MAXIMIZING YIELD AND NET RETURNS TO NITROGEN, PHOSPHORUS AND POTASSIUM FERTILIZER APPLICATION IN RICE (*Oryza sativa. L*) PRODUCTION ON LOWLAND SOILS

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Enemona Marinus UGBAJE, B. AGRIC. (A.B.U) 2012

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A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSTY ZARIA, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER OF SCIENCE DEGREE IN SOIL SCIENCE.

DEPARTMENT OF SOIL SCIENCE,

FACULTY OF AGRICULTURE,

AHMADU BELLO UNIVERSITY,

ZARIA, NIGERIA

AUGUST, 2018

DECLARATION

I declare that the work in this dissertation entitled '**MAXIMIZING YIELD AND NET RETURNS TO NITROGEN, PHOSPHORUS AND POTASSIUM FERTILIZER APPLICATION IN RICE (O*ryza sativa*. L) PRODUCTION ON LOWLAND SOILS**' has been carried out by me in the Department of Soil Science. The information derived from the literature has been duly acknowledged in the text and list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other Institution.

Enemona Marinus UGBAJE ______________________ __________________

Signature Date

CERTIFICATION

This dissertation entitled '**MAXIMIZING YIELD AND NET RETURNS TO NITROGEN, PHOSPHORUS AND POTASSIUM FERTILIZER APPLICATION IN RICE (O*ryza sativa*. L) PRODUCTION ON LOWLAND SOILS**' by Enemona Marinus Ugbaje meets the regulations governing the award of the degree of Master of Science of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Prof. C.K. Daudu ____________ ________________
Chairperson, Supervisory Committee Signature Date

Prof. E.Y. Oyinlola ____________ ________________
Member, Supervisory Committee Signature Date

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Prof. A.A. Yusuf ____________ ______________
Head of Department Signature Date

Prof. S.Z. Abubakar ____________ ____________
Dean, School of Postgraduate Studies Signature Date

DEDICATION

I dedicate this work to Almighty God for His guidance and protection.

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ABSTRACT

Rice (*Oryza sativa* .L*)* is an important staple and source of income for farmers in Nigeria. Current fertilizer recommendations for rice do not commonly consider fertilizer cost relative to paddy price (CP). The rates needed for maximizing yield rather than profits have been rather estimated. As the cost of fertilizer increases relative to the price of paddy, the nutrient rate needed to maximize net returns, typically called the economically optimal rate (EOR), is expected to decrease. To this end, fertilizer trials were conducted at Wushishi in Niger state and Kadawa in Kano state in 2015 cropping season to: quantify the yield response of lowland rice to nitrogen, phosphorus and potassium applications; estimate the EOR at different CP; evaluate the components of Nitrogen Use Efficiency (NUE). The trials consisted of different rates of N (0, 40, 80, 120, 160 kg/ha), P (0, 7.5, 15, 22.5 kg/ha) and K (0, 10, 20, 30 kg/ha) arranged in an incomplete factorial combination and laid out in a randomized complete block design with three replicates. At plot level, paddy yield and components of yield were measured. Mean yield without nitrogen in Kadawa and Wushishi were 2.6 and 5.05 tons/ha respectively. There were significant increases in yield with N application in both locations. Paddy yield was increased by 3 tons/ha in Wushishi with the application of 80 kg/ha of N. Similarly, 40 kg/ha produced maximum paddy yield of 3.55 tons/ha in Kadawa. Estimated optimum nitrogen rates from asymptotic non-linear regression model were 114kg/ha and 106kg/ha for Wushishi and Kadawa respectively. As the CP increased, the range of profitability and EOR decreased. In Kadawa, EOR ranged from 61 to 32 kg ha^{-1} of N at CP of 2 to 10. Values for EOR were 82 to 49 kg/ha for CP of 2 to 10 for Wushishi. Yield was not significantly increased with P and K applications in both locations. Agronomic Efficiency (AE) and Partial Factor Productivity decreased with increasing N rate in both locations. In Wushishi, AE and PFP at CP of 2 were 32.6 kg/kg and 95.6 kg/kg respectively. Similarly, AE and PFP at CP of 2 in Kadawa were 15.1 kg/kg and 59.6 kg/kg respectively. Nitrogen fertilization was observed to be more profitable in Wushishi due to greater crop response. Applying Nitrogen at economically optimal rate can help reduce expenditure on fertilizer while maximizing profits for rice growers. Environmental pollutions commonly associated with nitrogen fertilization can also be reduced.

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CHAPTER ONE

1.0 INTRODUCTION

Rice (*Oryza sativa* L.*)* is an important staple for more than half of the world's population. It accounts for 18.99% of calorie, 1.83% of fat and 12.73% of protein intake per day (FAOSTAT, 2011). The demand for rice may increase by 60% by 2025 (Fageria *et al.,* 2003). The demand for rice is growing particularly in sub-Saharan Africa due to rapid population growth, consumer preference and rising income. Nigeria is the largest consumer of rice in sub-Saharan Africa with an estimated demand of 6.7 million metric tons of milled rice (USDA, 2017). Production is estimated at 3.8 million metric tons of milled rice and has failed to keep pace with the growing demand resulting to the importation of 2.6 million metric tons of milled rice to fill the gap. (USDA, 2017).

Low yield has been identified as major constraint to rice production in Nigeria where average yield is estimated at 1.88 tons per hectare (USDA, 2017). Soil nutrient depletion and low fertilizer use have been commonly cited as yield limiting factors in Nigeria (Ezui *et al.*, 2010; Liverpool-Tasie *et al.*, 2014). Farmers understand the need to apply nutrients to their land but little is used due to the economic and social factors surrounding access to fertilizer. High cost and delayed delivery of fertilizer are major limitations to its use in rice production. The expenses incurred in procuring fertilizer in Sub-Saharan Africa are two to six times the cost in Europe or the United States (Sanchez, 2002). Cost of importation, market inefficiencies and transportation cost are some of the factors responsible for high fertilizer prices. Excessively high fertilizer cost usually reduces the profitability of fertilizer use (Kaizzi *et al.*, 2012a).

Several studies have reported significant increase in yield of rice with fertilizer application. Ishaya and Dauda (2010) reported optimum yield of 7 tons/ha with application of 130 kg/ha of nitrogen in the sudan savanna. Kamara *et al.* (2011) observed yield increase of 3 tons/ha with the application of 100kg/ha of N to NERICA varieties. In a trial conducted by Jibrin *et al.* (2010) in the sudan savanna, 120kg/ha of N increased yield by 62.9%.

