rice plants (Drew, 2000).

2.5 Rice Plant Soil Water Relations and Gas Exchange

Factors associated with low soil Eh conditions can influences plant water relations through stomata closure and slower water uptake than under aerated conditions (Pezeshki, 2001;

Else *et al.*, 2013; Jackson *et al.*, 2002; Everad and Drew, 1989); Neumann *et al.*, 2013). Increased internal water stress and leaf dehydration leading to stomata closure have been reported in some rice species due to a decrease in plant root permeability under flooding conditions (Pezeshki, 2001; Kozlowski, 2013; Hiron and Wright, 1983). Reduced water uptake due to plant root dysfunction may include altered cation/anion concentration in xylem sap (Else *et al.*, 2013; Jackson, 2014). Decreased hydraulic conductance of plant roots has been reported in the literature for many plant species (Else *et al.*, 2013; Jackson, 2014).

The extent of development of internal water stress reported for some rice species shows wide ranges; but in most cases the initial stomata occurs in the absence of significant changes in plant water status (Pereira, 1987; Tang (1982). The rapid stomata closure and maintenance of a favorable water status, is likely due to low transpiration rates for which a slow water absorption rate by roots may sufficiently compensate rather than sustained root conductivity (Pezeshki and Chamber, 1985).

Stomata in certain mangroves did not respond to Eh as low as -180 mV over short term experimental exposures (Pezeshki *et al.*, 1997). The stomata closure is concomitant with a reduction in photosynthesis. However, under stomata re-opening may occur leading to photosynthetic recovery (Pezeshki, 1994). The degree of resumption of stomata functioning appears to be dependent on species, duration of reducing conditions and the intensity of soil reduction.

2.6 Rice Cultivation Systems and their Effects on Enhanced and Sustainable Rice Production

Rice occupies about 46 million ha^{-1} or about 35% of the global land area suitable for rice production and is mostly found in South and Southern Asia (Maclean *et al.*, 2002). In

West Africa, the rainfed upland rice cultivation systems occupy 82% of the area under rice cultivation and accounts for 75% of the rice produced in the region (WARDA, 1994). In Tanzania, of the 330,000 ha^{-1} of the area under rice production, 74 % is under rainfed lowland rice, 20% upland rice and 6% irrigated rice (Kanyeka *et al.*, 1994).

De Datta (1995) classified rice cultivation in accordance with source of water supply as rainfed or irrigated. Based on land and water management practices rice lands are classified as lowland (wet land preparation of fields) and upland (dry land preparation of fields). Further, according to water regimes, rice lands have been classified as upland with no standing water, lowlands with 5-50 cm of standing water and deep water with greater than 50 cm of standing water (De Datta, 1995). Kanyeka *et al.* (1994) classified rice cultivation systems in semi arid areas of Tanzania as rainfed lowland based on water availability. The system is characterized by water deficit at various stages during the growth cycle of rice plants, hence limiting nutrient availability and nutrient uptake, which in turn limits rice growth with consequent low yields. The cultivation of rainfed lowland rice in Cambodia (Laungan and Knops, 2011). Laos, Nepal, Thailand and Madagascar (Fujisaka, 2013) showed that the management practices do not differ from those practiced in Tanzania. These management practices include; land preparation, crop establishment (direct seeding or transplanting), weeding and harvesting. The only exceptions are the rice fields in the flood plains near rivers, which receive water from floods (Enserink *et al.*, 1994) and the rice fields are not banded. This type of rice production system is referred to as unbanded flooded rain fed lowland rice system due to adequate water availability and is also common in the southern parts of Tanzania (Kanyeka *et al.*, 1994).

According to water balance as classified by Garrity *et al.* (1986) which is based on water retention potential (slope and soil texture), rainfall amounts and length of the growing season, rainfed rice of Tanzania is drought prone. The production of rainfed rice in semi arid areas of Tanzania is practiced in banded fields to conserve the runoff water (Kajiru *et al.*, 1998; Meertens *et al.*, 1999).

2.7 Response of Rice to Soil Amendments

Nutrient status in soils where rainfed rice is cultivated is often low and response to applied nutrients is often modest due to limited availability of soil moisture (Lathovilayvong *et al.*, 1998, Mazid and Dell, 2013). Thus, the magnitude of response may not be closely related to soil test values for the essential plant elements (Angus *et al.*, 2015), but rather to the nutrient in soil moisture interactions consequently limited amounts of fertilizers are applied in these systems because of inadequate soil moisture as there is no guarantee for crop growth success (Khunthasuvon *et al.*, 1998; Lie *et al.*, 2011).

Therefore, farmers adjust their fertilizer application rates based on their expectation of whether the season will be favorable or not (Wade *et al.*, 2013) and, this depends on whether there is standing water in the field or not. For instance, the time of disappearance of standing water relative to time of flowering has been related to yield reduction in late season dry periods (Jearakongman *et al.*, 1995), even when the soil remained moist. This response was attributed to a drop in soil pH when the free water disappeared, leading to a decline in availability of nutrients, especially for P and Fe (Khunthasuvon *et al.*, 1998; Fukai *et al.*, 2014). In simulation studies, Jongdee *et al.* (1997) reported mean yield losses of 33% in North East Thailand due to drought. Most of the yield reduction was due to reduced nutrient availability as a result of limited translocation of nutrient from the soil mass to the root surfaces of plants as water supply declined (Jongdee *et al.*, 1997). Better matching the nutrient supply with crop demand is often considered as the basis for improving and stabilizing yield, in irrigated as well as rainfed lowland rice cultivation systems (Lafitte and Edmeades, 1994).

The main nutrients source for lowland and upland rice production are organic and inorganic fertilizers. The main inorganic fertilizers commonly used in rice production systems include urea ($CO(NH_2)_2$) and triple super phosphate ($Ca(H_2PO_4)_2$). N and P are the major nutrient elements deficient in most soils. On the other hand. organic manures/ amendments include crop residues and animal wastes which release nutrient after decomposition and mineralization for plant uptake.

2.8 Rice Response to Mineral Fertilizers

Nitrogen and phosphorus deficiencies are the most common nutrient disorders in upland rice production systems (Reddy and Delaune, 2013; Dong *et al.*, 2014). Significant rice yield responses to N applications such as urea with water depths of 5-15 cm have been reported by Meertens e*t al.* (1999). However, these studies were of short duration using limited ranges of nitrogen rates (20 to 30 kg N/ha) hence not conclusive. The response of rainfed lowland rice to P fertilizer applications is not as frequent as those of other upland crops even in soils deficient in P (George, 2014), because P has little effect on rice grain and straw yields. Applying P had no effect on grain yields despite increased P uptake (George, 2014; Lea and Miflin, 2011). High grain yield response to N in the study by Laffite (1998) in the Philippines was consistent with results obtained in Southern China (George, 2014). Several researchers have also reported upland rice yields of $\geq$ 5t/ha in Brazil (Dastan *et al.*, 2013), and Northern China (Wang *et al.*, 2014) when N and P were applied indicating that the response of upland rice cultivars to P application depend on the N status of the soils in question, that is the NP interaction.

Application of P only had little effect on grain yield and P uptake (Sahrawat, 2010). In contrast, the difference in response to P under N application conditions was consistent with those studies in Brazil (Flageria, 2011) and West Africa (Sahrawat, 2010). Pheav *et* *al.* (2005) reported that application of 8 - 10 kg P ha^{-1} in acid soils in Cambodia maintained yields at 2.5 – 3 t ha^{-1} above the control and small positive balance left in the soils. Further, the P balance was sensitive to proportion of rice straw returned to the soils (Pheav *et al.*, 2005). Rice responses to N and P studies in Zanzibar have not been that comprehensive, hence the need to undertake more studies so as to come up with the appropriate rates for optimal rice production.

Responses to nitrogenous fertilizers vary among crops. Tanaka *et al.* (1985) observed a constant increase in rice yields with increased nitrogen levels from 0 to 100 kg ha $^{-1}$. However, at N application rates beyond 100 kg ha^{-1}, yields started to decline due to nutrient imbalance. At Dakawa Rice Farm (Tanzania) Semoka and Shenkalwa (1985) reported significant increase in rice yield with increase application of nitrogen. At Mbarali Rice Farm (Tanzania), Temu (1985) reported significant increased in rice yields of 7.85-8.24 t ha^{-1} with application of 200-250kg N ha^{-1} on alluvial soils for the rice variety IRR8.

Zhao *et al.* (2011) reported that very high N levels frequently decreased rice yields due to plant lodging, increased disease incidences, pest infestations and high percentages of unfilled grains. Kajiru *et al.* (1998), reported that 30 kg N ha^{-1} as urea ($CO(NH_2)_2$) was economically profitable in Maswa district planosols. Due to the low N contents in most soils in the rice growing areas of Zanzibar, significant rice yield response ranging from 2.5 – 3 t ha^{-1} to N application as urea to fields flooded with water to the depths of 5-15 cm have been reported by Meertens, (2011).

2.9 Response of Rice to Organic Soil Amendments

A wide variety of organic plant nutrient resources are available for use as soil amendments in rice production. However, the current trends of organic resource management practices in Tanzania indicate that only animals dung and to a lesser extent, compost excreta mixed with animal bedding materials) are used in crop production (Meertens, 2011). Other organic soil amendments include green manure such as *Sesbaniasesba* and *Crotalaria ochroleuca* which are used as fallow crops prior to rice transplanting (Meertens, 2011).

Doberman *et al.* (2000) reported that the use of locally available organic plant nutrient resources started in 1940s at Mwabagole Rice Station, Mwanza, Tanzania. The control yield under research condition were compared with puddling in green shoots of cassava tree (*Manihot glaziovii*) and Cassia (Cassia spp) about a month before transplanting and with application of farmyard manure. Results over two seasons showed that the puddling of 10 ton cassava tree shoots ha^{-1} increased rice yield by 1419 kg ha^{-1}.

Further research on the use of manures for soil fertility improvement in rice production in Northwest Tanzania declined due to the availability of relatively inexpensive mineral fertilizers as a result of government subsidies on fertilizer prices. Complete withdrawal of subsidies on mineral fertilizers in Tanzania during the 1990s gave new impetus to such type of investigations. For instance, Otsyina *et al.* (1995) reported the cultivation of *Sesbaniasesban*, *Sesbaniarostrata* and *Crotalaria ochroleucaa*s fallow plants for incorporation to the soil prior to rice transplanting as a supplement to inorganic fertilizers.

Otsyina *et al.* (1995) assessed the use of dried leaves from *Leucaena leucocephala* as green manure for incorporation in rice fields as a source of plant nutrients for rice. The dried leaves were incorporated prior to rice transplanting and also at four and eight weeks after transplanting. Total applications of 3.0 to 6.0 tons dried *Crotaria ochroleucas* leaves ha^{-1} were adopted and compared to control plots where the mean results for three seasons showed that application of 3.0 ton dried *Crotaria ochroleucas* leaves ha^{-1} increased rice yields to 3018 kg ha^{-1} compared to the control yield of 2438 kg ha^{-1} while six ton dried *Crotaria ochroleucas* leaves ha^{-1} gave an average rice yield of 3198 kg ha^{-1}.

Upon consideration of the labor involved in transporting large amounts of green matter to the farm, it was suggested to grow the green manure plant on the farm boundaries or on the bands between the rice fields (Otsyina *et al.*, 1995). However, Nair (1988) reported that biomass production by green manure plants in semi arid environments is seriously restricted by inadequate soil moisture for the plants. It was further noted that growing trees on bunds was unattractive to farmers as these bunds were usually used as foot paths. In addition, growing trees on bunds might further aggravate the problem of birds because such trees offer landing, nesting and hiding places for birds and rodents that feed on rice.

Makoye and Winge (1996) compared the application of 30 kg N ha^{-1} as urea ($CO(NH_2)_2$) to rice plant at tillering with an incorporation of 10 t ha^{-1} of both farmyard manure and rice husks prior to rice transplanting, where two seasons results gave yields of 3480 to 3580 kg compared to the control yield of 2580 kg ha^{-1}. However, sufficient amounts of rice husks are only available near milling machines and have other uses like source of heat energy for cooking. The increase in rice yields with the application of rice husks was attributed to the increased moisture retention and storage by the husks hence extending the period of water availability to the rice plants.

In spite of the above investigations on the use of inorganic and organic soil amendments in rainfed rice production, there has not been a parallel and systematic investigation on the response of rainfed rice to the combined effects (interactions) of farmyard manure and inorganic fertilizers in Zanzibar.

2.9.1 The soil amendments added to rice soils

Low recovery of applied N by flooded rice is usually assumed to results largely from nitrification-denitrification process (Bell and Seng, 2004). Other losses of nitrogen in waterlogged soils include leaching losses of nitrate and ammonia, and ammonia volatilization (Fukai *et al.*, 2014). Denitrification is one of the major process by which nitrogen is lost from a flooded soil. Ammonia nitrogen applied to the oxidized soil surface is nitrified and the resulting NO_3-N is leached down into the reduced subsurface layer, where it is subsequently denitrified and lost from the soil as N_2O and N_2 (Homma, 2011). Denitrification is enhanced by alternate flooding and draining (Beringer, 2014), while continuous submergence minimizes it and even leads to a substantial accumulation of nitrogen (IRR, 2005). Deep placement of nitrogen has been shown to be superior in many parts of rice growing areas of the world because it minimizes denitrification (Azeez and Averbeke, 2013). In the United States, subsurface placement of ammonium nitrogen is recommended for rice in California (Jackson and Drew, 1984).

Ammonia volatilization is not considered to be an important mechanism of nitrogen loss from a waterlogged soil except in situation where ammonia concentration occurs in conjunction with high pH, high temperature, and low cation exchange capacity (Greenway *et al.*, 2014). The extent of loss of ammonia (from top dressed N) is a function of the soil and fertilizer, NH_4-N concentrations, pH, air movement and temperature (Bell and Seng, 2004). Yoshida (1986) found that most of the NH_3 losses from flooded soils occurred during the first 9 days after N application. Significant losses of N were correlated with an increase in soil pH and were greater from urea than from ammonium sulphate, from which losses below pH 7.5 were very small whereas Travis (2011) reported NH_3 volatilization losses up to 12% of surface applied ammonium sulphate for flooded rice in Thailand (soil pH 7.0-7.5) (IRRI, 2005). Loss of 14.2% of surface applied ammonium sulphate was reported but when the fertilizer was incorporated into the soil the loss was reduced to 7.0 % (Yoshida, 1987).

2.9.2 Current status of rice production in Zanzibar

In Zanzibar, of the 26 600 ha^{-1} of the land under rice production, 29% is under rainfed lowland rice, 69% upland rice, and 2% irrigated rice (Juma, 2011). Meertens *et al.* (1999) gave a detailed account of the introduction and characterization of rainfed rice environment in Zanzibar.

Emphasis on subsidy policy for rice production has been an important element in the government policy as a whole, as early as 1975. Inputs subsidies are utilized quite extensively in the cultivation of rice (BoT, 2011). Prices to farmers for inputs like fertilizers, irrigation water, agro-chemicals and mechanization services, are fixed by the government which itself bears the differential costs for their provision. The inputs subsidies are designed to stimulate production in the drive to food self-sufficiency, and aims at encouraging fertilizer use mainly in paddy production. This has been achieved with added advantage of creating awareness to farmers on the importance of fertilizer use in the production of other crops (MALNR, 2009).

2.9.3 Strategies, approaches and practices towards increased rice production

Studies on rice production in Zanzibar have revealed some progress in the use of improved rice varieties like the NERICA and TXD albeit at low pace (BoT, 2011). Government institutions in collaboration with some International Development Partners have been urged to come up with specific strategies to support the adoption of the improved rice varieties to boost productivity. Experience from other Africa countries indicate that NERICA is highly productive and can be grown in areas with varied climatic conditions and fertilizer use (Juma, 2010), as the NERICA rice variety has the ability to withstand drought conditions.

Emphasis on irrigation farming as a pre-requisite to enhanced rice production is of paramount importance in the attainment of food security. Well planned transformation in rice production is needed to adopt modern techniques through mechanization and utilization of improved seeds and fertilizers and pest and disease control. Adoption of the state of the art research activities through increased resources allocation so as to increase rice production is paramount in Zanzibar. Although there has been some improvement, opportunity cost plays an important role to sustainable paddy farming. This is compounded by the weak financial position of the majority of the subsistence rice farmers. Continued subsidies on agricultural inputs particularly tractors, fertilizers and seed are very important for sustainable paddy farming in Zanzibar.

The government intervention in agricultural marketing is closely related to the perception about the structure, conduct and performance of private marketing channels. Also important are the links between marketing intervention and their objectives, especially those of price policies. The views that private traders are able to exploit farmers or consumers by exercising local monopoly power are widely prevalent as a reason or excuse for marketing interventions (Ellis, 1992). The objectives most commonly advanced for government marketing policies are: to protect farmers or consumers from parasitic traders, to reduce the marketing margin, to improve quality and to improve food security.

Government intervention in marketing in Zanzibar started after the 1964 revolution. Under the period of study, 1990 public interventions were mainly concentrated on export of cloves and importation and distribution of rice, sugar, wheat flour and farm inputs. Further the setting of sales and marketing margins and, to a limited extent, on providing guaranteed minimum support prices for selected domestic food crops (food security crops like rice, maize, cassava, banana and yams) were taken on board. Thus the agriculture marketing in Zanzibar was shared both by private and public sectors.

Very little is known about the structure of the marketing systems of common food stuffs and about the quantities of food stuff moving through the system (Ellis, 1992). While all crops have the marketing system, rice has some difficulties because of the availability of imported rice. The price is high compared to imported rice; also the quality is poor due to inefficiency of milling machines. Taste behavior also contributes; farmers also are not prepared to sell at the low price set by the government. It is clear that this marketing structure has influenced the development of rice production and rice self-sufficiency strategy.

The extent and magnitude of low rice yields in Zanzibar is widespread, hence the need to adopt the participatory approaches to integrated soil fertility management (Ley *et al.*, 2002), where the entire stakeholder community namely the researchers, farmers, extension staff, policy makers, and agricultural input providers and stockiest are involved. Such approaches include participatory learning and action research (PLAR) and participatory technology development (PTD). The integrated soil fertility management (ISFM) approaches to soil fertility management, which involves management of available plant nutrient resources in the most efficient way by capitalizing on the best use of the locally available resources should be emphasized. Further, adoption of integrated soil fertility management approaches would make use of the local knowledge decision making as well as the research based on the understanding and analysis of the underlying processes, thus a holistic approach to the causes of low rice yields in Urban West District in Zanzibar would be the most appropriate option. Further the various aspects of integrated natural resources management (INRM) and intergrated plant nutrient management (IPNM) should be adopted in achieving enhanced and sustainable rice production in Zanzibar.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

Fertilizers used were; urea (46% N) and triple super phosphate (45% P_2O_5). These are commonly used in rice cultivation in Zanzibar and are available at subsidized prices. Rice Variety, NERICA No 12 is resistant to insect pests like stem borer, diseases such as blast, and problematic soils with high yielding, highly responsive to mineral fertilizer and non shattering characteristics (Uleid, 2007).

3.1.1 Location of the study areas

The study was based in West District Zanzibar, and the criteria used in selecting the study areas/sites were based on rice producing areas, where rice yields are still low ranging from 1.5 to 2.0 t ha^{-1}.

3.1.2 Description of the study sites

The study was conducted at Bumbwi, Mtwango and Kizimbani villages in the West District of Zanzibar. The study areas are located between latitude 5^o – 7^o South and longitude 39^o– 40^o East at 1200 to 1300 meter above sea level (Fig. 1). The climate of the West District is moderately hot with an average annual temperature of 24 ^{0}C with minimum daily temperature ranging from 19 to 20 ^{0}C and the maximum daily temperature range from 28 – 31 ^{0}C. Cool days are experienced towards the end of the rainy season in May and June and hot periods from December to March. The rainfall is of bimodal, with short and long rainy seasons whereby the short rainy (*Vuli*) season starts from October to December while the long rainy season (*Masika*) starts from March and lasts to the end of May (Uleid, 2007).

The annual rainfall ranges from 900 to 1000 mm with reliable amounts and distribution of rains during long rains seasons, throughout the Island, whereas the short rains are reliable only in certain areas (FAO/IFAD, 1989). The long rains are adequate for growing an early rice variety without supplementary irrigation (Ingram, 1997). The 4-yr meteorological data of Zanzibar Island during the study are as summarized in Table 2.

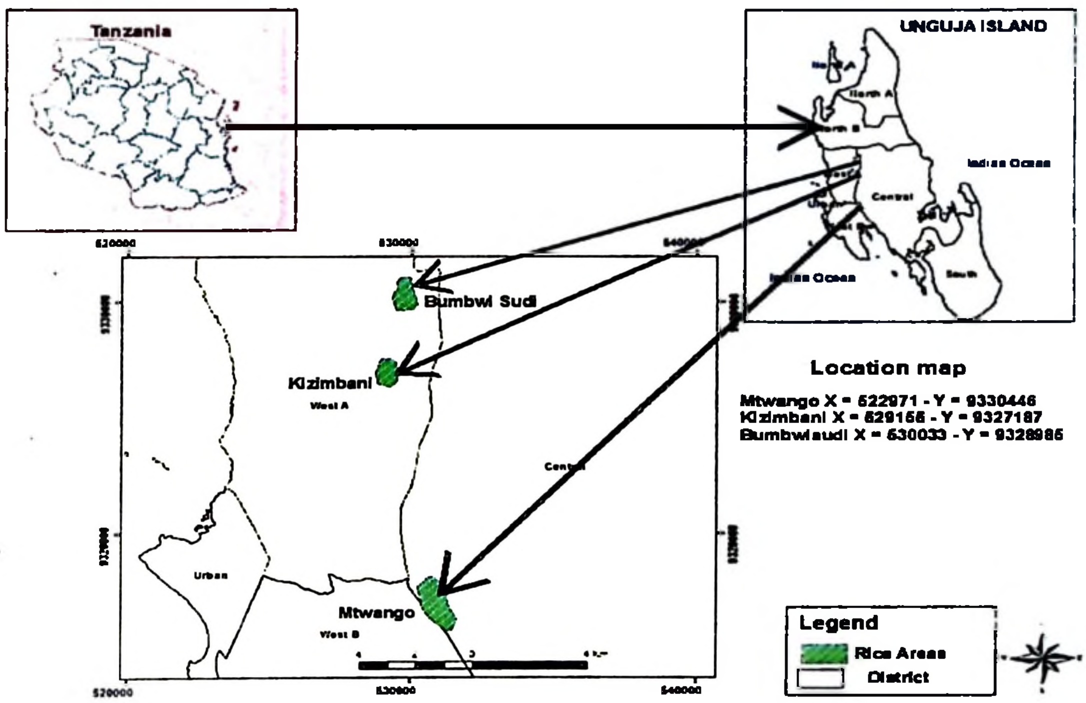

Figure 1: Map of the Kizimbani, Bumbwi and Mtwango Villages

The dominant soil types are mainly Gleyic Luvisols in Kizimbani, Dystris Vertisols in Bumbwi and Gleyic Luvisols in Mtwango (Uleid, 2007). The Bumbwi soils are sandy loam to sandy clay loam over iron stone mostly associated with granite boulders on the high altitude areas. These soils are light brownish-grey whereas the sub soils are yellowish grey. The parent materials have low soil fertility because of the nature of the parent materials (FAO/IFAD, 1989). For Kizimbani, the soils are generally clayey with a characteristic hard pan present in the subsoils. These soils are dark brownish grey to black heavy clay loams to sandy clay and some are calcareous (Uleid, 2007). In Mtwango, the soils are sandy loam to sand clay loam and are well drained with respect high rice yields. The soils in general are moderately suitable for rice production due to their high drainage capacity and low soil fertility status.

Table 2: Mean Monthly Meteorological Data of the Zanzibar Island for the Period 2010-2014

Data	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum temperature (°C)	31.5	32.0	31.9	30.2	29.5	28.5	28.9	28.9	29.9	30.5	30.5	31.2
Minimum temperature (°C)	22.9	23.7	23.1	23.4	22.7	21.7	20.6	19.6	19.1	20.0	21.2	22.5
Mean temperature (°C)	27.2	27.8	27.5	26.8	26.1	25.3	24.6	24.3	24.5	24.3	25.9	26.9
Rainfall (mm)	75.0	74.0	136.0	388.0	241.0	60.0	49.0	42.0	47.0	90.0	207.0	156.0
Humidity	79.0	79.0	82.0	87.0	86.0	83.0	83.0	82.0	82.0	76.0	78.0	79.0

Source Kizimbani Meteorological Station (2014)

3.2 Methods

3.2.1 Soil fertility evaluation

Selection of the soil sampling sites from identified farmers' fields (Bumbwi (4 fields), Kizimbani (7 fields), and Mtwango (8 fields), was based on the farmer's rice production/cultivation history where low rice yields are common. It has been reported that these soils have low total nitrogen and available phosphorus as the major limiting plant nutrients, whereas total nitrogen content is very low (0.01% N) and phosphorous is (< 8 mg kg^{-1} as reported by Uleid, 2007).

3.2.1.1 Soil sampling

Composite soil samples were gathered from the identified farmer's fields an areas of about 3 ha based on the simple random sampling plan (Petersen and Calvin, 1986). The depth of sampling was 0 - 30 cm representing the rooting zone of rice plants. Sampling was done using a soil auger. Each composite soil sample was constituted of not less than 20 point samples from each farmer's field. The point samples were thoroughly mixed to constitute the composite sample of that particular farm and were used for analysis in the determination of key soil properties for the establishment of the fertility status of the soils. Preparation of the composite soil samples for analysis included air drying. grinding. sieving through 2 mm sieve and then stored in well labeled plastic containers (Pleeysier. 1995) for laboratory analysis to determine the relevant physical – chemical properties of the soils.

3.2.1.2 Soil analysis

Analysis of the soil samples was conducted at the Kizimbani Agricultural Research Institute, Zanzibar. The parameters determined included; particle size distribution, soil pH, organic carbon, total nitrogen, plant available phosphorus, cation exchange capacity, exchangeable bases, exchangeable acidity, and plant extractable micro-nutrients. namely Cu, Fe, Zn and Mn.

The particle size distribution was determined by the hydrometer method based on the procedure by Gee and Bauder (1986) and pH in distilled water by the potentiometric method (Thomas, 1996). Organic carbon was determined by the wet oxidation method (Nelson and Sommers, 1996) and the total nitrogen by the micro- Kjeldahl digestion-distillation method (Bremner and Mulvaney, 1996). Plant available phosphorus was determined by the Bray-1 method (Kuo Shio, 1996). CEC was determined by the buffered 1M- neutral ammonium acetate saturation method (Thomas, 1996) and the exchangeable bases Ca, Mg and K, and Na in the ammonium acetate filtrates were quantified by atomic absorption spectrophotometer and flame photometer, respectively. Plant available Zn. Cu, Fe, and Mn were extracted by the DTPA- TEA method (Reed and Martens. 2008) and quantified by atomic absorption spectrophotometer.

3.2.1.3 Field Experiment

Selection of the three experimental sites, one each from Bumbwi, Kizimbani and Mtwango, was based on soil texture (high % clay content), and low rice yields 1.5 -2.0 t ha^{-1}. The field experiments were conducted for three consecutive seasons 2012/3, 2013/14, and 2014/5, on a new piece of land for each season, but within the three hectare piece of land sampled for soil fertility evaluation where the treatments were as in season one. Based on the above selection criteria, farmer's fields are sites for Bumbwi. Mtwango, and Kizimbani.

3.2.1.4 Seedbed preparation

Seedbed preparation included ploughed the land using a tractor followed by harrowing two weeks after plough so as to allow the weeds to die.

3.2.1.5 Design of the experiment

The experiment was a 5^2 factorial in a Randomized Complete Block Design (RCBD), and the size of each treatment plot was 5m x 4m and banded so as to allow for the periodic ponding of the plots. N and P were applied at the rate of 0 kg ha^{-1}, 50 kg ha^{-1}, 100 kg ha^{-1}, 150 kg ha^{-1} and 200 kg ha^{-1} and 0 kg ha^{-1}, 20 kg ha^{-1}, 40 kg ha^{-1}, 80 kg ha^{-1}, and 120 kg ha^{1}, as urea $CO(NH_2)_2$ (46% N) and (45% P_20_5), respectively. The treatment combinations were as presented in Table 3.

Table 3: Treatment combinations design

	N_0 (0)	N_1 (50)	N_2 (100)	N_3 (150)	N_4 (200)
Factors and levels			**Treatment Combination**		
P0 (0)	N_0P_0	N_1P_0	N_2P_0	N_3P_0	N_4P_0
P1 (20)	N_0P_1	N_1P_1	N_2P_1	N_3P_1	N_4P_1
P2 (40)	N_0P_2	N_1P_2	N_2P_2	N_3P_2	N_4P_2
P3 (80)	N_0P_3	N_1P_3	N_2P_3	N_3P_3	N_4P_3
P4 (120)	N_0P_4	N_1P_4	N_2P_4	N_3P_4	N_4P_4

Note: N_0 (0 kg N ha^{-1}), N_1 (50 kg N ha^{-1}), N_2 (100 kg N ha^{-1}), N_3 (150 kg N ha^{-1}), N_4 (200 kg N ha^{-1})
P_0 (0 kg P ha^{-1}), P_1 (20 kg P ha^{-1}), P_2 (40 kg P ha^{-1}), P_3 (80 kg P ha^{-1}), P_4 (120 kg P ha^{-1})

Table 4: Weather conditions at Bumbwi, Kizimbani and Mtwango during the study cropping seasons (2012/5)

Study Sites	Month	Rainfall Mm 2012/2015	Min ^0C	Temperature Max ^0C
Kizimbani	January	35	22	33.3
	February	36	23.1	31.4
	March	48.8	25.2	33.4
	April	241.7	23.9	30.3
	May	129.1	23.4	30
	June	47.1	21.7	28.8
	July	13.5	20.7	29.9
	August	39.6	19.6	27.5
	Sept	42.9	18.6	27.6
	October	74.3	17.5	31.5
	November	91.5	19.5	31.6
	December	70.5	20.7	31.5
Mtwango	January	34	23.3	34.3
	February	30	22.2	32.2
	March	42.4	24.1	33.1
	April	239.2	23	30
	May	128.1	23.1	29.9
	June	55.1	21	27.2
	July	35.3	20.7	29.5
	August	41.0	20.6	28.9
	Sept	45.0	19.6	29.9
	October	86.5	17.3	30.5
	November	105.5	20.2	39.4
	December	65.75	22.5	30.5
Bumbwi	January	33	24.5	33.4
	February	34	23.2	31.2
	March	47.6	23.1	32.3
	April	239.4	22.5	29.8
	May	128.4	23.2	29.5
	June	46.7	22.3	27.4
	July	36.7	21	28.1
	August	40.5	18.7	26.5
	Sept	43.6	17.3	27.7
	October	82.6	16.5	28.2
	November	75.5	18.7	37.4
	December	76.8	21.5	28.8

3.2.1.6 Weather Conditions at the Study areas during the Study Period 2010/5

The location and meteorological data of the study areas namely Bumbwi, Kizimbani and Mtwango is as presented in tables 2 and 4. Weather conditions at Bumbwi, Kizimbani and Mtwango did not vary much during the cropping seasons although there were slight differences in rainfall distribution during the growing season at all sites. However, for Kizimbani in July the rainfall was relatively low compared to the other two sites. Mean maximum rainfall was 241.7 mm in April while the minimum rainfall was 13.5 mm in July and the driest period in West District was in December- January (Table 4). In addition the mean maximum and minimum temperatures for all sites were almost the same during the seasons as from April to August. The temperature varied between 27.2 to 33.1 ^{0}C, 29.9 to 33.4 ^{0}C and 28.1 to 31.8 ^{0}C for Mtwango, Kizimbani and Bumbwi, respectively. The highest temperature was recorded at Kizimbani in the month of March (33.4 ^{0}C). The critical rainfall for rice is 900 mm and temperature fall below 14 ^{0}C. The rainfall and temperature were adequate for rice growth conditions. In general, the temperature regime of Zanzibar is satisfactory for rice production. This is supported by the fact there is no time in Zanzibar when the temperature fall below 14 ^{0}C or rises above 35 ^{0}C (De Datta, 1981). The amounts of rainfall received during long rains is adequate for growing an early rice variety without supplementary irrigation as presented in tables 2 and 4. At about 900 to 1000 mm water is required for growing rice on lowland soils (Ingram, 1997). Effects of rainfall on rice growth performance determined by the amount, intensity; distribution and duration of the rainfall season. The amounts and distribution of rainfall are the most important rainfall parameters limiting yield of rice (De Datta *et al.*, 1985). Weather conditions are very crucial in rice production.

3.2.1.7 Management of the field experiment/agronomic practice

Sowing was done in March in year 2012. Weeding was done manually by using a small hand hoe and hand pulling. First weeding was done two weeks after seed weed emergence and the second weeding was done when the rice was at three to four leaf stages. There were no pests or disease outbreaks during the period of the study for the three seasons. Phosphorus was applied at the rates of 0, 20, 40, 80 and 120 kg P ha^{-1} at planting time, nitrogen was applied at the rates of 0, 50, 100, 150 and 200 kg N ha^{-1}, at two equal splits applied at two weeks after seedling germination and the second split at booting stage.

3.2.1.8 The Residual Effects of N and P Experiments

The study was conducted in those three areas at Kizimbani, Mtwango and Bumbwi. Experiment design was the Randomized complete blocks design, with three replications at each site. The residual effect was to determine the accumulation of the initially applied N and P. The N and P involved growing of rice during second and third season on treated plots without further application of N and P. The land was ploughed, harrowed, sown and weeded by using a small hand hoe and hand pulling. First Weeding was done two weeks after weed emergence and the second weeding was done when the rice was at three to four leaf stages. Phosphorus was applied at the rates of 0. 20, 40, 80 and 120 kg P ha^{-1} at planting time and nitrogen was applied at the rates of 0, 50, 100, 150 and 200 kg N ha^{-1}, separates, at two equal splits applied at two weeks after seedling emergence. Spacing was 10 x 10 inch and 30 cm double rows spacing and size of each of treatment plot was 5 x 4 m. The yields data were collected from 1 m^2 area in each treatment plot, which was threshed, winnowed, and sun dried to 14% moisture content. Moisture meter device was used to determine grain moisture content by squeezing grain after drying to constant moisture.

3.2.2 Data collection

The data collected included;

i) Field observation/field overview/survey in identifying suitable land for agriculture by using local soil indicators of the fertility status of the soil of studies areas were observed, by doing field observation by observing different vegetation present to that area, through walking around the field.

ii) Rainfall data were collected from the nearby station during the research/study period 2012/5.

iii) Plant height data were collected at 30, 60 and 90 days after seed emergence. 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 centimeters (cm).

iv) Number of days to 50% flowering days to 50% heading were 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.

v) Number of days from sowing to harvest was recorded by counting the number of days from sowing to harvest.

vi) 1000 grain weight (g) corrected to 14% moisture content, 1000 fully grains were 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.

vii) Grain yields: This was determined for grains from one meter harvested area of each plot, which was threshed, winnowed, and sun dried to 14% moisture content. Moisture meter device was used to determine grain moisture content by squeezing grain after drying to constant moisture.

viii) Straw yield, one square meter quadrant ($1m^2$) from each plot were harvested at physiological maturity from the ground surface and all materials were sun dried until constant weight before been weighed using an electronic balance. Weight for each plot was recorded without grains for biomass yield determination in t ha^{-1}.

3.2.3 Statistical analysis of the data

The data collected from field experiment and residual experiment were subjected to analysis of variance (ANOVA) using Genstat (Fourteenth Edition) computer software. Where the treatment effects were significant, the means were separated using the Duncan Multiple Range Tests (DMRT 5%), based on the statistical model $Yij = \mu + Ai + Bj + (AB)ij + eijk$ Where $Yijk$ = response, μ = general mean, A = main effect of phosphorus, B = main effect of nitrogen, AB = interaction of phosphorus and nitrogen, eijk = Error term effect in accordance with procedure described by Gomez and Gomez (1984). In case of any significant differences was used to compare/separate the treatments means.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Soil Fertility Status of the Soils of the Study Areas

Preliminary soil fertility survey and soil management data, interpretation of the soils analytical data and identification of local indicators of soil fertility were used as guides in the categorization of the fertility status of the soils.