1.1 Statement of Problem

The Fertilizer recommendation for all irrigated lowland rice in Nigeria has been 100 kg/ha N, 60kg/ha P_2O_5 and 60kg/ha K_2O (Chude *et al.,* 2011) with the assumption that the need for applied nutrients is constant over varieties, seasons and diverse agro-ecological zones. Fertilizer recommendations are commonly developed without considering the cost of fertilizer relative to the price of paddy typically referred to as fertilizer cost to paddy price ratio (CP). Instead, the fertilizer rates needed to attain maximum yield have often been estimated. The CP is an indicator of how much of an output is required to purchase a kilogram of a nutrient (Liverpool-Tasie *et al.*, 2014). As the fertilizer cost increases relative to price of paddy, the Economically Optimum Rate (EOR), described as the nutrient rate needed to maximize net return to fertilizer use, is expected to decrease (Wortmann *et al*., 2007). In Nigeria, Liverpool-Tasie *et al.* (2014) observed that the CP can be as low as 1.7 and high as 11.2 in some years and farming systems. Applying fertilizer at existing recommendations when the CP is high could lead to low net returns on fertilizer use. Kaizzi *et al.* (2012a) and Kaizzi *et al.* (2014) developed regression equations to relate CP and EOR for maize and rice respectively. This provided a means for estimating EOR at any CP value.

In addition, Nitrogen is the most limiting nutrient in rice production as it is prone to losses by volatilization, leaching and denitrification (Wortmann *et al.*, 2010). The high cost of nitrogen in the developing world requires that higher yield are attained with minimum nitrogen fertilization

(Havlin *et al., 2014)*. Adoption of improved agronomic practices to increase efficient use of fertilizer N is therefore critical to profitability and environmental sustainability. Agronomic efficiency and partial productivity are components of Nitrogen Use Efficiency that are closely related to profitability and are higher at EOR (Wortmann *et al.*, 2007). In Uganda, application of N at EOR was observed to increase nitrogen use efficiency in upland rice compared to N rate that gave maximum yield (Kaizzi *et al.*, 2014). Similarly, Kaizzi *et al.* (2012a) and also observed higher efficiency of N use by maize at EOR in Uganda.

1.2 Justification

Existing blanket fertilizer recommendations for lowland rice require periodic revision because the growth and need of crops for supplemental nutrients can vary greatly among fields, seasons and years as a result of differences in crop-growing conditions, crop and soil management, and climate. Furthermore, the variation across locations and seasons of CP (Liverpool-Tasie *et al.*, 2014) requires that fertilizer recommendations be fine-tuned to ensure maximum profitability of fertilizer use. Additionally, the inability to accurately determine fertilizer rates leads to over fertilization in some years and locations and under fertilization in others with lower NUE. As a result, there is a clear need to improve fertilizer management strategies.

1.3 Aims and Objectives

The general objective of the study therefore was to provide recommendations for optimizing yield and profit from fertilizer use by rice farmers. The specific objectives were to;

1. Quantify the response of lowland rice to N, P and K

2. Determine the economically optimal nutrient rate for N, P, K at different fertilizer cost to paddy price ratios (CP).
3. Evaluate the Nitrogen Use Efficiency of lowland rice in the savanna.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Botany of Rice

Rice (*Oryza sativa* L.) is an annual grass with round culms, flat leaves and terminal panicles. Varieties with growth duration ranging from 70 to 160 days exist in diverse environments. The grain is a caryopsis in which the single seed is fused with the wall which is the pericarp of the ripened ovary forming the grain which is the seed. Each rice panicle (which is a determinate inflorescence on the terminal shoot), when ripened, contain on average 80 to 120 grains, depending on varietal characteristics, environmental conditions and the level of crop management (Dobermann and Cassman, 2002). The floral organs are modified shoots consisting of a panicle on which are arranged a number of spikelet. Each spikelet bears a floret which, when fertilized, develops into a grain. A rice crop producing on an average 300 panicles per m^2 and 100 spikelet per panicle, with an average spikelet sterility of 15 percent at maturity and a 1000-grain weight of 20 g will have an expected yield of 5.1 tons ha^{-1} (Dobermann and Cassman, 2002).

2.2 Rice consumption and production

Rice is consumed by more than three billion people in the world (GRiSP, 2013). There has been an increase in the demand for rice in Sub-Saharan Africa due to increased urbanization, population growth, consumer preference and rising income (Liverpool-Tasie *et al.,* 2014). Nigeria is the largest consumer of rise in sub-Saharan Africa with an estimated demand of 6.7 million metric tons of milled rice (USDA, 2017). Rice is second only to cassava in urban centers and sorghum in rural areas in terms of consumption and first in terms of annual expenditure (Kuku-Shittu and Pradesha, 2013). The total land area that is cropped to rice in Nigeria is estimated at 3.2 million hectare (USDA, 2017). The country produces an average of 3.8 million metric tons of milled rice annually (USDA, 2017). The main production ecologies for rice are rainfed lowland, irrigated lowland, rainfed upland, mangrove swamp (Nwilene *et al.*, 2008).

2.3 Constraint to rice production in Nigeria

The inability of Nigeria to meet its domestic demand for rice requires that it imports 2.6 million metric tons of milled rice annually (USDA, 2017). Rice production is mainly in the hands of smallholder farmers in the savanna agro-ecological zone who rely on suboptimal use of agricultural inputs such as fertilizers, unimproved seeds and other agrochemicals (Akintayo *et al.*, 2011). Soil-related factors militating against rice production include poor crop response to applied nutrient, iron toxicity, salinity and soil nutrient depletion (GRiSP, 2013).

The soils of the savanna are characterized by low activity clay with kaolinite and sesquioxides (FeOH) dominating the clay fraction (Moberg and Esu, 1991). Savanna soils are highly weathered and accompanied with high decomposition and mineralization and as such have low organic matter content. Nitrogen, Phosphorus and Sulphur nutrients mineralized are usually insufficient to support crop growth. The soil types ranged from loamy sand to sandy loam in the top (Abu and Malgwi, 2001). Daudu *et al.* (2006) reported that soil fertility depletion below critical levels is a major constraint to crop production in the Nigerian savanna and that nutrient depletion and soil degradation have become serious threats to agricultural productivity in this zone.