4.1.1 Local indicators of the fertility status of the soils of West-District

Local indicators of soil fertility (LISF) (Appendix 5) assessed included; soil colour, soil structure, soil texture by the feel method, presence of worms, cracks, salts, sand, gravel and drying up characteristics. Vegetation related indicators included dominance of certain types of plants and crop performances at Bumbwi, Kizimbani and Mtwango which are the main rainfed rice production areas. Local indicators that relate to high soil fertility included; abundance of earthworms, high water holding capacity, presence of plants in a dry environment, good crop performance, less compaction and the growth of certain plants like *Solunium indicum* and *Commelina spp.* Low soil fertility indicators included; yellow and red colour of the soil, compacted soils, stunted growth of the plant, presence of rocks and stones and salt visible as white patches (very few) on the soil surfaces. Local indicators of soil fertility of study areas are as presented in Appendix 5. Based on the LISF the soils of Bumbwi, Kizimbani and Mtwango were categorized as moderately suitable for rice cultivation.

4.1.2 The physical and chemical properties of the composite soil samples

The physical and chemical properties of the composite soil samples from Bumbwi (four sites), Kizimbani (seven sites) and Mtwango (eight sites) are presented in Tables 5, 6 and 7, respectively.

The textural classes of the soils ranged from sandy clay loam to clay (Table 5, 6 and 7). The high clay content (37%) for Kizimbani soil would restrict percolation of water through the soils, hence encouraging water ponding in the banded fields. It has been reported that soils with high clay content are suitable for rice production because of their high capacities to retain plant nutrients and soil moisture (De Datta, 1981). High clay content extends and improves the water use efficiency of the harvested rain water by the rice plants. It has also been reported that rice performs well in fine to medium textured soils (Landon, 1991). Based on the textural classes of the soils in West District in Zanzibar, most of the soils are suitable for rice production, if the other growth factors are optimal. However, the Mtwango soils are not suitable due to the low clay contents, hence low soil moisture retention capacities. For such soils, organic soil amendments should be applied so as to improve their water retention capacities and improve water permeability especially in compacted soil (De Datta, 1981). The source of organic matter could include rice straw that can be incorporated into the soils after harvest.

The soils are acidic with pH values (in water) for Bumbwi soil ranged from 5.3 (strongly acidic) to 6.7 (slightly acidic), 4.9 to 5.7 (strongly acidic) for Kizimbani and 4.7 to 5.8 (strongly acid) for Mtwango (Table 5, 6 and 7). The soil pH values are within the appropriate range (5 to 8) for normal rice growth De Datta (1981), the critical pH range for rice growth below pH 4 bacterial activity is reduced and nitrification of organic matter is significantly retarded De Datta (1981). Soil reaction influences availability of plant nutrient (Landon, 1991). However, it has been reported that cultivation of rice is even possible in soils with pH of up to 9.0 although yield will somewhat be negatively affected (De Datta, 1981). Based on soil pH, the soils in the study areas are suitable for rice cultivation.

Table 5: Some Physico-chemical properties of the surface (0-30 cm) soils of Bumbwi

Parameters/Location	Sites			
	Bumbwi	Kitundu 1	Kitundu 2	Mkanyageni
Particle size distribution (%)				
Sand	65	57	71	62
Silt	13	10	12	14
Clay	22	33	17	24
Textural class	SCL	SCL	SL	SCL
pH(H_2O) (1:2.5)	6.0	6.7	6.5	5.3
OC%	0.98	0.80	0.71	0.41
OM (%)	0.12	0.34	1.23	0.71
Total N (%)	0.11	0.09	0.10	0.06
Bray-1P (mg kg^{-1})	30.30	6.77	8.50	8.23
CEC ($cmol_{(+)}$ kg^{-1})	14.2	16.0	13.8	12.5
Exchange Bases ($Cmol_{(+)}$ kg^{-1})				
Ca^{2+}	4.13	9.41	5.80	4.43
Mg^{2+}	0.60	0.97	0.83	1.26
K^{+}	0.18	0.25	0.16	0.23
Na^{+}	0.51	0.36	0.49	0.52
PBS	38.16	68.68	52.75	51.52
DTPA Extractable in micronutrients (mg kg^{-1})				
Zn	0.65	0.48	0.47	0.65
Cu	0.70	0.33	0.22	0.42
Mn	36.0	20.00	46.00	92.00
Fe	104.0	69.00	87.00	93.00

SCL = Sandy Clay loam; SL = Sandy loam

On the other hand the inverse relationship between soil pH and most of the soil micro nutrients (Fe, Zn, Mn and Cu) content is known to exist (Wissuwa *et al.*, 2006; Rahman *et al.*, 2013). In their study on the effects of pH on micronutrient distribution in the soil. Rerkasem and Jamjod (2010) found that the amounts of Fe, Zn, Cu and Mn were higher at low pH than at high pH levels.

The organic carbon contents ranged from 0.41 to 0.98% for Bumbwi, 0.08 to 0.93% (Table 5) for Kizimbani and 1.42 to 2.46% (Table 6) and for Mtwango (Table 7). These values are rated as low for Bumbwi to very low for Kizimbani and Mtwango according to Landon (1991 as presented in Appendix 1. Soil organic carbon content of >2% would be rated medium to be adequate for normal growth and yield of rice (Sahrawat, 2010). A low percentage organic carbon content translates, to low organic matter content in soils. Organic matter in soils influence the physical, chemical and biological properties of soils, such as soil structure, water and nutrients retention and micro-biological activities. Low organic matter in rice soils can be increased by incorporating the rice straw and other plant residues or growing legumes such as cowpeas and mug bean after rice harvesting, so as to capitalize on biological nitrogen fixation (BNF).

Table 6: Physico- chemical properties of the surface (0-30cm) soils of Kizimbani

	Sites						
Location	**Field 1**	**Field 2**	**Field 3**	**Field4**	**Field 5**	**Field 6**	**Field 7**
Particle size distribution (%)							
Sand	35	44	45	42	29	57	59
Silt	27	20	21	20	21	16	12
Clay	48	36	34	38	50	27	29
Textural class (USDA)	C	CL	CL	CL	C	SCL	SCL
pH (H_2O) (1:2.5)	5.7	5.6	5.6	4.9	4.9	5.6	5.6
O.C. (%)	0.48	0.83	0.93	0.32	0.30	0.13	0.08
O.M. (%)	1.95	1.96	1.65	1.47	1.61	1.93	1.89
Total N (%)	0.11	0.11	0.08	0.09	0.11	0.11	0.10
Bray-1 P (mg kg^{-1})	1.46	4.88	0.88	3.26	3.11	3.40	3.15
CEC ($cmol_{(+)}$ kg^{-1})	18.75	16.48	21.60	17.20	20.85	17.85	15.60
Exchangeable base ($cmol_{(+)}$ kg^{-1}							
Ca^{2+}	6.31	5.48	6.84	2.88	2.75	5.10	6.48
Mg^{2+}	1.83	2.30	2.50	3.60	4.00	2.23	1.80
K^+	0.45	0.41	0.25	0.36	0.26	0.24	0.22
Na^+	0.68	0.25	0.50	0.65	0.47	0.57	0.47
PBS (%)	49.44	51.21	46.71	43.54	35.87	45.60	57.50
DTPA Extractable (mg kg^{-1})							
Zn	0.5	1.00	0.90	0.68	0.83	0.75	1.33
Cu	0.80	1.05	0.95	0.55	0.60	0.45	0.70
Mn	43	42	60	14	102	22	52
Fe	84	86	148	154	86	98	102

C = Clay; C l = Clay loam; SCL = Sandy clay loam;

The percentage total nitrogen contents in 18 out of the 19 soils, equivalent to 94.7% fall below the critical level of 0.8 to 1 % T N (De Datta, 1981). The total N in the soil rated as low ranging from 0.06% to 0.11 %, (Table 5) at Bumbwi, 0.08 % to 0.11 % (Table 6) at Kizimbani and 0.05 % to 0.10 % (Table 7) at Mtwango, respectively. The soils rated as low for Bumbwi, Mtwango and Kizimbani (Appendix 1) according Landon (1991) for normal rice growth and yield. Nitrogen is known to be the most important nutrient for rice (Epstein and Bloom, 2005) as the crop requires relatively high amount of N. Total N in these soils is not adequate for optimal rice production. This makes nitrogen a major constraint to rice production in West District of Zanzibar (Tables 5, 6, and 7). Epstein and Bloom (2005) reported that 0.2 to 0.3 % of total N in soils as optimum level for rice. It has also been reported that every tone of rice grain produced, the crop removes 20.5 kg N from soil (Yoshida, 1986). It follows therefore, that if high rice yields are expected, total N level in the soils has to be higher than those found in these soils.

Plant available phosphorus (Bray-1-P) in the soil ranged from (6.77 to 30.3 $mgkg^{-1}$) at Bumbwi, Mtwango and Kizimbani respectively, (Table 5, 6 and 7). Available phosphorus in 11 out of the 19 soil samples, equivalent to 57.89 % fall below the critical level (6 $mgkg^{-1}$) (Landon, 1991) making available phosphorus a major constraint to rice production in West District in Zanzibar.

The cation exchange capacity (CEC) of the soils in the study areas ranged from 12.5 to 16.0 $cmol_{(+)}kg^{-1}$ 15.6 to 21.6 $cmol_{(+)}kg^{-1}$ and 10.0 to 17.2 $cmol_{(+)}kg^{-1}$ for Bumbwi, Kizimbani and Mtwango sites, respectively (Tables 5, 6 and 7). The CEC values ranged from medium (10.0 to 17.2 $cmol_{(+)}kg^{-1}$) at Mtwango (Table 7) medium (12.5 to 16.0 $cmol_{(+)}kg^{-1}$) at Bumbwi and (15.6 to 21.6 $cmol_{(+)}kg^{-1}$) at Kizimbani according (Landon. 1991). The CEC contribute to the soils low soil organic matter contents in the soil, the nature of the parent materials from which the soils were developed and types of clay minerals in the soils. The low CEC of the soils is an indication of their capacities to retain cations.

Table 7: Physico – chemical properties of the surface (0 – 30 cm) soils of Mtwango

	Sites							
Location	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Particle size distribution (%)								
Sand	51	59	50	51	46	66	80	61
Silt	19	17	19	17	25	15	13	15
Clay	30	24	31	32	29	18	7	15
Textural class (USDA)**	**SCL**	**SCL**	**SCL**	**SCL**	**SCL**	**SL**	**LS**	**SL**
pH (H_2O) (1: 2. 5)	5.8	5.1	4.7	5.8	5.3	5.3	5.0	4.9
O. C. (%)	0.12	0.12	0.39	0.42	0.33	0.94	0.82	0.93
O.M. (%)	1.94	1.94	2.40	2.46	2.30	1.63	1.42	1.61
Total N (%)	0.10	0.08	0.08	0.10	0.09	0.07	0.05	0.07
Bray – P ($cmol_c$) kg^{-1})	1.54	9.88	5.6	2.6	4.0	9.3	8.3	7.70
CEC ($cmol_c$ kg^{-1})	13.3	16.0	14.3	13.8	17.2	15.3	10.0	12.3
Exchange Base ($Cmol_c$ kg^{-1})								
Ca^{2+}	3.3	3.2	3.3	4.5	4.3	5.5	1.5	2.4
Mg^{2+}	1.60	1.92	0.70	2.50	2.13	1.05	0.59	0.81
K^+	0.60	0.33	0.35	0.40	0.56	0.47	0.37	0.18
Na^+	0.84	0.55	0.58	0.74	0.49	0.58	0.47	0.44
PBS (%)	47.66	37.50	34.47	58.98	43.48	49.67	29.30	31.13
DTPA extractable (mg kg^{-1})								
Zn	1.25	0.58	0.65	0.95	0.98	0.93	0.83	0.60
Cu	0.70	0.05	0.43	0.50	0.65	0.30	0.08	0.10
Mn	36	92	77	108	67	92	25	16
Fe	110	82	132	76	132	122	100	112

C = Clay; C l = Clay loam; SCL = Sandy clay loam Field 1 Mtwango farm. Field 2 Pongwe sites. Field 3 – Misufini sites, Field 4 - Kibonde Mzungu farm, Field 5 –. Mkorogo farm. Field 6 – Birikani farm. Field 7– Chunga sites, Field 8- Sarawe sites).

Exchangeable Ca levels in the soils ranged from 4.13 to 9.41, 2.75 to 6.84 and 2.4 to 5.5 $cmol_{(+)}kg^{-1}$ for Bumbwi, Kizimbani and Mtwango, respectively (Table 5, 6 and 7). The Ca ranged from (2.4 to 5.5 $cmol_{(+)}kg^{-1}$) that is considered as low at Mtwango (Table 7) to medium (4.13 to 9.41 $cmol_{(+)}kg^{-1}$) at Bumbwi and (2.75 to 6.84 $cmol_{(+)}kg^{-1}$) at Kizimbani (Table 5 and 6) according to Landon (1991). The medium to very high levels of exchangeable Ca in the soils could be attributed to high content of Ca in the parent materials and possibly the use calcium ammonium nitrate as a fertilizer in the study areas.

Exchangeable Mg in soils ranged from 0.60 to 1.26 , 1.80 to 4.00 and 0.59 to 2.50 $cmol_{(+)}kg^{-1}$, for Bumbwi, Mtwango and Kizimbani, respectively (Tables 5, 6. and 7). The Mg ranged low (0.60 to 1.26 $cmol_{(+)}kg^{-1}$) at Bumbwi (Table 5), low (0.59 to 2.50 $cmol_{(+)}kg^{-1}$) at Kizimbani (Table 7) and medium (1.80 to 4.00 $cmol_{(+)}kg^{-1}$) at Mtwango (Table 6). According to Landon (1991) the critical level of Mg is 0.5$cmol_{(+)}kg^{-1}$ according to Landon (1991), the soils in the study areas, have adequate amounts of exchangeable Mg for rice production. The exchangeable Mg could be attributed to high contents of Mg in the parent materials from which the soils were formed.

Exchangeable K levels in the soils ranged from 0.16 to 0.25. 0.22 to 0.45 and 0.18 to 0.60 $cmol_{(+)}kg^{-1}$ for Bumbwi, Kizimbani and Mtwango, respectively (Tables 5, 6, and 7). The K ranged low (0.16 to 0.25 $cmol_{(+)}kg^{-1}$) at Bumbwi, (0.22 to 0.45 $cmol_{(+)}kg^{-1}$) at Kizimbani and (0.18 to 0.60 $cmol_{(+)}kg^{-1}$) at Mtwango according the Landon (1991). Overall, K is a major constraint to rice production in the West District of Zanzibar. However exchangeable K levels in soils are of limited value in predicting crop response to K. This is supported by (Pillai, 2005), who generalized that rice plants growing on soil with exchangeable K of $>$ 0.20 $cmol_{(+)}kg^{-1}$ may not respond to K fertilization.

Exchangeable Na levels in the soil ranged from 0.36 to 0.52, 0.25 to 0.68 and 0.44 to 0.84 $cmol_{(+)}kg^{-1}$ for Bumbwi, Kizimbani and Mtwango, respectively, (Tables 5, 6 and 7). These values, on average, are rated as medium (0.3 to 0.70 $cmol_{(+)}kg^{-1}$) for Bumbwi,(0.25 to 0.68 $cmol_{(+)}kg^{-1}$) at Kizimbani and (0.44 to 0.84 $cmol_{(+)}kg^{-1}$) at Mtwango according to London (1991).

Percentage base saturation of the soils ranged from 38.39 to 68.68%, 35.87 to 57.50% and 29.30 to 58.98% for Bumbwi, Kizimbani and Mtwango, respectively (Tables 4, 5, and 6). These values, are rated as medium (38.39 to 68.68%) at Bumbwi, (35.87 to 57.50%) at Kizimbani and (29.30 to 58.98%) for Mtwango. These values are rated as medium (20-60%) to high (> 60%) according to Verley (1983). Low base saturation implies presence of low level of basic cations in the soil as an indication of low soil fertility, and high base saturation is frequently used as an indication of high soil fertility according to Landon (1991). The critical level in soils for percentage base saturation is less than 20% according to Verley (1983).

The DTPA extractable Zn in the composite soil samples ranged from 0.47 to 0.65, 0.50 to 1.33 and 0.58 to 1.25 mg kg^{-1} soil for Bumbwi, Kizimbani and Mtwango, respectively (Tables 5, 6, and 7). These values on average are rated as very low (0.2-0.8mg kg^{-1}) for Bumbwi and adequate (0.8-1.5 mg kg^{-1}) for Kizimbani and Mtwango according De Datta (1981). Zinc is therefore a major constraint to rice production in West District Zanzibar. Sharma (2006) established the value of 0.86 mg kg^{-1} as the critical limit for rice production. These results imply, therefore, that inadequate supply of Zn to rice plants could be one of the factors contributing to the low rice yields obtained in study areas that are West District Zanzibar.

The DTPA extractable Cu in the soils ranged from 0.22 to 0.70, 0.45 to 1.05 and 0.05 to 0.70 mg kg^{-1} for Bumbwi, Kizimbani and Mtwango, respectively (Tables 5, 6 and 7).

These values on average are categorized as very low (0.2-0.8 mg kg^{-1} soil) to adequate (0.8 -1.5 mg kg^{-1} soil) according to De Datta (1995). The DTPA extractable Cu is rated as very low (0.2 to 0.8 mg kg^{-1} soil) for Bumbwi and Mtwango and adequate (0.8 -1.5 mg kg^{-1} soil) for Kizimbani. Based on the preliminary soil fertility Cu is a major constraint to rice production in West District in Zanzibar based on the categorization by De Datta (1981). De Datta, (1995) gave the critical level for DTPA extractable Cu of 0.5 to 0.8 mg kg^{-1}.

The DTPA extractable Mn in soils ranged from 20 to 92, 14 to 102 and 16 to 108 mg kg^{-1} soil for Bumbwi, Kizimbani and Mtwango, respectively (Tables 5, 6 and 7). These values are rated as very high (16 to 108 mg kg^{-1}) soil according De Datta (1981). These values are well above the critical levels for rice as established by De Datta (1995). Hence the soils in the study areas have adequate amounts of available Mn for rice production.

The DTPA extractable iron in the soils ranged from 69.0 to 104, 84.0 to 154.0 and 76.0 to 132.0 mg kg^{-1} soil for Bumbwi, Kizimbani and Mtwango, respectively (Tables 5, 6 and 7). These values are rated as very high (>27 $mgkg^{-1}$) according De Datta, 1995 rating system. The soils in the study areas, therefore, have adequate amounts of available Fe for rice production. The toxic level for Iron in soils is below the critical of 4.5 mg kg^{-1} according Sahrawat (2010).

Based on the soil fertility status categorization for Bumbwi (Four sites), Mtwango (eight sites) and Kizimbani (seven sites). Moisture stress affects nutrient availability by limiting the translocation of nutrient from the soil mass to the root surfaces and the metabolic processes in the plants. Thus soil fertility status rating for rice should be based on both local indicators soil fertility (LISF) and (TISF) total indicator soil fertility values/factors and soil management practices and technologies. The final fertility status of these areas was adequate for rice production.

4.1.3 Suitability for rice production

The suitability parameters for rice production in Tables 5, 6 and 7) indicate that the soils are moderately to marginally suitable for rice production for upland rice and rainfed rice production. The major limitations of the rainfed rice production systems in West-District include low total nitrogen, low organic matter, low available phosphorus, low zinc, copper and low soil pH values.

Based on these, soils of West District are not optimally suitable for rice production. For optimal rice production, therefore, the above limitations must be rectified by adoption of appropriate soil fertility management strategies and options, like application of proper soil amendments such as nitrogen fertilizers and manures. The development of salt affected soils in Bumbwi areas should be carefully monitored and corrected timely and appropriately so as to avoid decline in rice production.

4.2 Field Experiments

4.2.1 Rice grain yields

The effects of N and P on rice grain yields at Mtwango, Bumbwi and Kizimbani are presented in Figures 2, 3 and 4, respectively. Rice grain yields increased with increasing rates of N, and P and NxP interactions.

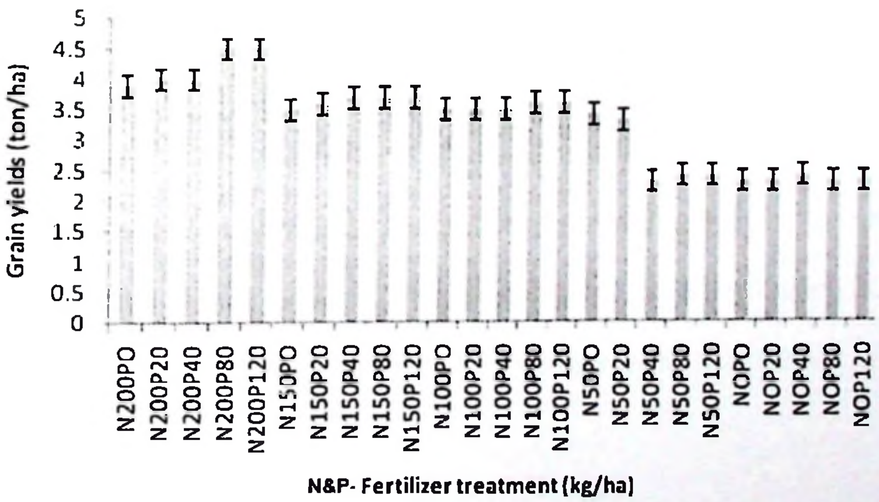

Figure 2: Effect of the interaction of N and P fertilizer on grain yield at Mtwango

Grain yields increased with increasing rates of N, P in the three cropping seasons (2012/15). The trend in the increase in the response was in the order of NP>N>P and the increases were statistically significant ($P<0.001$) as presented in Appendix 9, 10 and 11. The positive response to N was attributed to the low initial levels of N in the soils at the experimental sites compared effect to P.

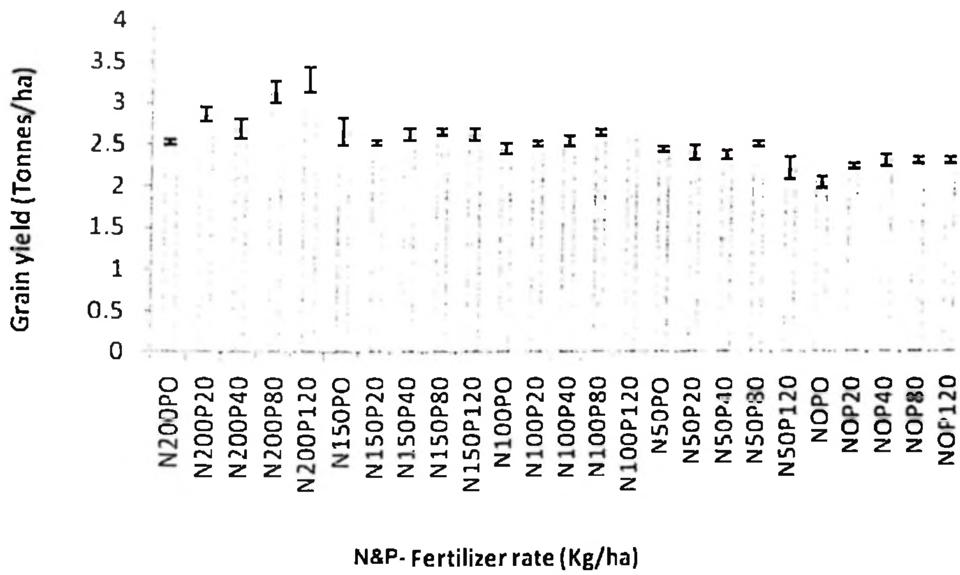

Figure 3: Effect of the interaction of N and P fertilizer on grain yield at Bumbwi

Increases in grain yield following of N and P application ranged from 2.131 to 4.33 t ha^{-1} 2.06 to 3.30 t ha^{-1} and 2.30 to 3.60 t ha^{-1}, respectively (Figures 2, 3 and 4). The highest increase in grain yields as results of N application was due to increased dry matter yields, at the rate of N 200 kg N ha^{-1} (Figure 2, 3, and 4). Furthermore; N is, among other thing, responsible for increased size of leaves and grains (De Datta, 1981). The high yields were obtained associated with good rains hence more runoff and root absorbed nutrient for grain yield (Table 4). Smith *et al.* (2001) revealed that nitrogen fertilization increased number of grain and panicle, per square meter and the total number of spikelet's, reflecting increased grain productivity.

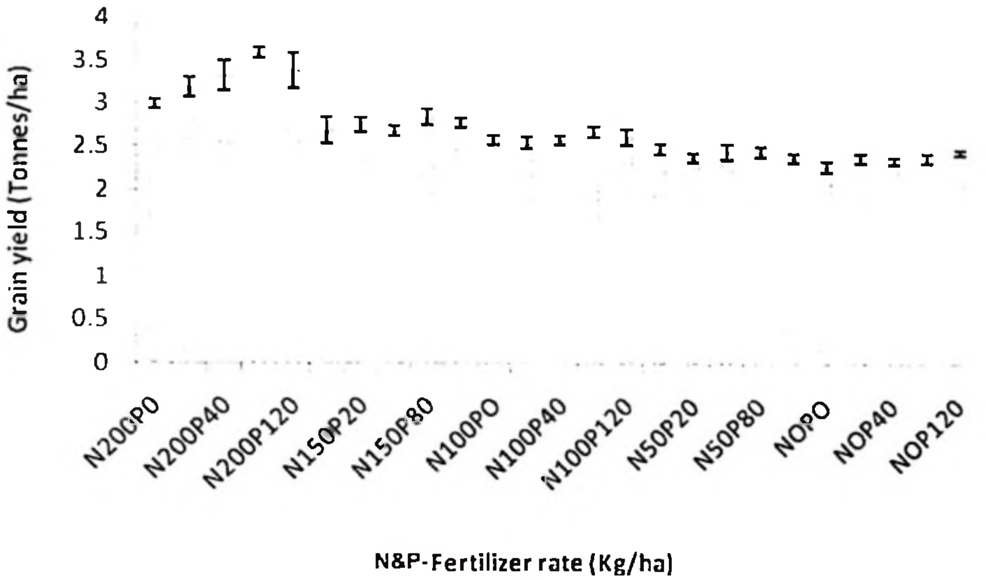

Figure 4: Effect of the interaction of N and P fertilizer on grain yield at Kizimbani

From the data shown there is an increase (systematic) in yield as N & P are increased. However the maximum yield 4.33, 3.60 and 3.30 ton ha^{-1} for Mtwango, Kizimbani and Bumbwi, respectively. I recommend to farmer to use of 80 kg P ha^{-1} and 200 kg N ha^{-1}.

4.2.2 Effect of N and P on Rice Plant Height

The increase in rice plant with increasing N rates was statistically ($P<0.001$) as presented in Appendices 9, 10 and 11, at 30, 60 and 90 days after rice seed germination. The results for effect of N and P, on rice plant heights at 30, 60 and 90 days from seedling germination for Bumbwi, Mtwango and Kizimbani are presented in Figures 5, 6, 7, 8, 9, 10,11, 12 and 13 respectively.

Plant height increased with increasing rates of N and P, and NxP interaction. The increases in heights of plants were in the order Bumbwi> Mtwango > Kizimbani. The increase in rice plant heights with increasing number of days after emergence and with exactly at 30 days after seedling emergence.

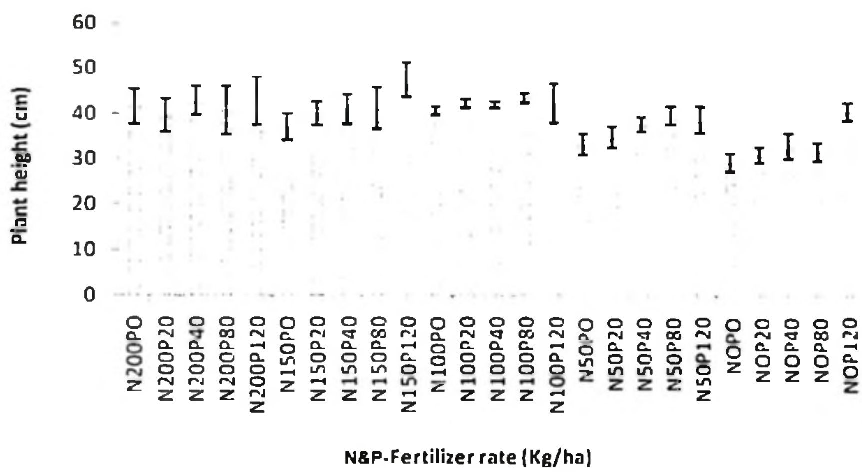

Figure 5: Effect of the interaction of N and P fertilizers on Plant height 30 days at Bumbwi

The increase in plant height with increasing rates of N and with increase in age could be attributed to increased availability of in N rice plants, and improvement in growth rates of plants due to N fertilizer application. The positive response to N fertilizer application was attributed to low levels of initial N in soils at establishment of the experiments (Tables 5, 6 and 7).

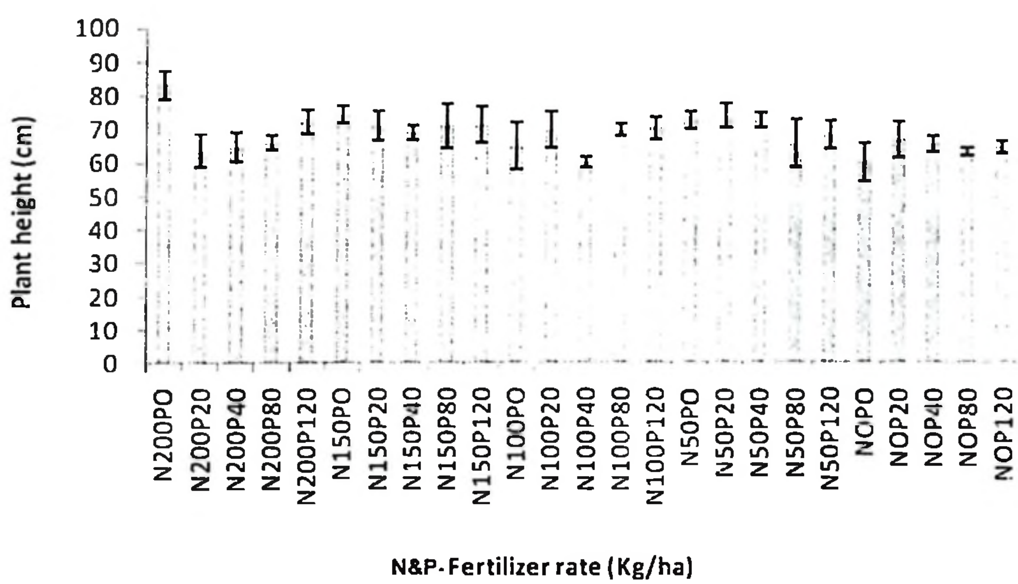

Figure 6: Effect of the interaction of N and P fertilizer on Plant height 60 days at Bumbwi

Increases in plant height exactly at 30 days after seedling emergence due to N and P application ranged from 29.83 to 48.00, 33 to 47.00 and 30.33 to 45.33 cm, at Bumbwi, Mtwango and Kizimbani, respectively (Figures 5, 8 and 11). The increase in plant height in response to application of N fertilizers was probably due to enhanced availability of nitrogen, which enhanced leaf area development resulting in to higher photo-assimilates production and thereby resulting in more dry matter accumulation (Pennamperum,1999). Moreover, increase in plant height increase number of tiller/m^2, which later increased dry matter accumulation in plants (Yoshida, 1986).

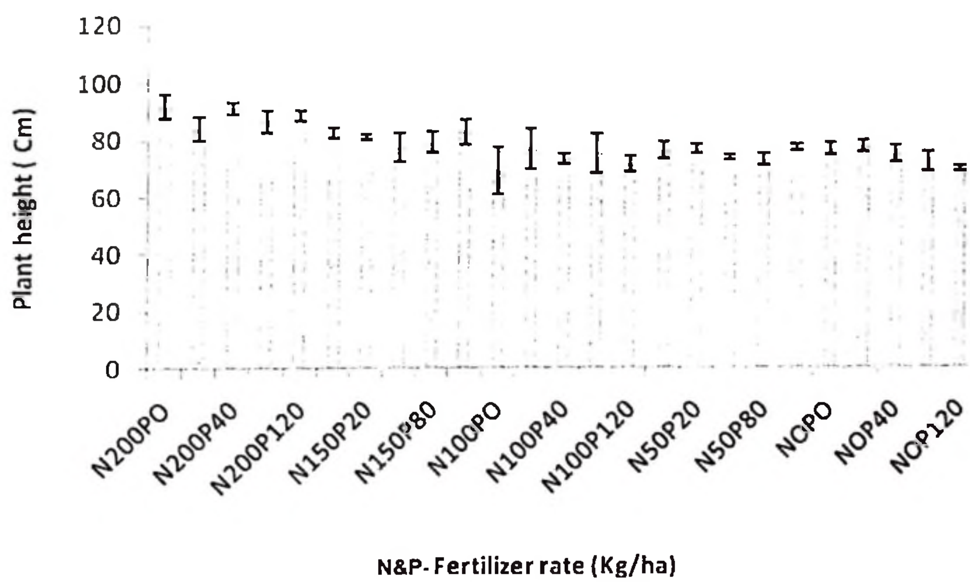

Figure 7: Effect of the interaction of N and P fertilizer on Plant height 90 days at Bumbwi

Plant height increased with increase in age and increase in rates of N, and P and NxP interaction. Increases in height was in order of Bumbwi > Mtwango > Kizimbani (Figures 5, 8 and 11). The increase in rice plant height with increasing number of days after emergence N rates was significant in (P<0.001) (Appendices 9, 10 and 11), at 60 days after seedling emergence.

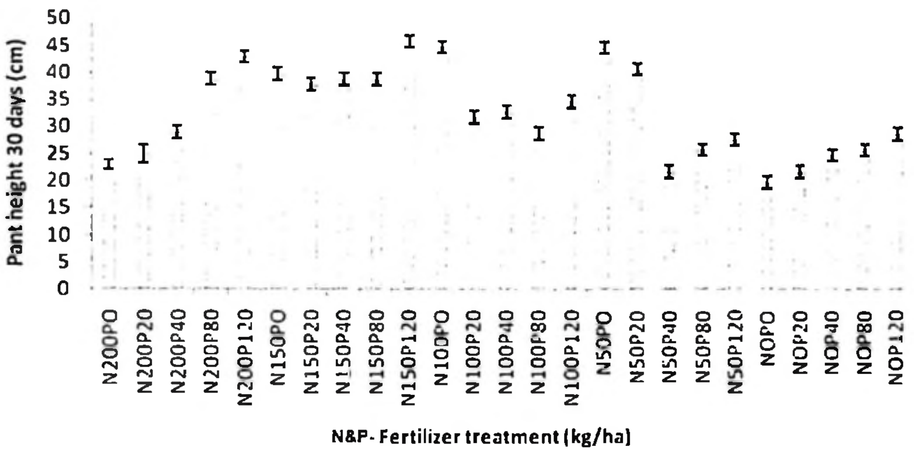

Figure 8: Effect of the interaction of N and P fertilizer on Plant height 30 days at Mtwango

Increases in plant height exactly at 60 days after seedling emergence due to N and P application ranged from 59.93 to 83.33 cm, 39 to 76.00 cm and 54.66 to 83.00 cm, at Bumbwi, Mtwango and Kizimbani, respectively (Figure 5, 8, and 11). The increase in plant height with increasing rates of N and with increasing number of days could be attributed to the increased availability of N to the rice plant, and increase in growth rates of the plants due to the N fertilizer application.