2.4 Fertilizer use in Nigeria

The consumption of inorganic fertilizer was in the past considered low in sub-Saharan Africa where annual application rate was estimated to be 12 kg/ha (Sommer *et al.,* 2013). High cost of fertilizer, delayed delivery of fertilizer, lack of credit facilities and poor crop management practices were advanced as factors responsible for low nutrient use (Kaizzi *et al*, 2012a).

However, Vanlauwe *et al* (2006) and Liverpool-Tasie *et al,* (2014) posited that the general held view that fertilizer use is low in Sub-Saharan Africa lacks sound scientific basis. Using the 2010/11 and 2012/13 Nigeria Living Standard Measurement Survey-Integrated Survey on Agriculture (LSMS-ISA) panel dataset, Liverpool-Tasie *et al.* (2014) reported an average fertilizer application rate of more than 100kg/ha in Nigeria which is significantly higher than the commonly reported average of 12kg/ha. Average fertilizer use in rice production was estimated at 230 kg/ha in 2010 and 225 kg/ha in 2012. Observed use rates are contingent upon soil type, farming systems, crop response and political connections. Average fertilizer use in northern Nigeria tends to be higher than in its use in the southern part of the country due to poor soil fertility, cultivation of high value crops and long history of subsidy (Liverpool-Tasie *et al.*, 2014). Fertilizer applications are generally below levels considered to be economically optimal except for areas with poor crop response to applied nutrient (Liverpool-Tasie *et al.,* 2014).

2.5 Fertilizer Profitability

Contemporary crop husbandry is business and farmers invest in fertilizer not only to increase yield but also to make profit (Kyveryga *et al.,* 2007). Crop response to applied nutrient and cost of fertilizer relative to the price of economic yield are major determinants of nutrient application rate needed to maximize net returns which is commonly referred to as economical optimal rate

(EOR). Factors that increase fertilizer expenses, such as transportation cost, reduce the profitability of investment in fertilizer. In contrast, those factors that raise the market values of economic yield are expected to increase the profitability of fertilizer. Poor crop response to fertilizer, high cost of fertilizer and low paddy prices in sub-Saharan Africa often lead to low net returns to fertilizer use. (Vlek, 1990; Sanchez, 2002).

Rice farmers in the northern part of Nigeria, with long history of fertilizer use, have been found to be applying nitrogen above levels considered to be economically optimal (Liverpool-Tasie *et al*. 2014). These regions have been observed to have negative yield response to nitrogen application (Liverpool-Tasie *et al*., 2014).This observed trend could be due to increased soil acidity and micronutrient depletion, and decreased cation exchange capacity, exchangeable cations and upset cationic balance (Yusuf and Yusuf, 2008). Even in situations where crop response to nutrient application has been reported to be considerably high, the high cost of fertilizer acquisition has significantly reduced the profitability of its use (Liverpool-Tasie *et al*., 2014).

2.6 Rice Production Ecology

Rice grows in a wide range of environments and is productive in many situations where other crops would fail (GRiSP, 2013). Most classifications of rice environments are based on altitude (upland vs. lowland) and water source (irrigated or rainfed). Irrigated lowland rice is grown in bunded fields with ensured irrigation for one or more crops a year (GRiSP, 2013). Farmers generally try to maintain 5–10 cm of water on the field (GRiSP, 2013). Irrigated rice is grown mostly with supplementary irrigation in the wet season and is reliant entirely on irrigation in the dry season (GRiSP, 2013). Rainfed lowland rice is grown in bunded fields that are flooded with rainwater for at least part of the cropping season to water depths that exceed 100 cm for no more than 10 days (GRiSP, 2013).

2.7 Soil Properties of Lowland Ecology.

Properties of lowland rice soils change because of flooding. These changes affect the physical, chemical, and biological properties and consequently rice yields (Fageria *et al.,* 2011). The most significant chemical changes are increase in the pH of acidic soils and decrease in the pH of alkaline soils, reduction in the redox potential, and increase in the electrical conductivity or ionic strength. The magnitude of change of these chemical processes depend on soil type, microbial biomass, soil organic matter content, and rice cultivar or genotype planted (Fageria *et al.,* 2011). All these changes influence availability of essential plant nutrients. Availability of essential nutrients is significantly influenced by flooding the rice soils. Availability of P, K, Si, Fe, Mn, and Mo increased in flooded soils, and availability of S, Zn, and Cu decreased (Fageria *et al.*, 2011). Availability of N depends on its proper management. If applied in the reduced soil zone, its uptake may improve as a result of fewer losses by denitrification (Havlin *et al.,* 2014). Both nitrate and ammonium ions can be assimilated by the rice plant, but better stability of the ammonium form in flooded soils makes it the superior form of N for lowland rice (Fageria *et al.*, 2011). In addition, the ammonium (NH_4^+) form of N requires less energy for absorption by plants compared to the nitrate (NO_3^-) form of N (Fageria *et al.,* 2011). In addition, Al toxicity is decreased in flooded acidic soils because of the increase in soil pH (Fageria *et al.,* 2011). Flooding also favors microbial processes that release essential nutrients for plant growth (Havlin *et al.,* 2014).

2.8 Mineral Nutrition of Rice

2.8.1 Nitrogen (N)

Functions and deficiency symptoms of N

Nitrogen is the most important nutrient for rice and its deficiency occurs almost everywhere unless nitrogen is applied as fertilizer (Fairhurst *et al.*, 2007). Nitrogen increases the number of seeds per panicle, leaf size and growth (Fairhurst *et al.*, 2007). The colour of leaves is an indicator of N status of rice. The uptake of P and K is increased with adequate supply of N. Low indigenous N supply, insufficient supply of N fertilizer and low NUE are some of the causes of deficiency of N. Deficiency symptoms include stunted growth, yellowish green older leaves or whole plants. N deficiency is widespread in soils with coarse texture and low organic matter content (Fairhurst *et al.,* 2007)

Influence of submergence on N availability and Uptake

Under flooded condition, a major part of N is lost through leaching and denitrification (Fageria *et al.,* 2013). Application of fertilizer on the oxidized layer of a waterlogged soil can easily lead to downward movement of nitrate by diffusion and percolation into the underlying reduced layer, where it is rapidly denitrified (Havlin *et al.,* 2014). When ammonium based fertilizer are applied to the reduced zone of submerged soils, NH_4^+, is either adsorbed on to the soil colloids, immobilized by microbes or bound to organic matter (Fairhurst *et al.,* 2007). Losses from leaching are minimal except in sandy soils. Surface applied fertilizers such as urea are prone to volatilization due to rapid hydrolysis. Loses by volatilization are later minimized at midtillering due to the formation of surface roots that increase the uptake of topdressed fertilizers (Fairhurst *et al.,* 2007).