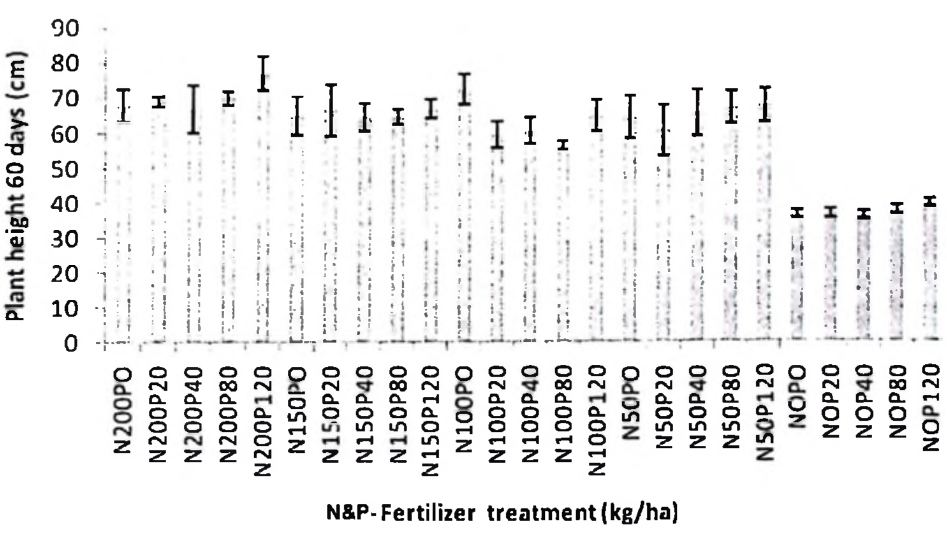

Figure 9: Effect of the interaction of N and P fertilizer on Plant height 60 days at Mtwango

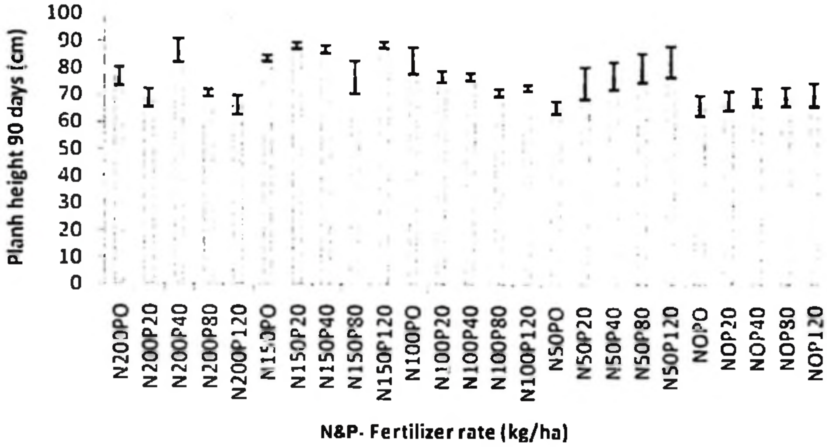

Figure 10: Effect of the interaction of N and P fertilizer on Plant height 90 days at Mtwango

Sharma (2006) reported that application of 180 kg N ha^{-1} resulted in greater plant height in rice than 100kg N ha^{-1}. 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 plants. Okeleye *et al.* (2006) and Oikeh *et al.* (2013) reported that enhanced rice 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.

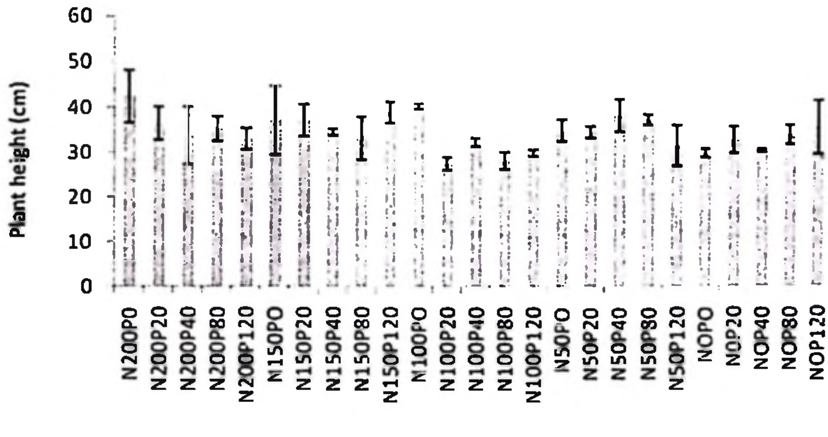

Figure 11: Effect of the interaction of N and P fertilizer on Plant height 30 days at Kizimbani

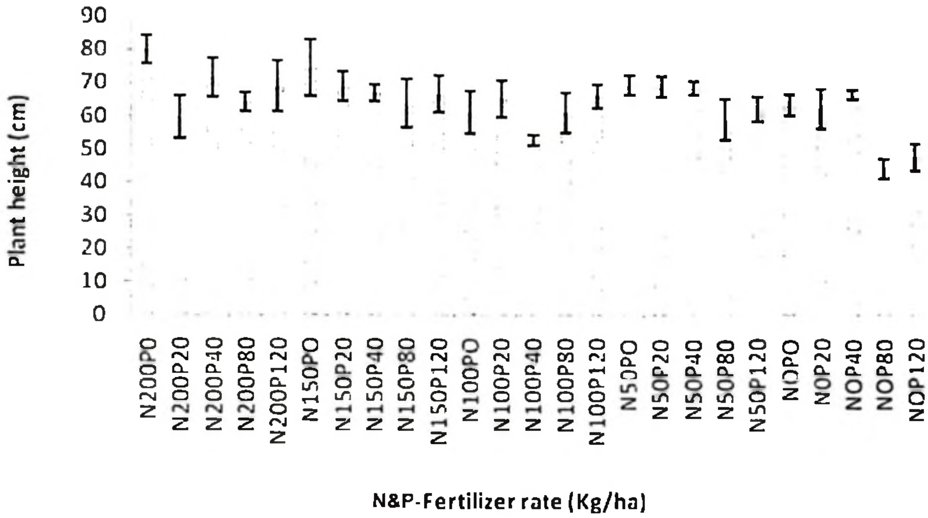

Figure 12: Effect of the interaction of N and P fertilizer on Plant height 60 days at Kizimbani

Plant height increased with increased in age and rates of N, and P and NxP interaction. The increases in plant heights were in the order of Mtwango > Bumbwi > Kizimbani for nitrogen, Mtwango ≥ Bumbwi > Kizimbani for phosphorus.

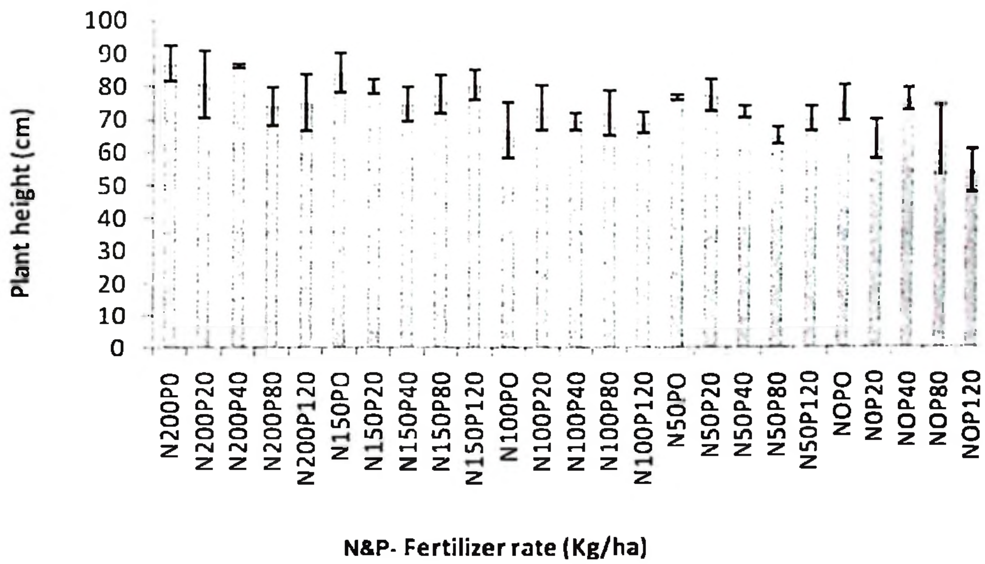

Figure 13: Effect of the interaction of N and P fertilizer on Plant height 90 days at Kizimbani

Increases in rice plant heights with increasing number of days after seedling emergence and increase the number of days, with increasing N rates, the plant heights was statistically insignificant (P<0.001) as presented in Appendices 9, 10 and 11. Increases in plant height exactly at 90 days after seedling emergence due to N and P application ranged from 69.30 to 92.00 cm, 67 to 92.00 cm and 57.50 to 89.66 cm, at Bumbwi, Mtwango and Kizimbani, respectively (Figures 7, 10 and 13) The plant height was increases in order of N, P and NxP interaction.

4.2.3 Effect of N and P fertilizer on number of days to 50% flowering of rice Plants

The effects of N and P on rice plants to 50% days flowering at Mtwango. Bumbwi and Kizimbani sites are as presented in Figures 14, 15 and 16, respectively. The 50% days flowering increased with increasing rates of N, P and NxP interactions.

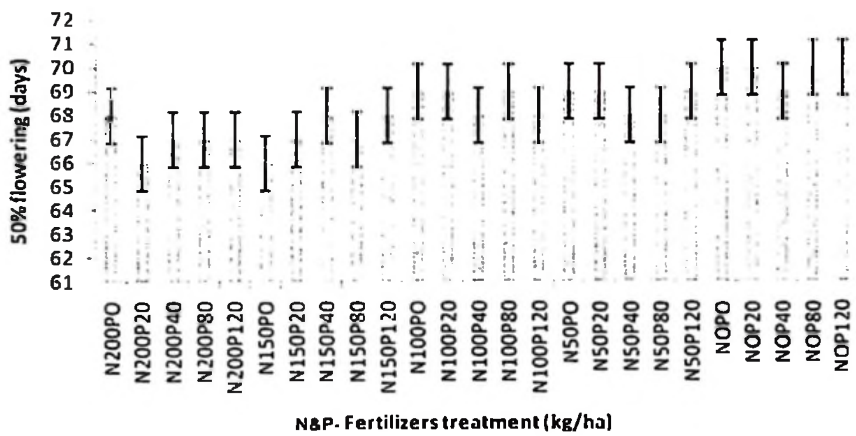

Figure 14: Effect of the interaction of N and P fertilizer on number of days to 50 % flowering at Mtwango

The trend in the number of days to 50% flowering was in the order of N>P and the increases were statistically significant (P<0.001) (Appendices 9, 10 and 11). Bumbwi site increases NxP interaction was at the rate 80 kg P ha-^{1} and 200 kg N ha^{-1}. Increases in exactly number of days to 50% flowering due to N and P application ranged from 66 to 70 days 66.33 to 70 days and 65 to 70 days, at Bumbwi, Mtwango and Kizimbani, respectively, (Figures 14, 15 and 15).

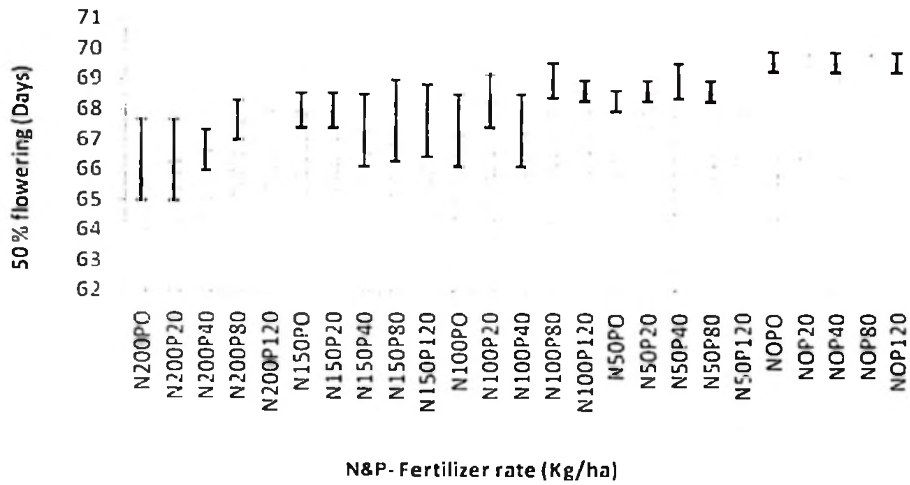

Figure 15: Effect of the interaction of N and P fertilizer on number of days to 50 % flowering at Bumbwi

Mtwango 120 kg P ha^{-1} and Kizimbani farm 80 kg P ha^{-1} and 200 kg N kg ha^{-1}. From the results it showed the change from vegetative to reproductive growth this phenomenon is known as vernalization. The results showed (Table 4) this temperature favorable condition to promote early flowering. Penhawar and Parsazadeh (2011) reported that phosphorus is important for plant growth and promotes early flowering that led to controlling environmental factor in flowering. A major portion of grain carbohydrate comes from photosynthesis, during the ripening period (Wilson *et al.*, 2014).

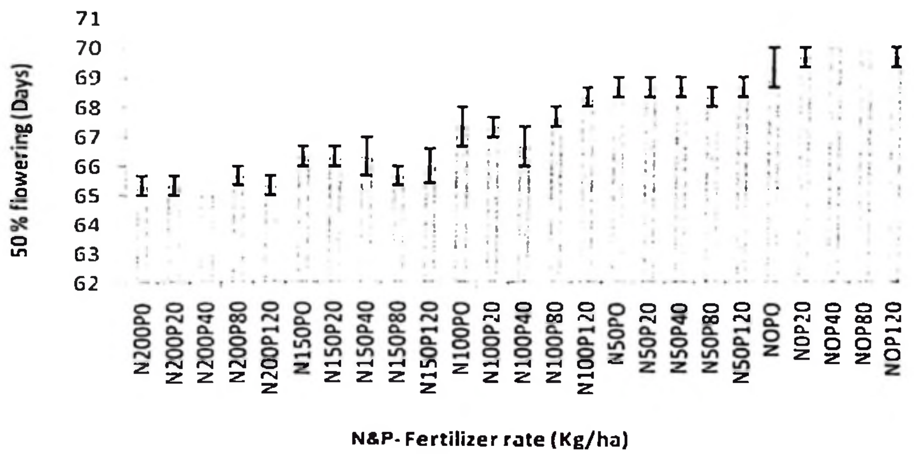

Figure 16: Effect of the interaction of N and P fertilizer on number of days to 50 % flowering at Kizimbani

4.2.4 Response of Rice to N and P amendments

The effects of N, P and NxP interaction on rice plants from sowing to harvest at Mtwango, Bumbwi and Kizimbani sites are as presented in Figures 16, 17 and 18, respectively.

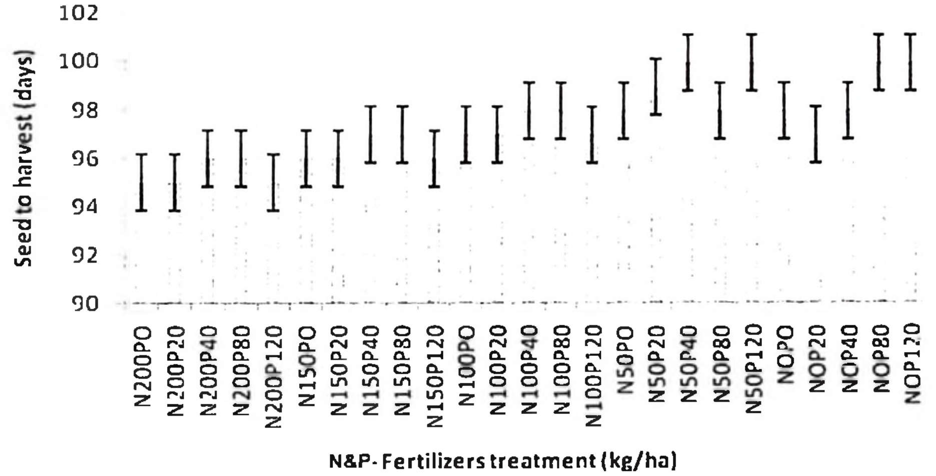

Figure 17: Effect of the interaction of N and P fertilizer on sowing to harvest at Mtwango

The number of days from sowing to maturity in all experimental sites increased with increasing rates of N, P and NxP interaction. The increase was in the order Mtwango $\geq$ Bumbwi $\geq$ Kizimbani for nitrogen, Kizimbani > Bumbwi and Mtwango for phosphorus.

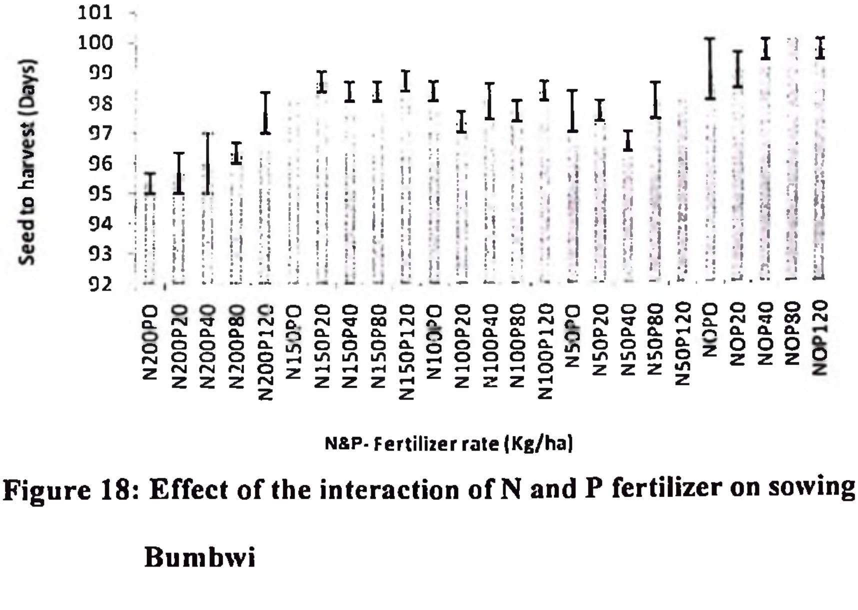

Figure 18: Effect of the interaction of N and P fertilizer on sowing to harvesting at Bumbwi

The trend in rice response from sowing to harvest was in the order of N-NP-P and the increases were statistically significant (P<0.001) as presented in Tables 8, 9 and 10. Increased with increase in rates of N and P and NxP interaction, increases were in the order of Kizimbani > Bumbwi and Mtwango for nitrogen, Mtwango > Bumbwi and Kizimbani, for phosphorus (Figures 17, 18 and 19), increased with increasing rates of N and P during the three cropping seasons (2012/15). Increases on sowing to harvest due to N and P application ranged from 94.00 to 100 days, 94 to 100 days and 95.00 to 100 days, at Bumbwi, Mtwango and Kizimbani, respectively, (Figures 16, 17 and 18). The rainfall amounts in relation to rice growth development phases showed that in all three seasons with maximum rainfall was 241.7 mm in April while the minimum rainfall was 13.5 mm in July (Table 4). This condition was favourable for N and P for stimulating plant growth. Phosphorus plays an important role in plant tissues and primarily as a constituent of the nucleotides, nucleic acid, phospholipids, phosphor protein and phosphorylated sugars (Ortiz Monasterio *et al.*, 2001). This condition favoring growth of seedlings also favors germination. As a matter of fact, seed must contain adequate minerals to support seedlings until they are autotrophic (Ortiz Monasterio *et al.*, 2001).

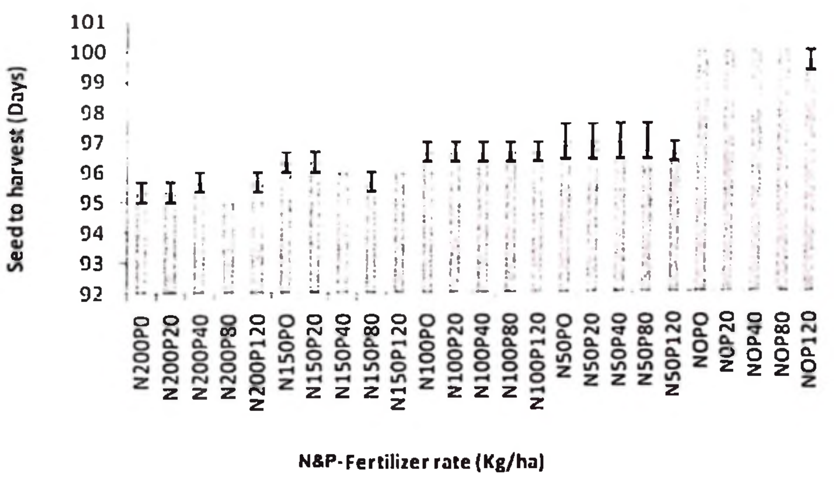

Figure 19: Effect of the interaction of N and P fertilizer on sowing to harvest at Kizimbani

4.2.5 Effects of N and P on 1000 Grain Weight of Rice

Data on effects of N and P on 1000 grain weight at Mtwango, Bumbwi and Kizimbani are as presented in Figures 20, 21 and 22, respectively.

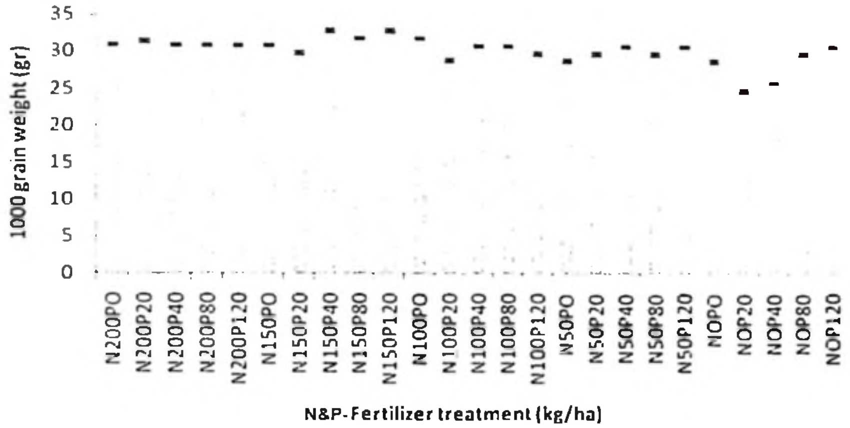

Figure 20: Effect of the interaction of N and P fertilizer on 1000 grain weight at Mtwango

Weight of 1000-grain increased with increase in rates of N and P and NxP interaction. The 1000-grain weight in all experiments increased with increasing application rates of N and P. The increase in 1000-grain weights were in the order of Kizimbani > Bumbwi and Mtwango for nitrogen (Figures 20, 21 and 22), Mtwango > Bumbwi and Kizimbani, for phosphorus, and increased for the NP interaction with increasing rates of N and P during the three cropping seasons (2012/15). The trend in the response was in the order NP>N>P and these were statistically significant (P<0.001) as presented Appendices 9, 10 and 11.

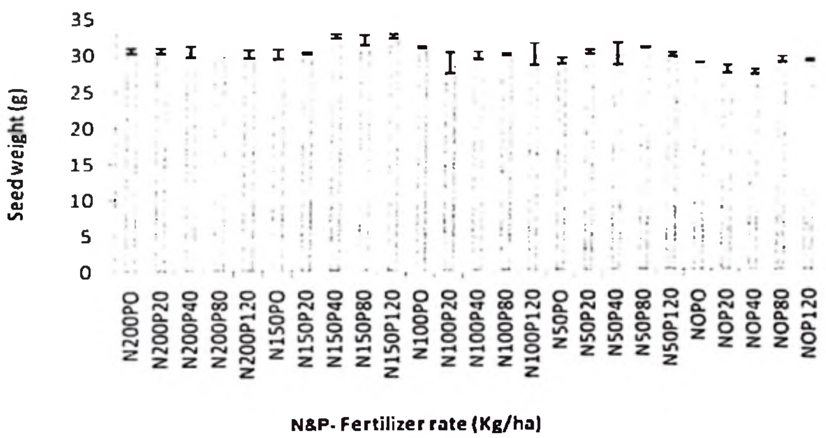

Figure 21: Effect of the interaction of N and P fertilizer on 1000 – grain weight at Bumbwi

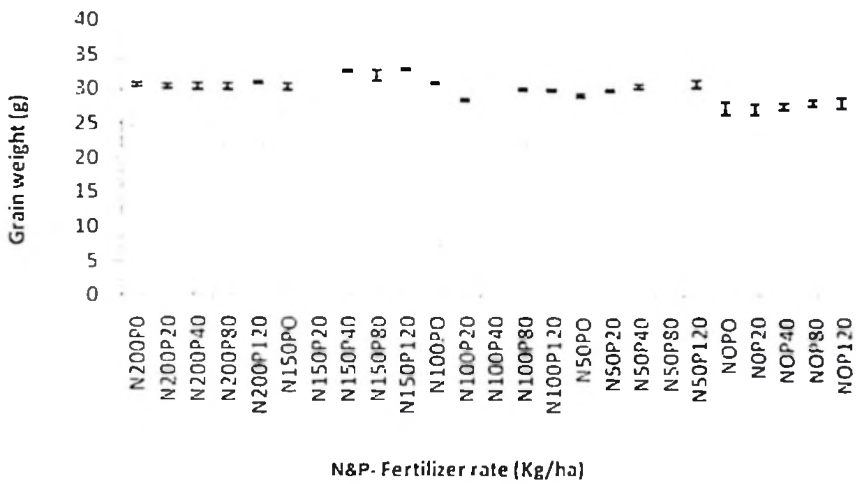

Figure 22: Effect of the interaction of N and P fertilizer on 1000 – grain weight at Kizimbani

Increases in 1000-grain weight with N, P and NxP interaction application ranged from 26.33 to 32.66 gram, 27.66 to 32.66 gram and, 27.50 to 33.20 gram, for Mtwango, Bumbwi and Kizimbani, respectively (Figure 18, 19 and 20 respectively. Grain weight is an important yield component in rice production, which is determined by supply of assimilates during the ripening period and the capacity of the developing grain to accumulate the translocated assimilates and increased protein content in the grains (Ntanos and Koutroubas, 2002). So that advice farmers to use desirable seed qualities for planting materials, free from insect pest and diseases, free from weed seeds, must come from vigorous parent plants, must know genetic and yield potential – improved varieties and high germination percentage and purity.

4.2.6 Rice plant biomass (straw yields)

The response of the rice plants to N and P applications in terms of straw yields (dry matter) yields is as presented in Figures 23, 24 and 25, at Mtwango, Bumbwi and Kizimbani respectively. The trend in the increase in straw dry matter yields were in the order N>P and the increases were statistically significant (P< 0.001) in Appendices 9, 10 and 11. The increases in straw dry matter yields for the main effects of N and P ranged from 0.7 to 3.30 t ha^{-1} 0.9 to 2.86 t ha^{-1} and 0.76 to 3.30 t ha^{-1} Figures 22, 23, and 24 at Mtwango, Bumbwi and Kizimbani, respectively. The rice straw yields increased with increasing rates of N, P and NxP interaction (Figures 22, 23 and 24).

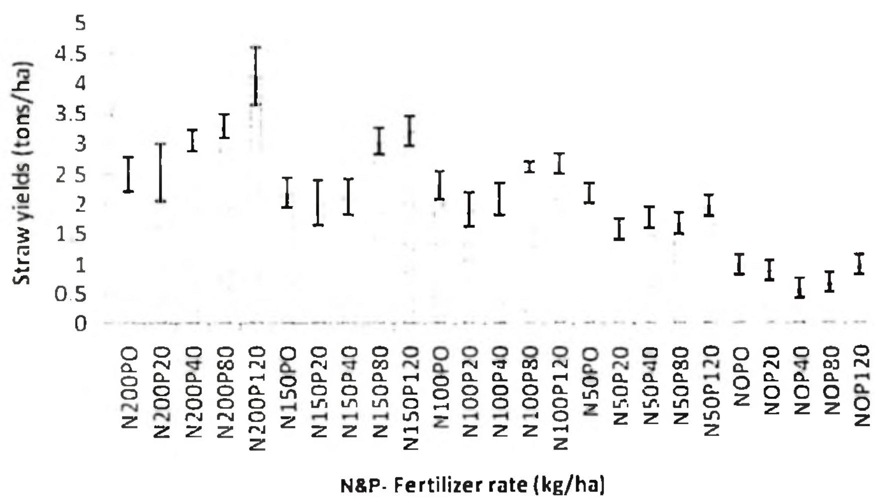

Figure 23: Effect of the interaction of N and P fertilizer on rice straw at Mtwango

The minimum straw yields with phosphorous fertilizer were 0.76, 0.90 and 0.76 t ha^{-1} at Mtwango, Bumbwi and Kizimbani, respectively (Figures 24, 25 and 26).

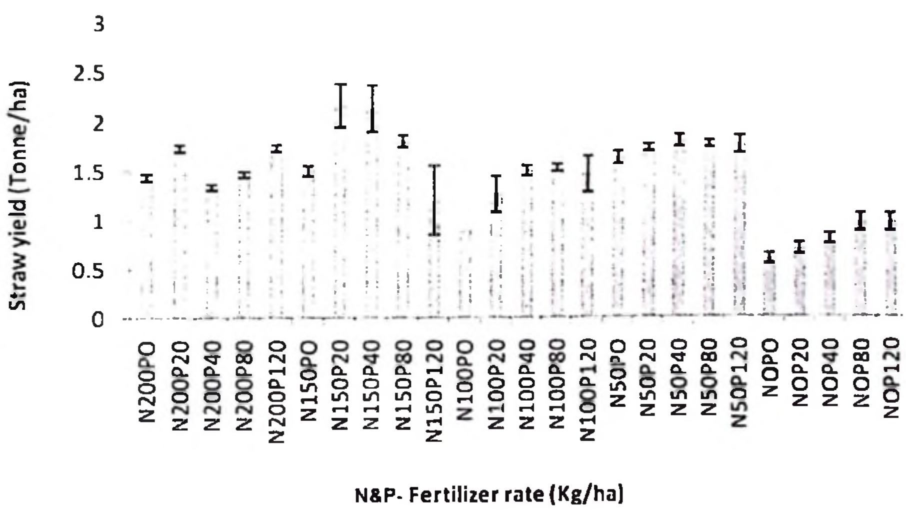

Figure 24: Effect of the interaction of N and P fertilizer on straw yield at Bumbwi

From the data in Figures 24, 25 and 26, nitrogen application had the greatest increase on straw dry matter yields and the increase was attributed to the increase in soil N as the soil at trial sites were deficient N. The increased straw in dry matter yields with the application of P was attributed to the increased N and other nutrient availability to the plants. consequent to the decomposition and mineralization of the P which contained substantial amount of the essential plant nutrients (Figures 23, 24 and 25). Kato *et al.* (2006) reported similar trends with increasing rates of nitrogen and phosphorus which significantly increased straw dry matter yield of rice when water supply was adequate and frequent. Also Penhawar and Parsazadeh (2011) showed that fertilizer application increased straw yields and the increases were more pronounced for N and NxP interactions (Figure 23, 24 and 25), compared to P because could be attributed to soil moisture content variations during the rice growing seasons 2012/15). Further. the high pH in the soils and exchangeable Ca could have to some extent reduced the availability of P to the rice plant through the transformation of the native and applied P to non-available P forms.

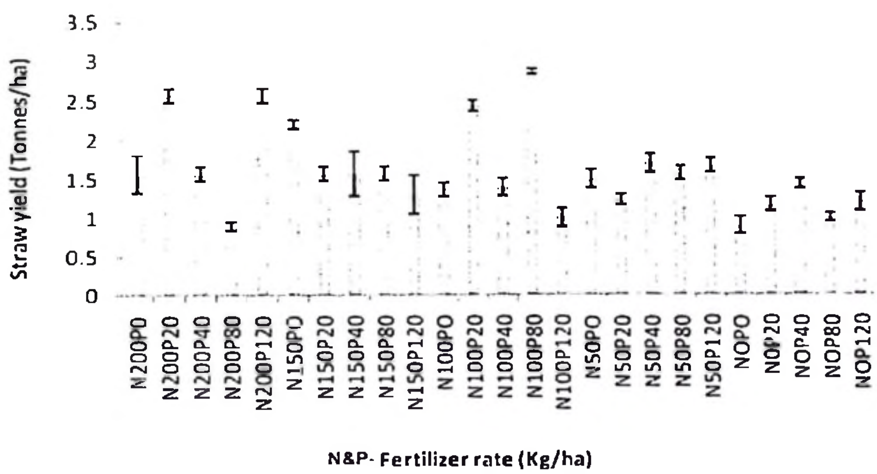

Figure 25: Effect of the interaction of N and P fertilizer on straw yield at Kizimbani

4.2.7 Residual effect of nitrogen and phosphorus on rice yields

4.2.7.1 Residual effects on rice yields for 2012/2013 Cropping Season

The rice yields effects of phosphorous and nitrogen at Mtwango, Bumbwi and Kizimbani are as presented in Figures 26, 27 and 28, respectively. The grain yields increased with increasing rates of N and P applications for season 2012/13. The trend in the increase in grain yield was in the order NP>N>P (Figures 26, 27 and 28) and increases were statistically significant. The increase in rice grain yields for the N, NP and P ranged from 2.70 to 5.56 t ha^{-1}, 3.26 to 5.73 t ha^{-1} and 2.93 to 5.70 t ha^{-1} as presented in Figures 25, 26 and 27 at Mtwango, Bumbwi and Kizimbani, respectively. The interaction of N and P in 2012/13 season was due to the synergetic interaction of N and P on the rice growth performance. This was boosted by good rain received (Table 4). The rainfall tends to increased N and P availability to the rice plants by facilitating the movement of the nutrients from the soil mass to the root surfaces. Water availability promoted uptake of both N and P which promoted rapid growth and root development, respectively. The residual effects on rice yields for initial is higher compared other season. The yields for cropping season 2012/13 for the treatment $N_{200}P_{120}$ was 5.73, 5.56 and 5.70 t ha^{-1} at Bumbwi, Mtwango and Kizimbani are as presented in Figures 26, 27 and 28, respectively. The increase in rice grain yields was in the order Bumbwi > Kizimbani > Mtwango. For such soil, organic amendments should be applied so as to improve their water retention capacities (Homma *et al.*, 2004; Samson *et al.*, 2004) have reported differential movement of water along the top sequence in rainfed lowland rice.

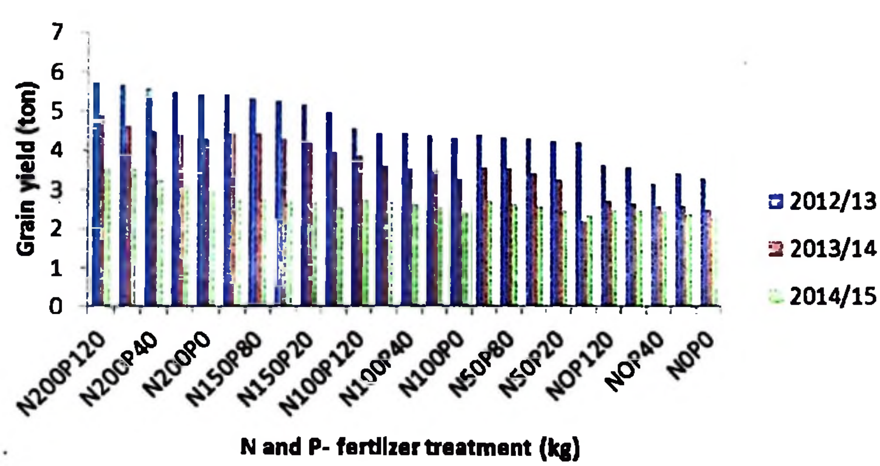

Figure 26: Effect of the interaction of N and P fertilizers of the residual effect on grain yield at Mtwango

4.2.7.2 Residual Effect on rice yields in the 2013/2014 cropping seasons

The residual effects of phosphorous and nitrogen fertilization application to the soil for Mtwango, Bumbwi and Kizimbani were as presented in Figures 26, 27 and 28, respectively. The grain yields increased with increasing rates of N and P applications for season 2013/14. The trend in the increase in grain yield was in the order N>P (Figures 25. 26 and 27) and increases were significant. The increase in grain yields for the main effects of N and P ranged from 2.40 to 4.60 t ha^{-1}, 2.46 to 4.90 t ha^{-1} and 2.50 to 4.9 t ha^{-1} as presented in Figures 26, 27 and 28 at Mtwango, Bumbwi and Kizimbani, respectively. The increase grain yields for N P were 4.90, 4.90 and 4.60 t ha^{-1} at Bumbwi, Kizimbani and Mtwango, respectively, are as presented in Figures 25, 26 and 27. The yield is low 2013/14 compared 2012/13 seasons due, to the low total nitrogen, low organic matter (Table 5, 6, and 7), might have been caused by limited use of organic soil amendment, N, uptake by rice plant, remove of harvesting residue and leaching, interaction of N and P on the rice growth performance. The month of July, the rainfall was relative low in Kizimbani in (Table 4), due to the fact that, field lost water through percolation and seepage due to the coarse textural classes of soils ranged from sandy clay loam to clay (Table 5, 6 and 7).