Nitrogen Use Efficiency and fertilizer N management for lowland rice

Amongst all nutrient elements, N is often the most limiting in crop production as it is prone to loses due to volatilization, leaching and denitrification (Fairhurst *et al.,* 2007). Pollution of ground water and increased greenhouse gas effect are commonly associated with nitrogen application. The cost of nitrogen in the developing world is expensive and requires attainment of high yield with minimum N rates (Havlin, *et al*., 2014). This makes the efficiency of nitrogen use important to maximizing profit while protecting the environment. Different indices have been adopted to assess the NUE of a production system (Appendix 2.). The choice of any one of these indices depends on practicality of an investigation and availability of data sets. NUE is usually calculated based on either the difference method (the difference between yield and/or nutrient uptake in fertilized and unfertilized plot) or the isotope-labeled fertilizer technique to estimate crop recovery of applied N. (Fairhurst *et al.,* 2007). NUE generally decreases with increase in nutrient application and is highest at low N rate. As yield level reaches the climatic/genetic potential of the crop of interest, NUE declines because the effect of other yield limiting factors becomes pronounce (Fairhurst *et al.,* 2007).

In a review done by Ladha *et al*. (2005) on irrigated rice, average global Agronomic Efficiency (AE) and Partial Factor Productivity (PFP) of applied N in research station trial were 22 and 62 kg/kg respectively. While AE and PFP in South-East Asia were 12 and 49 kg/kg in that order (Dobermann *et al*., 2002). Haefele *et al*. (2001) reported 17 and 46 kg/kg respectively as AE and PFP in on-farm trials in West Africa. Fageria *et al*. (2013) observed variation in NUE with different rice genotypes and reported an average AE of 40kg/kg. Mahajan *et al*, (2010) also detected variation of NUE among aromatic rice cultivars in India. The investigation by Mahajan *et al*, (2010) and Fageria *et al.* (2013) stressed the importance of adopting improved rice genotype in enhancing NUE. Implementing improved fertilizer practice by selecting accurate N rate, right placement of fertilizer, observing proper timing of application and using the right source is significant to enhancing NUE.

The time of application of split doses of fertilizer N varies because critical growth stages of rice under different systems occur at different times. Nitrogen fertilizer is typically applied in at least two or more split doses in most of the rice production systems (Bijay-Singh and Singh, 2017). The first application is often termed as basal dose. Sometimes the basal application represents the largest portion (50–75 % of the total N requirement) of N fertilizer applied in any single application during the growing season (Bijay-Singh and Singh, 2017). In transplanted rice systems, N fertilizer is applied to the soil surface and mechanically incorporated before the field is flooded, applied to the soil surface and incorporated by the flood water, or injected into the soil (Nwilene *et al.,* 2008; Bijay-Singh and Singh, 2017). Split doses of fertilizer N applied as top dressings after the basal dose are utilized more efficiently than basal application. Due to low rates of fertilizer N (around one-third of the total fertilizer N), a highly developed rice root system, and the high plant N requirement around panicle initiation stage, recovery efficiency of top dressed N dose is very high and may range between 45 and 82 % Bijay-Singh and Singh, 2017).

Tarfa and Kiger (2013) showed that deep placement of urea briquette can improve the AE of lowland rice Northern Nigeria. This practice involves placement of briquette urea of 1– 3g in a saturated soil 5-7cm deep and 40cm wide. NUE in this system was increased by 40% with 61% yield increase over farmers' practice in Northern Nigeria (Tarfa and Kiger 2013). In trials conducted by Kaizzi *et al,* (2014) on Upland rice in Uganda, application of fertilizer at EOR was shown to result in higher NUE compared to applying at nutrient rates that gave maximum yield.

The significance of Economically Optimum Rate (EOR) in improving the efficiency was well advanced by Wortmann *et al*, (2007), Kaizzi *et al*. (2012b) and Dobermann *et al.* (2011)

Rice response to nitrogen fertilization

Researches have shown that nitrogen is the most limiting nutrient in the savanna agro-ecological zone of Nigeria (Yusuf *et al*, 2008). Findings by Ishaya and Dauda (2010) in the Sudan savanna agro-ecological zone of Nigeria showed that application of 130 kg N/ha increased yield of lowland rice from 0.3 to 7 tons/ha with a soil test of 0.12 g/kg of total nitrogen. In the same environment, response of different cultivars of lowland rice to nitrogen application was generally linear with rates of up to 120kg/ha (Jibrin *et al.*, 2010). Kamara *et al.* (2011) reported a linear yield increase from 2 ton/ha to 5 ton/ha when 100 kg N/ha was applied to rainfed lowland rice with soil test of 1.4 g/kg of total nitrogen. Fageria *et al*. (2013) reported linear and quadratic response to nitrogen by different lowland rice genotypes in Brazil.

2.8.2 Phosphorus

Functions and deficiency symptoms of phosphorus

Phosphorus is an integral component of ATP which is important in energy storage and transfer (Havlin *et al.,* 2014). It is mobile within the plant and promotes tillering, root development, early flowering and ripening (Fairhurst *et al.,* 2007). Phosphorus can be deficient in soils with low indigenous P supply, soils with low mineral P fertilization and soils with high P fixing capacity (Fairhurst *et al.,* 2007). Low P use efficiency and excessive use of N fertilizer with insufficient P application are some of the causes of P deficiency. Coarse-texture soil containing small amounts of organic matter and small phosphorus reserves are particularly prone to P deficiency.