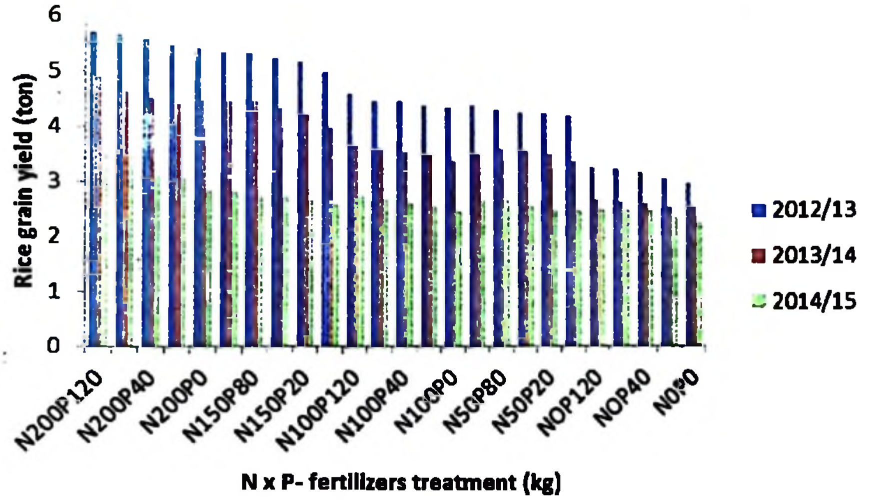

Figure 27: Effect of the interaction of N and P fertilizer of the residual effect on grain yield at Bumbwi

4.2.7.3 Residual Effect on rice yields 2014/2015 cropping seasons

The residual effects of phosphorous and nitrogen fertilization application to the soil for Mtwango, Bumbwi and Kizimbani were as presented in Figures 26, 27 and 28, respectively. The response of rice to N and P application in terms of grain yields is as presented in (Figures 26, 27 and 28) at Mtwango, Bumbwi and Kizimbani, respectively. The grain yields increased with increasing rates of N and P applications for season 2014/15. The trend in the increase in grain yield was in the order N>P (Figures 26, 27 and 28) and increases were significant. The increase grain yields for the main effects of N and P ranged from 2.26 to 3.53 t ha^{-1}, 1.90 to 3.5 t ha^{-1} and 2.23 to 3.5 t ha^{-1} as presented in Figures 25, 26 and 27 for Mtwango, Bumbwi and Kizimbani, respectively. The Mean maximum rainfall was 241.7 mm in April while the minimum rainfall was 13.5 mm in July (Table 4). The rainfall tend to facilitate the movements of the nutrient from the soil mass to root surface, due to the fact the low total nitrogen might have been caused by limited use of organic soil amendments N uptake by plants, remove of harvesting and residue, leaching, denitrification and burning of crops residues. The rates of N to be added to the soil should be determined by field N fertilizers. This also has been also reported by George (2014). Samonte *et al.* (1998) from the results it shows that the initially residual fertilizer had higher yield compared to the second season.

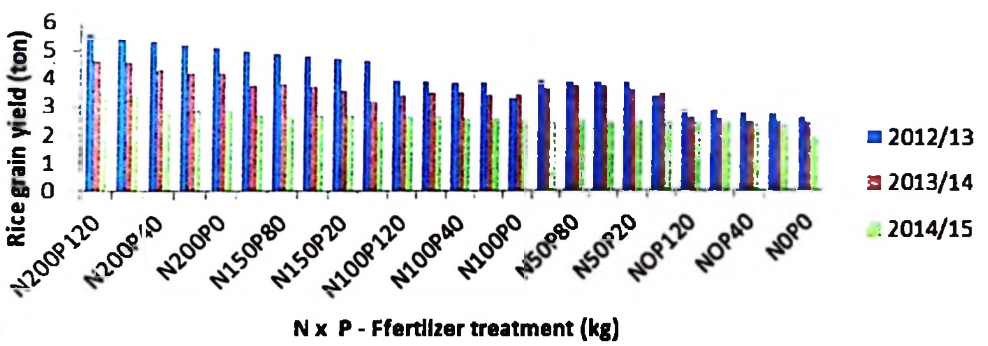

Figure 28: Effect of the interaction of N and P fertilizers of the residual effect on grain yield at Kizimbani

The yields for the 2012/13 cropping season were, 2.60 to 5.56 t ha^{-1}, 3.26 to 5.73 t ha^{-1} and 2.93 to 5.7 t ha^{-1} , for 2013/14 cropping season, 2.40 to 4.60 t ha^{-1}, 2.46 to 4.90 t ha^{-1}, and 2.50 to 5.90 t ha^{-1} and 2014/5 cropping seasons were 1.90 to 3.50 t ha^{-1}, 2.26 to 3.53 t ha^{-1} and 2.23 to 3.5 t ha^{-1} at Mtwango, Bumbwi and Kizimbani, respectively, (Figures 26, 27 and 28) with combination of 200 kg N ha^{-1} and 120 kg P ha^{-1}. The interaction of N and P in 2012/13 season was due to the synergetic interaction of N and P on the rice growth performance. This was boosted by good rain received (Table 4). The rainfall tends to increase N and P availability to the rice plant by facilitating the movement of the nutrient from the soil mass to the root surfaces. Water availability promoted the uptake of both N and P which promoted rapid growth and root development, respectively. The yield is low for their 2013/14 and 2014/15 seasons compared with 2012/13 seasons, respectively due, to the low total nitrogen, low organic matter (Tables 5, 6, and 7), might have been caused by limited use of organic soil amendment, N, uptake by rice plant, remove of harvesting residue and leaching.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This chapter highlights the overall conclusions with respect to the objectives of this study as stated in chapter one. It further, outlines the implications inferred from the conclusions and finally proposes recommendations and future research needs which are aimed at improving and sustaining rice production in Zanzibar.

Fertility Status of Rice Soil in West District in Zanzibar

From the physico-chemical properties of the composite soil samples the following conclusion can be made;

i) The soil fertility evaluation are categorization into three classes, low, medium and high based on the technical indicator of soil fertility for study area, the nutrient status of the soils.

   (a) Bumbwi soils were limiting nutrient for rice yields such as, low for total nitrogen, low organic carbon, very low available zinc content, low exchangeable K^+, low Mg^{2+}, very low Cu, low available phosphorus.

   (b) Kizimbani soils were strong acidic (low pH) below the optimum range for normal growth, with low contents of available zinc, low levels of total nitrogen, very low organic carbon, low available phosphorus, low available of Zn, low Cu, and;

   (c) Mtwango soils were limiting nutrients for rice yields such as: low total nitrogen, very low organic carbon, and low available zinc content, low phosphorus, low CEC, low calcium, low potassium and very low Cu.

ii) Based on the results of the N and P trial for consecutive season on application phosphorous as triple super phosphate and nitrogen as urea increased rice grain yield and the response was in order of N>P. for rice variety Nerica No 12 responds to different rates and combination of N&P, suggesting that high and sustainable rice yields can be achieved through the use appropriate soil amendments based on soil analytical data.

iii) Based on the N&P balance and their mobility's in the soils. N should be applied in splits so as to limit the loss of N through leaching and volatilization when the rice yields are ponded.

5.2 Recommendations

The following recommendations are made with respect to improved rice production on the West District in Zanzibar.

i) The rates of 40-80 kg P ha^{-1} of P and 200 kg N ha^{-1} are recommended to replenish the amount being removed by rice plant yearly.

ii) Rice farmers in Zanzibar are advised and encouraged to use nitrogen and phosphorus fertilizers so as to increase and sustain rice production, hence attainment of food security and increase farm income and livelihoods.

iii) Soil amendments for improvement of rice plants growth are needed.

iv) Further research should be done to establish the following

- K, Mg and Cu, should be included in field trials in areas testing low in these nutrients.
- Micro element status for all major rice growing soils of Zanzibar and establishment of critical levels for rice.

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APPENDICES

Appendix 1: General soil fertility Rating attribute properties (Adopted from Landon, 1991)

	General Rating				
Soil characteristics	Very low	Low	Medium	High	Very high
Organic matter (%)	< 1.0	1-2	2-4	4-6	> 6
Total nitrogen (%)	< 0.05	0.05-0.1	01-0.2	0.2-03	>0.3
Exchangeable Cacmol (+)kg^{-1}	< 2.0	-	5-10	10-20	>20
Exchangeable Mg cmol(+) kg^{-1}	< 0.5	-	1.5-3.0	3.0-8.0	>8.0
Exchangeable K cmol (+) kg^{-1}	< 0.1	-	0.3-0.6	0.6-1.2	>1.2
Cation Exchange Capacity cmol (+) kg^{-1}	<5	5- 15	15 -25	25-	>40
Available P (mgkg^{-1})	-	< 7	7-20	40 > 20	-

Appendix 2: Response of rice to N & P rates (grain yield components) at Bumbwi in seasons 2013 - 2015

Fertilizer Rate	Season 0 Grain yield ($t\ ha^{-1}$)	Season 1 (2013/14) Grain yield ($t\ ha^{-1}$)	Season 2 (2014/15) Grain yield ($t\ ha^{-1}$)
$N_{200}P_{120}$	5.73a	4.90a	3.53a
$N_{200}P_{80}$	5.66a	4.63ab	3.53a
$N_{200}P_{40}$	5.56a	4.50b	3.26b
$N_{200}P_{20}$	5.46ab	4.40b	3.16b
$N_{200}P_{0}$	5.40ab	4.30bc	2.96c
$N_{150}P_{120}$	5.40ab	4.43b	2.83d
$N_{150}P_{80}$	5.33ab	4.43b	2.76de
$N_{150}P_{40}$	5.26ab	4.30bc	2.73def
$N_{150}P_{20}$	5.16ab	4.20bcd	2.66defg
$N_{150}P_{0}$	4.96b	3.96cd	2.53fghi
$N1_{00}P_{120}$	4.56c	3.86de	2.73def
$N_{100}P_{80}$	4.43c	3.60ef	2.66defg
$N_{100}P_{40}$	4.43c	3.53ef	2.60efgh
$N_{100}P_{20}$	4.36c	3.46ef	2.53fghi
$N_{100}P_{0}$	4.30c	3.26f	2.43hij
$N_{50}P_{120}$	4.40c	3.53ef	2.70def
$N_{50}P_{80}$	4.30c	3.50ef	2.60efgh
$N_{50}P_{40}$	4.26c	3.36f	2.53fghi
$N_{50}P_{20}$	4.20c	3.20f	2.46ghi
$N_{50}P_{0}$	4.16c	2.16f	2.33ij
$_{NO}P_{120}$	3.60d	2.66g	2.46ghi
$_{NO}P_{80}$	3.53d	2.60g	2.46ghi
$_{NO}$P40	3.13d	2.53g	2.43hij
$N_{0}P_{20}$	3.36d	2.53g	2.36ij
$N_{0}P_{0}$	3.26d	2.46g	2.26j
Grand mean	4.863	3.654	2.704
CV	4.572	5.039	2.84
$LSD_{0.05}$	0.365	0.302	0.126

Means within column bearing same or without letter (s) is not significantly different from each other's according to Duncan Multiple range Test (DMRT) at 5% significant level.

Appendix 3: Response of rice to N & P rates (grain yield components) for grain yield components at Kizimbani in seasons 2013 - 2015

Fertilizer Rate	Season 0 (2012/13) Grain yield (t/ha)	Season 1 (2013/14) Grain yield (t/ha)	Season 2 (2014/15) Grain yield (t/ha)
$N_{200}P_{120}$	5.7a	4.9a	3.5a
$N_{200}P_{80}$	5.66ab	4.63ab	3.5a
$N_{200}P_{40}$	5.56ab	4.5abc	3.13b
$N_{200}P_{20}$	5.46ab	4.40abc	3.06b
$N_{200}P_{0}$	5.40abc	4.46abc	2.83c
$N_{150}P_{120}$	5.33ac	4.43ab	2.80c
$N_{150}P_{80}$	5.30abc	4.43abc	2.73cd
$N_{150}P_{40}$	5.23abc	4.30bc	2.73cd
$N_{150}P_{20}$	5.16bc	4.20bc	2.66cd
$N_{150}P_{0}$	4.96c	3.96cd	2.56cde
$N1_{00}P_{120}$	4.56d	3.63de	2.73cd
$N_{100}P_{80}$	4.43d	3.60de	2.66cd
$N_{100}P_{40}$	4.43d	3.53de	2.60cde
$N_{100}P_{20}$	4.36d	3.46de	2.53cde
$N_{100}P_{0}$	4.30d	3.36e	2.43def
$N_{50}P_{120}$	4.36d	3.46de	2.63cde
$N_{50}P_{80}$	4.26d	3.56de	2.63cde
$N_{50}P_{40}$	4.23d	3.53de	2.53cde
$N_{50}P_{20}$	4.20d	3.46de	2.46def
$N_{50}P_{0}$	4.16d	3.33e	2.43def
$_{NO}P_{120}$	3.23e	2.63f	2.46def
$_{NO}P_{80}$	3.20e	2.60f	2.46def
$_{NO}P40$	3.13e	2.56f	2.43def
N_0P_{20}	3.03e	2.50f	2.33ef
N_0P_0	2.93e	2.50f	2.23f
Grand mean	4.508	3.68	2.685
CV	4.37	5.974	3.960
$LSD_{0.05}$	0.323	0.360	0.174

Means within column bearing same or without letter (s) is not significantly different from each other's according to Duncan Multiple range Test (DMRT) at 5% significant level.

Appendix 4: Response of rice to N & P rates (grain yield components) at Mtwango in seasons 2013 - 2015

Fertilizer Rate	Season 0 Grain yield (t ha^{-1})	Season 1 Grain yield (t ha^{-1})	Season 2 Grain yield (t ha^{-1})
$N_{200}P_{120}$	5.56a	4.60a	3.5a
$N_{200}P_{80}$	5.40b	4.56a	3.5a
$N_{200}P_{40}$	5.33bc	4.30b	2.90b
$N_{200}P_{20}$	5.20cd	4.20b	2.90b
$N_{200}P_{0}$	5.10de	4.20b	2.90b
$N_{150}P_{120}$	4.96ef	3.76cd	2.70bc
$N_{150}P_{80}$	4.86fg	3.80c	2.70bc
$N_{150}P_{40}$	4.80gh	3.70cde	2.70bc
$N_{150}P_{20}$	4.70hi	3.56defg	2.70bc
$N_{150}P_{0}$	4.60i	3.20h	2.5cde
$N1_{00}P_{120}$	3.93j	3.40g	2.66bcd
$N_{100}P_{80}$	3.90j	3.50efg	2.66bcd
$N_{100}P_{40}$	3.83j	3.50efg	2.56cde
$N_{100}P_{20}$	3.83j	3.40g	2.56cde
$N_{100}P_{0}$	3.26k	3.40g	2.50cde
$N_{50}P_{120}$	3.93j	3.63cdef	2.46cde
$N_{50}P_{80}$	3.90j	3.70cde	2.53cde
$N_{50}P_{40}$	3.83j	3.70cde	2.46cde
$N_{50}P_{20}$	3.83j	3.56defg	2.50cde
$N_{50}P_{0}$	3.36k	3.46fg	2.46cde
$_{NO}P_{120}$	2.86l	2.60i	2.46cde
$_{NO}P_{80}$	2.83l	2.53ij	2.43cde
$_{NO}P40$	2.76l	2.46ij	2.40de
$N_{0}P_{20}$	2.70lm	2.43ij	2.30de
$N_{0}P_{0}$	2.60m	2.40j	1.90f
Grand mean	4.077	3.494	2.626
CV	2.065	2.374	3.626
$LSD_{0.05}$	0.138	0.136	0.156

Means within column bearing same or without letter (s) are not significantly different from each other's according to Duncan Multiple range Test (DMRT) at 5% significant level.

Appendix 5: The Local indicators of soil fertility (LISF) of the study areas.

Local indicator	Technical indicator
Good soil	
Black color	Rather high organic matter content
Cracks during dry season	High clay content
Good crop performance	Adequate supply of growth factors
Presence/Vigorous growth certain plant	Large supply of plant nutrient
Presence of plants in a dry environment	High water holding capacity (WHC)
Abundance of earth worms	High biological activity, high organic matter content and neutral pH
Poor soil	
Yellow and red colors	Low soil fertility/. Low organic matter content
Stunted growth	Physical, chemical and biological limitation
Salt visible on surface	High pH, high osmotic pressure
Presence of rocks and stones	Shallow soil

Appendix 6: Mean Effects of fertilizer rate for growth variables, yield and yield components at Bumbwi season 2012 - 2015

Fertilizer Rate	50% flower	1000 g Grain	Grain Wt	Plant height 30 days DAS	Plant height 60 days DAS	Plant height 90 days DAS	SS DAY	S yield
$N_{200}P_{120}$	70.00a	32.66a	3.30a	48.00a	83.33a	92.00a	100a	2.86a
$N_{200}P_{80}$	70.00a	32.33a	3.13a	44.10ab	74.50ab	91.33ab	99.10ab	2.56ab
$N_{200}P_{40}$	69ab	32.06ab	2.86b	43.00ab	74.00ab	88.83abc	99.09ab	2.56ab
$N_{200}P_{20}$	69ab	31.16bc	2.70bc	42.73ab	72.66abc	86.83abcd	98.28abc	2.43bc
$N_{200}P_0$	69ab	31.13bcd	2.66bcd	42.66ab	72.50abc	84.00abcde	98.16abc	2.20c
$N_{150}P_{120}$	69ab	30.66cdc	2.66bcd	42.50ab	72.33abc	83.16abcdef	98.10abc	1.70d
$N_{150}P_{80}$	69ab	30.66cde	2.66bcd	41.66abcd	71.33abc	82.83abcdefg	98.08abc	1.66de
$N_{150}P_{40}$	68bc	30.50cde	2.63cde	41.66abcd	71.00abc	81.26bcdefg	98.06abc	1.56def
$N_{150}P_{20}$	68bc	30.50cde	2.63cde	41.33abcd	71.00abc	74.43cdefghi	98.04abc	1.56def
$N_{150}P_0$	68bc	30.30cdef	2.60cdef	41.16abcde	70.16bc	77.73defghi	97.15bcd	1.56def
$N1_{00}P_{120}$	68bc	30.20cdef	2.56cdef	41.00abcde	69.66bc	77.66defghi	97.13bcd	1.55def
$N_{100}P_{80}$	68bc	30.20cdef	2.53cdefg	41.00abcde	69.66bc	77.46defghi	97.10bcd	1.55def
$N_{100}P_{40}$	68bc	30.16cdef	2.53cdefg	40.33abcdef	69.00bc	77.00cdefghi	97.06bcd	1.54def
$N_{100}P_{20}$	68bc	30.16cdef	2.53cdefg	40.26abcdef	68.10bc	76.93defghi	97.05bcd	1.53def
$N_{100}P_0$	68bc	30.13defg	2.53cdefg	39.66abcdef	66.66bc	76.90defghi	97.04bcd	1.45def
$N_{50}P_{120}$	68bc	30.06efg	2.46defgh	39.23abcdef	66.16bc	76.50defghi	97.02bcd	1.43def
$N_{50}P_{80}$	68bc	30.03efg	2.46defgh	38.16bcdefg	60.63bc	75.33efghi	97.00bcd	1.39def
$N_{50}P_{40}$	68bc	30.00efgh	2.43efghi	37.33abcdefg	65.20bc	75.00efghi	97.00bcd	1.30efg
$N_{50}P_{20}$	67cd	29.33fgh	2.40fghi	35.33bcdefg	65.00bc	74.00efghi	97.00bcd	1.23fghi
$N_{50}P_0$	67cd	29.16gh	2.33ghi	33.66cdef	64.83bc	73.66efghi	96.70bcde	1.20fghi
N_0P_{120}	67cd	29.16gh	2.33ghi	33.43defg	64.30bc	73.23fghi	96.50bcde	1.16ghi
N_0P_{80}	67cd	29.00hi	2.33ghi	32.16efg	64.83bc	72.33fghi	95.19def	1.00hi
N_0P_{40}	67cd	29.00hi	2.26hijj	31.50fg	62.76bc	71.66hi	95.16def	0.00hi
N_0P_{20}	66de	28.00ij	2.23ij	29.83g	60.00c	69.90i	96.10def	0.90i
N_0P_0	66de	27.66j	2.06j	39.39	59.93ch	69.30i	94.00defg	0.90i
Grand mean	68.24	30.185	2.556	39.95	68.54	78.57	97.60	1.592
S. Error	1.8	0..357	0.0780	3.154	46.15	3.708	0.921	0.133
Cv	2.00	2.1	5.3	13.9	11..70	8.20	1.6	12.30

Means within column bearing same or without letter (s) are not significantly different from each other's according to Duncan Multiple Range Test (DMRT) at 5% significant

Note: pH 30= plant height at 30 days after sowing, pH 60 = Plant height at 60 days after sowing, pH 90 = Plant height at 90 days after sowing. 50% FL = 50% days flowering, 1000- g wt= 1000- grain weight, G.Y per plot = Grain yield. SSDAY= Sowing to harvest days, S.Y per Pl= Straw yield per plot

Appendix 7: Mean Effects of fertilizer rate for growth variables, yield and yield components at Mtwango season 2013 - 2015

Fertilizer Rate	50% flower	1000 g Grain	Grain Wt	Plant height 30 days DAS	Plant height 60 days DAS	Plant height 90 Days DAS	SS DAY	S yield
$N_{200}P_{120}$	70.00a	32.66a	4.33a	47a	76a	92a	100a	3.30a
$N_{200}P_{80}$	69.66ab	32.33ab	4.10ab	46ab	76a	90ab	99ab	3.16ab
$N_{200}P_{40}$	69.33abc	32.16ab	4.06ab	43abc	72ab	88abc	99abc	3.00abc
$N_{200}P_{20}$	69.00abcd	31.66abc	4.00ab	43abc	70abc	86abcd	98abcd	2.7bcd
$N_{200}P_{0}$	69.00abcd	31.66abc	3.83bc	43abc	69abc	84abcde	98abcd	2.70bcd
$N_{150}P_{120}$	68.66bcde	31.50abc	3.70bcd	43abc	69abcd	82abcdef	98abcde	2.70bcd
$N_{150}P_{80}$	68.66bcde	31.33abcd	3.66bcd	42abc	68abcde	81abcdefg	98abcde	2.60cde
$N_{150}P_{40}$	68.66bcde	31.00abcde	3.66bcd	42abc	68abcde	81abcdefg	98abcde	2.40def
$N_{150}P_{20}$	68.66bcde	31.00abcde	3.46cde	42abc	68abcde	73bcdefgh	98abcde	2.36defg
$N_{150}P_{0}$	68.66bcde	31.00abcde	3.40cde	41abc	65abcde	79bcdefgh	97abcde	2.36defg
$N1_{00}P_{120}$	68.66bcde	30.66bcde	3.40cde	41abc	65abcde	78cdefghi	97abcde	2.16efgh
$N_{100}P_{80}$	68.33cde	30.66bcde	3.36de	41abc	63abcde	78cdefghi	97abcde	2.06fgh
$N_{100}P_{40}$	68.00def	30.66bcde	3.36de	40abc	62bcde	77cdefghi	97abcde	2.00fgh
$N_{100}P_{20}$	68.00def	30.33cde	3.33de	40abc	61bcde	75defghi	97abcde	1.96fgh
$N_{100}P_{0}$	67.66efg	30.33cde	3.20ef	39abc	61bcde	74defghi	97bcde	1.96fgh
$N_{50}P_{120}$	67.00fgh	30.33cde	2.83fg	38abc	61bcde	74efghi	97bcde	1.93fgh
$N_{50}P_{80}$	67.00fgh	30.33cde	3.00gh	36abc	60bcde	74efghi	97bcde	1.86gh
$N_{50}P_{40}$	67.00fgh	30.33cde	2.40ghi	36abc	58cdef	74efghi	97cde	1.83h
$N_{50}P_{20}$	67.00fgh	30.16cde	2.33hi	36abc	55defg	73efghi	97cde	1.80h
$N_{50}P_{0}$	66.66gh	30.00cdef	2.26hi	36abc	55efg	72efghi	96de	1.76h
$N_{O}P_{120}$	66.66gh	29.66defg	2.26hi	36abc	45fgh	72fghi	96de	0.9i
$N_{O}P_{80}$	66.66gh	29.50efg	2.23hi	35bc	43gh	71fghi	96def	0.83i
$N_{O}P_{40}$	66.66gh	28.33fg	2.23hi	35bc	41h	70ghi	96def	0.83i
$N_{0}P_{20}$	66.33h	28.00gh	2.16i	34c	40.h	68hi	96ef	0.80i
$N_{0}P_{0}$	66.33h	26.33h	2.13i	33c	39h	67i	94f	0.76i
Grand mean	67.933	30.48	3.137	39.95	61.149	78.05	97.60	2.040
S. Error	0.4163	0.615	0.1634	3.176	8.214	4.177	0.921	0.1818
CV	1.1	3.5	9.0	13.8	13.4	9.3	1.6	15.4

Means within column bearing same or without letter (s) are not significantly different from each other's according to Duncan Multiple Range Test (DMRT) at 5% significant

Note: PH 30= plant height at 30 days after sowing, PH 60 = Plant height at 60 days after sowing, PH 90 = Plant height at 90 days after sowing, 50% FL = 50% days flowering, 1000- g wt= 1000- grain weight, G.Y per plot = Grain yield, SSDAY= Sowing to harvest days, S.Y per Pl= Straw yield per plot

Appendix 8: Mean effects of fertilizer rate for growth variable, yield and yield components at Kizimbani season 2013 - 2015

Fertilizer Rate	50% days (flower)	1000 g wt (gr)	G wt (t/ha)	Plant hight 30days DAS (cm)	Plant height 60days (cm)	Plant height 90 days (cm)	SS DAY (days)	S yield (t/ha)
$N_{200}P_{120}$	70	33. 20a	3.60a	45.33a	83.00a	89.66a	100a	3.30a
$N_{200}P_{80}$	70a	32.83a	3.40ab	43.00ab	77.66ab	89.33a	100a	3.16ab
$N_{200}P_{40}$	69ab	32.30ab	3.33ab	41.66abc	74.83abc	87.00ab	100a	3.00abc
$N_{200}P_{20}$	69ab	31.26bc	3.20bc	41.00abcd	73.00abcd	83.50abc	100a	2.7bcd
$N_{200}P_{0}$	69ab	31.16bc	3.00cd	40.00abcd	72.33abcd	83.26abc	99a	2.70bcd
$N_{150}P_{120}$	68bc	31.16bc	2.86de	40.00abcd	72.16abcd	83.00abc	97b	2.70bcd
$N_{150}P_{80}$	68bc	31.00bc	2.80def	40.00abcd	72.16abcd	80.16abc	97b	2.60cde
$N_{150}P_{40}$	68bc	30.83cd	2.76ef	39.33abcd	72.00abcd	80.00abc	97b	2.40def
$N_{150}P_{20}$	68bc	30.66cd	2.70efg	39.33abcd	70.33abcd	79.33abc	97b	2.36defg
$N_{150}P_{0}$	68bc	30.50cd	2.70efg	38.33abcd	70.33abcd	79.16abc	96bc	2.36defg
$N_{100}P_{120}$	68bc	30.50cd	2.70efg	37.66abcd	70.00abcd	78.20abc	96bc	2.16efgh
$N_{100}P_{80}$	67cd	30.50cd	2.63efh	37.66abcd	68.66abcd	77.00abc	96bc	2.06fgh
$N_{100}P_{40}$	67cd	30.50cd	2.60fghi	37.33abcd	68.33abcd	77.33abc	96bc	2.00fgh
$N_{100}P_{20}$	67cd	30.36cd	2.60fghi	37.33abcd	68.00abcd	76.60abc	96bc	1.96fgh
$N_{100}P_{0}$	66cde	30.26cd	2.56fghi	36.66abcd	67.50abcd	76.16abcd	96bc	1.96fgh
$N_{50}P_{120}$	66cde	30.16cde	2.50ghij	36.00abcd	67.16abcd	75.16abcd	96bc	1.93fgh
$N_{50}P_{80}$	66cde	30.06cde	2.46ghij	36.00abcd	67.16abcd	74.66abcd	96bc	1.86gh
$N_{50}P_{40}$	66cdc	30.06cde	2.46ghij	35.66abcd	66.16abcd	72.93abcd	96bc	1.83h
$N_{50}P_{20}$	66cdc	29.50def	2.46ghij	35.00abcd	66.00abcd	72.00bcd	96bc	1.80h
$N_{50}P_{0}$	65cdcfc	28.83efg	2.40hij	34.33bcd	65.83abcd	71.66abcd	95cd	1.76h
$N_{O}P_{120}$	65ch	28.50g	2.40hij	34.33bcd	64.66abcd	69.33bcd	95cd	0.9i
$N_{O}P_{80}$	65ch	28.50g	2.40hij	32.66bcd	62.50bcd	68.00bcd	95cd	0.83i
$N_{O}P_{40}$	65ch	28.00g	2.40hij	32.66bcd	61.33bcd	67.00cd	95cd	0.83i
$N_{0}P_{20}$	64.83	27.70g	2.36ij	31.00cd	56.16cd	68.83cd	95cd	0.80i
$N_{0}P_{0}$	64.63	27.50g	2.30j	30.33cd	54.66d	57.50d	95cd	0.76i
Grand m	66.454	30.236	2.705	37.31	68.5	76.6	97.00	1.592
S. Error	0.3963	0.4280	0.0743	3.143	5.69	5.63	0.3413	0.1133
CV	1.0	2.5	4.8	14.6	14.4	12.7	0.6	12.3

Means within column bearing same or without letter (s) are not significantly different from each other's according to Duncan Multiple range Test (DMRT) at 5% significant level.

Note:

50% Flow = 50% flowering days

1000 gram wt = 1000 grain seed weight

Gwt = Grain weight

PH 30 = Plant height 30days after seed emergence

PH 60 = Plant height 60 days after seed emergence

PH 90 = Plant height 90 days after seed emergence

SS DAY = Sowing to harvest days

Appendix 9: ANOVA summary and probability level for variable components studied at Bumbwi

SOV	DF	50%	1000 GWT	Grain Yield	pH 30 Days	pH 60 Days	pH 90 Days	SS. Days	S. Yield
Blocks	2	0.890**	2.612**	0.032	318.458***	215.069**	9.524	0.083	0.053
Main Effect	24	3.431**	4.390***	0.211***	59.298***	79.032***	119.038	7.890***	0.532***
Error	48	1.48	0.383	0.018	29.847	83.901	41.258	0.350	0.042
Total	**74**	**6.0048**							

* Significant at 0. 05 level. ** = significant at 0.01 and *** significance at 0.001 level
Note: pH 30= plant height at 30 days after sowing. pH 60 = Plant height at 60 days after sowing. pH 90 = Plant height at 90 days after sowing. 50% FL = 50% days flowering. 1000- g wt= 1000- grain weight. G.Y per plot = Grain yield. SSDAY= Sowing to harvest days. S.Y per Pl= Straw yield per plot

Appendix 10: ANOVA summary and probability level for variable components studied at Mtwango

SOV	DF	50%	1000 GWT	Grain Yield	pH 30 Days	pH 60 Days	pH 90 Days	SS. Days	S. Yield
Blocks	2	1.853*	0.750	0.988***	73.717***	471.792**	10. 816	4.320	0.097
Main Effect	24	3.750***	65.821***	1.540***	42.639***	348.792***	136.859	4.888***	1.674***
Error	48	0.520	1.135	0.080	30.256	67.138	52.345	2.542	0.099
Total	**74**	**2623.106**							

* Significant at 0. 05 level. ** = significant at 0.01 and *** significance at 0.001 level
Note: pH 30= plant height at 30 days after sowing. pH 60 = Plant height at 60 days after sowing. pH 90 = Plant height at 90 days after sowing. 50% FL = 50% days flowering. 1000- g wt= 1000- grain weight. G.Y per plot = Grain yield. SSDAY= Sowing to harvest days. S.Y per Pl= Straw yield per plot

Appendix 11: ANOVA summary and probability level for variable components studied at Kizimbani

SOV	DF	50%	1000 GWT	Grain Yield	pH 30 Days	pH 60 Days	pH 90 Days	SS. Days	S. Yield
Blocks	2	0.693	1.022	0.192***	163.893**	304.990	152.500	0.280	0.206**
Main Effect	24	8.274***	6.440***	0.369***	110.828***	170.129***	40.220	7.694***	0.8688***
Error	48	0.471	0.549	0.016	29643	97.257	95.034	0.349	0.038
Total	**74**	**182.992**							

* Significant at 0. 05 level, ** = significant at 0.01 and *** significance at 0.001 level
Note: pH 30= plant height at 30 days after sowing, pH 60 = Plant height at 60 days after sowing, pH 90 = Plant height at 90 days after sowing, 50% FL = 50% days flowering. 1000- g wt= 1000- grain weight, G.Y per plot = Grain yield, SSDAY= Sowing to harvest days. S.Y per Pl= Straw yield per plot

Appendix 12: ANOVA summary and probability level for variable components studied in combined analysis

SOV	DF	50%	1000 GWT	Grain Yield	pH 30 Days	pH 60 Days	pH 90 Days	SS. Days	S. Yield
Blocks	2	4.031*	3.378	0.123	456.052***	114.831	60.678	1.053	0.090
Main Effect	24	13.836***	15.131***	1.619***	83.978***	349.141***	342.748	12.269***	1.814***
Site	2	11.791***	1.861	6.835***	145.272***	1440.094***	76.303	16.36***	7.373***
Interaction	48	0.809***	0.764***	0.251***	29.089***	93.549***	41.639	2.327***	0.632***
Error	148	0.904	0.684	0.0519	30.458	86.021	62.695	1.224	0.062
Total	**224**								

* Significant at 0. 05 level. ** = significant at 0.01 and *** significance at 0.001 level

Note: pH 30= plant height at 30 days after sowing. pH 60 = Plant height at 60 days after sowing. pH 90 = Plant height at 90 days after sowing. 50% FL = 50% days flowering. 1000- g wt= 1000- grain weight. G.Y per plot = Grain yield. SSDAY= Sowing to harvest days. S.Y per Pl= Straw yield per plot

Appendix 13: Experiment Design Randomize Complete Block Design (RCBD)

1	16	8	9	18	21	24	10	16	2	5	13	25	11	24
17	2	20	25	24	25	4	3	23	6	17	4	8	2	19
15	4	19	10	23	17	5	12	11	7	6	15	9	14	10
13	7	3	11	21	18	13	20	15	14	12	1	23	16	20
14	12	6	5	22	1	22	8	19	9	21	18	3	7	22

BLOCK 1 BLOCK 2 BLOCK3

NB:

1 $N_{200}P_{120}$ 2 $N_{200}P_{80}$ 3 $N_{200}P_{40}$ 4 $N_{200}P_{20}$ 5 $N_{200}P_0$

6 $N_{150}P_{120}$ 7 $N_{150}P_{80}$ 8 $N_{150}P_{40}$ 9 $N_{150}P_{20}$ 10 $N_{150}P_0$

11 $N_{100}P_{120}$ 12 $N_{100}P_{80}$ 13 $N_{100}P_{40}$ 14 $N_{100}P_{20}$ 15 $N_{100}P_0$

16 $N_{50}P_{120}$ 17 $N_{50}P_{80}$ 18 $N_{50}P_{40}$ 19 $N_{50}P_{20}$ 20 $N_{50}P_0$

21 N_0P_{120} 22 N_0P_{80} 23 N_0P_{40} 24 N_0P_{20} 25 N_0P_0