Deficiency symptoms include stunted growth, erect dark green with leaves low tillering (Fairhurst *et al.*, 2007)

Effect of submergence on P availability and uptake

Under flooded conditions, the availability of P is relatively high due to the reduction of ferric phosphate to ferrous phosphate and the hydrolysis of phosphatic compound (Havlin *et al.,* 2014). This may be more pronounced in acidic soils where phosphorus is immobilized by Fe and Al oxides (Fageria *et al.,* 2011). Similarly, P uptake in flooded alkaline soils also improves because of the liberation of P from Ca and calcium carbonate resulting from the decrease in pH. Therefore, crop response to P application is low (Fageria *et al.*, 2011). The high organic matter content of submerged soils also increases the availability of P through mineralization (Fairhurst *et al.*, 2007)

Rice response to phosphorus fertilization

In a lowland rice study conducted by Jibrin *et al* (2010) on a TypicNatrustalf in Nigeria, there was no significant yield response to P fertilization. In Uganda, Wanyama *et al.*, (2015) reported non-significant yield response to applied phosphorus and attributed it to build up of indigenous phosphorus supply under submerged condition. Application of 10 kg/ha of P increased yield by 0.3tons/ha on a fluvisol in Ivory Coast (Akassimadou *et al*., 2014).

Fertilizer P Management Strategy for lowland rice

Phosphorus management in rice aims at preventing P deficiency rather than treating P-deficiency symptoms. Significant response of modern rice varieties to P fertilizer may be observed after several years of intensive cropping, particularly when both N and K were applied or when the P-supplying capacity of the soil is low (Fairhurst *et al.*, 2007). Therefore, P management must focus on the buildup and maintenance of adequate available P levels in the soil to ensure that P supply does not limit crop growth and N-use efficiency (Fairhurst *et al.,* 2007). According to Fairhurst *et al*. (2007), the rule of thumb is: where the soil P supply is small, apply 8.7 kg/ha of P for each tonne of target Paddy yield. Phosphorus fertilizer is generally applied to rice at planting, but late application can be made provided it is not later than the time of active tillering. Broadcast preplant incorporated P application is effective as P drilled with the seed. However, due to rapid fixation of P, broadcast application of P at the five-leaf stage increased tissue P concentration, P uptake, and Paddy yield more than P broadcast applied to the soil surface at seeding (Bijay-Singh and Singh, 2017). Most commonly used fertilizers to supply P to rice are the highly water-soluble single and triple-super phosphates, diammonium phosphate, and sometimes monoammonium phosphate (Bijay-Singh and Singh, 2017).

2.8.3 Potassium

Functions of Potassium (K)

K is required for the transport of photosynthates in plant cells. It provides strength to plant cell walls and promotes greater canopy photosynthesis and crop growth. K deficiency is rife in soils that are low in indigenous K supply. Insufficient mineral K fertilization, complete removal of straw, and wide Na:K, Mg:K or Ca:K ratios are some of the causes of K deficiency. Deficiency symptoms include dark green plants with yellowish brown leak margins or dark necrotic spots first appear on the tips of older leaves (Fairhurst *et al.*, 2007)

Rice response to potassium fertilization

In the period spanning 1963-1973, there were no responses to K in most of the soils cropped to rice in Nigeria. It was inferred that the indigenous nutrient supply was adequate for the cultivars tested. However, subsequent investigations have found that K deficiency could limit rice yield under continuous cultivation (Ajayi *et al*, 1983). Wanyama *et al* (2015) reported non-significant lowland rice yield response to K in Uganda probably due to indigenous K supply from irrigation water. Akassimadou *et al*. (2014) observed a 1.5 tons/ha yield increase with the application of 75kg/ha of K in Ivory Coast.

Fertilizer K management strategy for lowland rice

Potassium management is considered part of long-term soil fertility management because K is not easily lost from or added to the root zone by short-term biological and chemical processes that affect N supply. Where soil K supply is small, the general strategy for K management for rice is to apply 25 kg/ha of K for each tonne of target Paddy yield increase over the yield of rice in the plots receiving no fertilizer K (Fairhurst *et al*., 2007). Fertilizer K is applied to rice by broadcast method immediately before or after transplanting, or split into multiple applications. In general, a major portion, and sometimes all, of the K fertilizer should be applied at or near the time of transplanting of rice (Fairhurst *et al*., 2007). Due to low cost and high K analysis, KCl is the most common source of K (Havlin *et al.*, 2014)

2.9 Developing Fertilizer Recommendation

The ample supply of nutrient to crops is a major determinant of crop yield, quality and return on investment for agricultural enterprise. The capacity of soils to supply sufficient amount of nutrient can be inadequate when soil nutrients depletion exceed replenishment thereby creating a negative nutrient balance (Yusuf and Yusuf. 2008). When the indigenous nutrient supply is inadequate to meet crop nutrient requirement, the use of fertilizer becomes important to optimize yield. Quantifying the nutrient application rate requires good knowledge of the nutrient status of the soil which can only be achieved through a comprehensive soil fertility evaluation. However, farmers in Nigeria rarely carryout routine soil testing due to lack of awareness, cost implication, inability to obtain representative samples and lack of access to soil testing laboratories (Carsky *et al.,* 2010).

Fertilizer recommendations in Nigeria are generally based on experiment conducted across locations and cropping seasons to obtain more reliable and consistent results. The relationship between added nutrients and crop yield is established in order to formulate a blanket recommendation for a particular agro-ecological zone with diverse soil and weather conditions. Such recommendations are not site-specific but only formulated to produce reasonable yield and net returns to investment in fertilizer (Chude *et al.,* 2011). Constant revisions of blanket recommendations are necessary when new varieties are adopted whose nutrient requirement may differ from existing ones. Changes in cropping system and yield target may also necessitate adjustments to existing generalized recommendations. Similarly, the continuous application of fertilizer can alter soil fertility levels which would require the revaluation of soil nutrient stock (Chude *et al.,* 2011). The current fertilizer recommendation for irrigated lowland rice are 100-120 kg/ha N, 60 kg/ha P_2O_5 and 60 kg/ha K_2O (Chude *et al.,* 2011).

2.10 Determination of optimal nutrient rate

Researchers often employ either mean comparison or mathematical function in the determination of optimal nutrient rate. As described by Nelson and Rawlings (1983) the use of multiple comparisons in the determination of fertilizer rate limits the choice of optimal rates to the treatments used in an experiment. Since fertilizer rate are continuous variables, it is difficult for investigators to draw conclusions about fertilizer rates not used in the experiment. The investigator can only hope that such rate is approximately close to the true optimum nutrient rate. This can result to over fertilization which may consequently lead to negative net return to fertilizer use. On the other hand, curvilinear response functions have proven to be effective in estimating optimal nutrient rates. Yield can be predicted for any level of a factor other than those used in the experiment and the optimal nutrient rate can be estimated from the mathematical function. The choice of curvilinear function can be more revealing wherein the predicted optimal rate is not limited to the treatments used in the experiment (Cady and Laird, 1973).

2.11Curvilinear response function

Curvilinear response functions are mathematical models that describe yield response to nutrient application (Havlin *et al*.., 2014). As shown in Fig. 1, there is a gradual increase in yield with nutrient application with yield increasing at a decreasing rate until a maximum yield level is reached where the nutrient becomes non-limiting. There is no yield response to applied nutrient beyond this level and there is a tendency for yield to decline when the nutrient reaches a toxic level. Jansen *et al*. (2013) described three kind of optimal nutrient rate that can be deduced from a response curver

- First, the nutrient application rate needed to attain maximum yield or a particular percentage of target yields (Fig. 2.1).
- The nutrient rate needed to maximize net returns to fertilizer per hectare. This is commonly referred to as the economically optimal rate (EOR) and is function of the ratio

of fertilizer cost relative to the price of Paddy (CP). The EOR is at all times lower than the yield maximizing rate. An increase in CP leads to a decrease in EOR and vice versa. Application of fertilizer beyond levels considered to be economically optimal for a particular CP leads to reduction in net returns to fertilizer even with yield increase. As shown in figure. 1, the N rate for maximum yield was 120 kg/ha. When the CP was 10, the profit maximizing rate was 44 kg/ha. But 33 kg/ha of N was the profit maximizing rate when CP increased to 20. Due to the variable nature of CPs across seasons and locations, farmers need to adjust the EOR when information on existing fertilizer prices and/or forecasted Paddy prices are available (Fig. 2.1)

- If the CP and the financial capacity of a farmer are to be considered, the nutrient rate that would maximize net returns for a given amount of money invested in fertilizer can be estimated. The benefit-cost ratio (BC) or the ratio of net profit relative to cost of fertilizer is used as an index for making such recommendation. Smallholder farmers commonly lack the financial resources to apply fertilizer at EORs and would require a minimum of 100% net return ($BC \geq 1$) within a period of 6-12 month to find a recommendation adoptable. Given their limited access to money, financially constrained farmers need to consider the BCs of fertilizer rates which are a function of application rates and CP. The

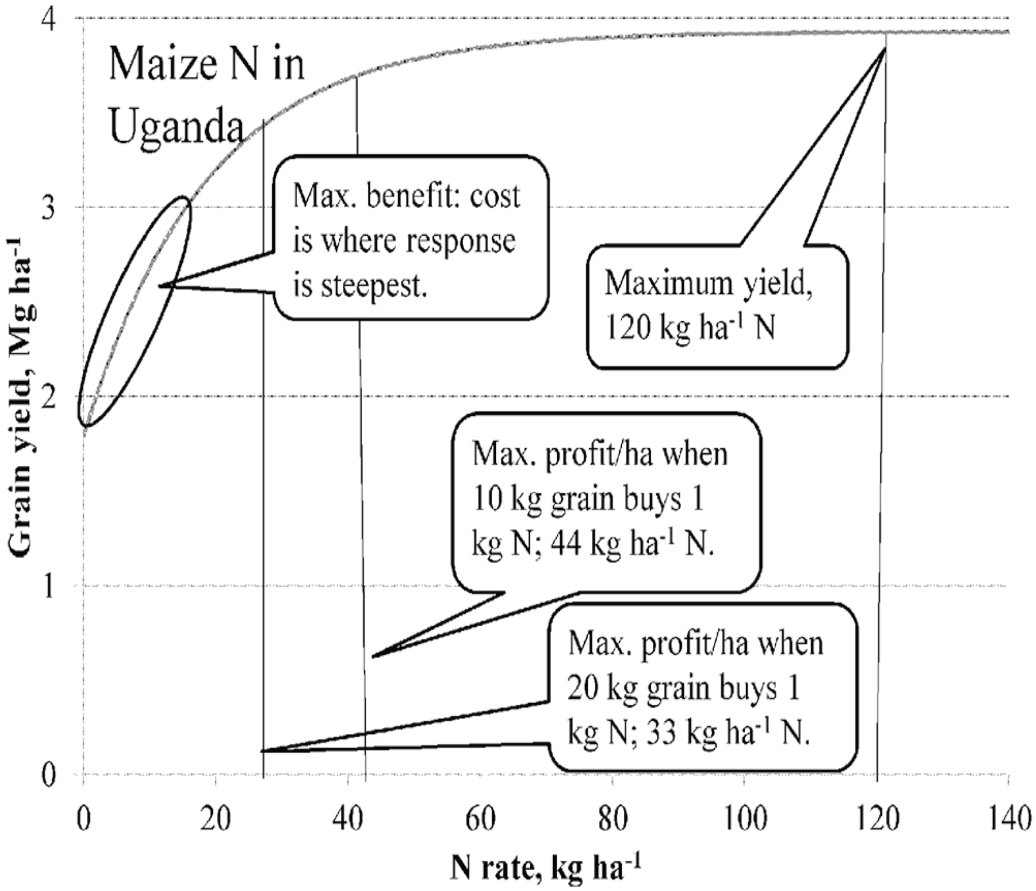

Figure.2.1 Maize response to nitrogen fertilization in Uganda
(Adapted from Jansen et al.,2013)

- highest BC occurs at the lowest portion of the response curve (indicated by the oval shape in Figure. 1) where crop response to nutrient application is highest and gradually decreases to zero at the economically optimal nutrient rate. The net return per unit cost of nutrient is expected to be greater with low nutrient levels compared to higher nutrient levels. Thus, for a smallholder farmer, instead of applying fertilizer at EOR to less land, it would be more profitable to apply nutrients to more land at less than the EOR. (Fig. 2.1)

Using the approaches mentioned above, Kaizzi *et al.* (2012a) conducted maize trials on Acricferralsols, nitisols, PetricPlinthisols in Uganda and reported optimal nitrogen rate for maize as 50kg/ha. However, the EORs were 45 to 24kg/ha with CPs of 10 to 30. The optimal phosphorus rate was 30kg/ha with an EOR of 9 to 1kg/ha for CPs of 10 to 50. A similar fertilizer trial was conducted with rice as the test crop on some Aeronosols, Acricferralsols, Nitisols, PetricPlinthisols. Yield was maximize with 100kg/ha of N with mean EOR ranging from 54 to 92 kg/ha of N at CPs of 10 to 2 (Kaizzi *et al.*, 2014). In the trials mentioned above, regression equations were developed to predict the EOR for any given CP. Similarly, polynomial equations were determined to estimate the BC for any CP and nutrient rate combination provided that the nutrient application rate does not exceed the optimal nutrient rate. This formed the basis for accurately predicting nutrient maximizing rates. In Nigeria, Ezui *et al*. (2010) and Ila, (2001) economically validated fertilizer recommendations for a diverse group of rice farmers in Nigeria. Liverpool-Tasie reported average EOR for rice in Nigeria to vary between 150 to 220 kg/ha of N irrespective of production ecology. There is limited information on the economic optimal nutrient rates for rice in lowland ecologies. Even where such information may exist such as those reported by Ila, (2001), there is often no basis for fine-tuning recommendations to account for variation in cost of fertilizer and price of Paddy.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location

The experiment was conducted at two sites. The first site was the Irrigation Research Station (IRS) of the Institute of Agricultural Research (IAR) located at Kadawa (latitude 11^0 39´ N, Longitude 08^0 27´ E and 500m above sea level) in the Sudan ecological zone of Nigeria. Average annual rainfall in the location ranges between 500-1000mm with mean annual temperature of 26-28^{o}C. Lowland rice is commonly grown by farmers in the location during the rainy season and supplemented by irrigation. The soils of the area are Alfisols that overlay older granites and younger metasediments of Precambrian to lower Palaeozoic (McCury, 1976)

The second site was the Upper Niger Basin Authority (UNRBA) Irrigation Site at Wushishi, Niger State. It is located in the Southern Guinea savannah Ecological zone (latitude 09^0 39´ N and longitude 06^0 5´ E at an altitude of 104m above sea level). It is located within the flood plains of river Ubandawaki and Bankogi. The mean annual rainfall is about 1500mm with mean annual temperature of 23-25^{o}C. The soils of the area are generally Inceptisols that belong to the aquaept great group of the USDA soil classification. They are derived from the floodplains of river Ubandawaki and Bankogi formed over the interphase of the Nupe sandstone and Basement complex with a flat low-laying topography (Oladipo, 1998)

3.2 Treatments and Experimental Design

The experiment was setup in a randomized complete block design with three replicates. Each replicate consisted of 15 plots. Each plot had a dimension of 5m x 3m with 1m between plots and 2m between replicates. The fertilizer nutrient rates evaluated were as follows: 40, 80, 120 and

160 kg N/ha; 7.5, 15 and 22.5 kg P/ha; 10, 20 and 30 kg K/ha. The treatment arrangement was an incomplete factorial to limit the number of treatments in consideration of Liebig's law of minimum, expecting nitrogen to be the most limiting nutrient followed by phosphorus (Table 3.1). Potassium is expected to be the least limiting. The Effect of N was tested with (15 kg P/ha) and without (0 kg P/ha) phosphorus application. The influence of P was examined only with applied N (120kg N/ha). The effect of K was tested with P and N applied.

3.3 Test Material

The crop cultivar used was FARO 44 (Sippi), a lowland rice variety of medium duration of 110-120 days maturity period was used. The variety is characterized by average yield (5-7 tons ha^{-1}). It is long grained rice and has high acceptability among the people in the two locations because of its good taste when cooked and its good market value relative to other varieties.

3.4 Fertilizer Sources and Management

The N, P and K sources were urea, Triple Super Phosphate (TSP) and Muriate of Potash (MOP). All of P and K together with 25% of N were applied a week after transplanting. At active tillering (21 days after transplanting), 25% N was surface broadcast; and the remaining 50% N was broadcast at Panicle initiation (42 days after transplanting).

3.5 Nursery Management

A nursery bed was prepared adjacent to the experimental fields in both locations. Cow dung and rice husk were incorporated during nursery bed preparation to aid easy removal of seedling. Seed were sown in the nursery on the 15 April, 2015 for Kadawa and 23 May, 2015 for Wushishi.

Table 3.1 Fertilizer Treatments

Treatment Number	**N (kg/ha)**	**P (kg/ha)**	**K (kg/ha)**
1	0		
2	40		
3	80		
4	120		
5	160		
6	0	15	
7	40	15	
8	80	15	
9	120	15	
10	160	15	
11	120	7.5	
12	120	22.5	
13	120	15	10
14	120	15	20
15	120	15	30

3.6 Land preparation

In Wushishi, site was harrowed with hoe. Whereas at Kadawa, the site was ploughed and harrowed with a tractor. Bunds were raised around each plot to prevent nutrient

3.7 Transplanting

Rice seedlings were transplanted to the main field on 6 May, 2015 in Kadawa and 12 June, 2015 in Wushishi respectively. A spacing of 20cm x 20cm was maintained at two seedlings per stand (Nwilene *et al.*, 2008).

3.8 Weed control

Roundup^{TM} (Glyphosate) was applied at 1.0kg a.i per hectare ten days before land preparation. Paraeforce^{TM} (Paraquat dichloride 200g/L) at 600g of a.i per hectare was applied a day before transplanting. Similarly, Butaforce^{TM} (Butachlor 500g/L) at 1.5kg a.i per hectare was applied a day before transplanting. Orizoplus^{TM} (2,4-D amine 200g/L + Propanil 360g/L) at 2.8 kg a.i ha^{-1} was applied three weeks after transplanting.

3.9 Harvesting

Harvesting was done when mature rice panicle ripened to golden brown. Plants were harvested manually with sickle from net plot of 3m^2. The harvest was sun-dried for 7 days and threshed to separate the paddy from the straw.

3.10 Data Collection

The following data were collected for each plot in both locations.

3.10.1 Paddy yield (tons ha^{-1})

Paddy yield was calculated by weighing harvested paddy from net plots using metler balance and expressed in tons ha^{-1} after drying. Paddy rice (100g) was subsampled per plot and oven dried at 70^{0}C for 72 hours to determine the moisture content (Yoshida *et al.*, 1976).

$$\text{Moisture Content (\%)} = \frac{(\text{Weight of Sun}-\text{dried paddy}) - (\text{weight of oven}-\text{dried Paddy})}{\text{weight of sun}-\text{dried Paddy}} \times 100 \text{ --------- } 3.1$$

Paddy yield was then adjusted to 14% moisture content.

$$\text{Adjusted Paddy yield (tons ha}^{-1}\text{)} = \text{(Initial Paddy yield)} \times \frac{100 - \text{Moisture content (\%)}}{86} \text{ -----------------} 3.2$$

3.10.2 Straw yield (tons ha^{-1})

Weight of straw was determined after drying and separating the paddy from the straw by threshing. Straw yield was measured with metler balance. Straw was sub-sampled (200g) for each plot and oven-dried at 70^{0}C for 72 hours. Straw yield was adjusted to oven-dried weight and expressed in tons per hectare (Yoshida *et al.*, 1976).

3.10.3 Biomass Yield (tons ha^{-1})

Total dry matter was determined by adding the values of paddy and straw yields of each treatment expressed in tons per hectare.

3.10.4 Harvest Index (HI)

Harvest index is the ratio of the crop economic yield (paddy yield) to the biomass yield (Kaizzi *et al.*, 2012b).

$$\text{HI} = \frac{\text{Paddy yield}}{\text{Biomass yield}} \text{ ---} \ 3.3$$

3.10.5 Panicle Number (m^{-2})

At physiological maturity, the number of panicles of ten tagged hills was determined and expressed in per square meter

3.10.6 Panicle length (cm)

The length of 10 randomly selected panicles at harvest was measured from the base of the inflorescence to the tip with a meter rule. The average was expressed in centimeter

3.10.7 Plant height (cm)

At physiological maturity, heights of 10 tagged plants were measured from the base to the tip using a meter rule. The average was then determined and expressed in centimeter.

3.11 Soil Analysis

Composite soil samples (0–20 cm depth) were made from six subsamples from each site. Samples were air-dried, ground and passed through a 2 mm mesh sieve. Particle size analysis was determined by hydrometer method (Bouyoucos, 1962). Soil pH was measured in water and 0.01M $CaCl_2$ using soil-solution ratio of 1:2.5 (Hendershot *et al*., 1993). Electrical conductivity was determined using conductivity meter. Organic carbon was determined using the Walkley-Black method as described by Nelson and Sommers (1982). Exchangeable bases were extracted with 1N Ammonium acetate at pH 7. Exchangeable acidity was determined by titrimetric method (McLean, 1982). Available P was determined using the Bray-1 method (Bray and Kurtz, 1945). Potassium and Na were measured by flame photometer. Ca and Mg were measured by Atomic Absorption Spectrophotometer. Effective cation exchange capacity was estimated by the summation method of exchangeable acidity and exchangeable bases.

3.12 Statistical Analysis

Data were analyzed using GenStat statistical package (VSN international, 2011). Analysis of variance was done using plot data for each location. Treatment means were compared using Duncan multiple range test (DMRT) at 5% probability level (Duncan, 1955). When significant nutrient rate effect occurred, a non-linear asymptotic yield function was determined for each location. The function was captured as $y = a - bc^n$. Where y = yield in tons/ha; a= near maximum Paddy yield; b = yield increase due to nutrient application; c^n determines the shape of the curvilinear response where c is a curvature coefficient and n is the nutrient rate. Paddy yield was correlated with yield components. Differences and relationship were considered significant at $\alpha \leq 0.05$.

The net return above fertilizer cost (NRF) at different nutrient rate was calculated yield from fitted N response function according to Wortmann *et al*. (2007).

NRF $= [P \times Y] - [C \times N]$. -------------------------------------- 3.4

Where P = price of paddy rice per kilogram

C = cost of nutrient per kilogram

N= nutrient application rate (kg/ha)

Y= increase in rice yield due to N application (kg/ha)

The nutrient rate that maximizes net return to fertilizer use or the EOR was determined for a range of CPs which included 2, 4, 6, 8 and 10. Economic analyses were performed with nutrient cost of ₦260/kg of Nitrogen and Paddy price were a function of nutrient cost and CP. Regression analyses were conducted to relate the effect of variation in CP on EOR.

Regression analyses using plot data and averaged across P rates were conducted to relate components of NUE to the different nutrient rates. The values of components of NUE were determined for each site. The following components of nitrogen use efficiency (NUE) were determined according to Cassman *et al.* (2002):

1. Partial factor productivity , PFP = $\frac{Y}{N}$ -- 3.5
2. Agronomic efficiency of applied N, AE = $\frac{Y-Y_o}{N}$ ------------------------------- 3.6

Where N = amount of nitrogen applied (kg/ha)

Y = crop yield with applied nitrogen (kg/ha)

Y_o = crop yield in a control plot with no N (kg/ha)

The units for all components were expressed in kg/kg.

CHAPTER FOUR

4.0 RESULTS

4.1. Soil Characteristics of the Study Sites

The physical and chemical properties of soils of the experimental locations and their corresponding fertility ratings according to FMANR (1990) are presented in Table. 4.1. The soil in Kadawa site was majorly sandy loam. The sandy nature of the soil might be attributed to the parent material as the soils were developed predominantly on deeply pre-cambrian Basement complex rocks such as granitic sandstone. Malgwi *et al*. (2000) and Voncir *et al*. (2008) reported that the dominance of sand contents in Northern Nigerian soils is as a result of sorting of materials by clay eluviation and surface wind erosion. The soil texture in Wushishi was generally clay loam. Oladipo (1998) described the soil of the location as aquept soil type.

Better crop performance is expected in Wushishi than Kadawa because clay to loamy clay soils is generally suitable for optimum rice yield in lowland ecology. Permeable, coarse-textured soils are less suitable for flooded rice production because they have low water and nutrient-holding capacities (Fageria *et al.,* 2011). Soil water retention in Kadawa was generally low during the growing season as the soil was highly drained. The maintenance of 5cm water which is generally recommended for lowland rice production (Nwilene et al., 2008) was achievable in Wushishi due to the fine soil texture.

Also, the organic matter content (17 g/kg) and total nitrogen (2.6 g/kg) of soils in Wushishi were high. In contrast, the soil organic matter (5 g/kg) and total nitrogen (1.1 g/kg) in Kadawa were low. The anaerobic condition of soils in Wushishi contributed significantly to the high organic matter content of the soil in the location. Under submerged conditions, the supply of free oxygen is low or absent and the decomposition of organic matter depends on the availability of electron

Table 4.1 Physical and chemical properties of soils in the study sites

	Kadawa		**Wushishi**	
Property	**Value**	**Fertility ratings***	**Value**	**Fertility ratings**
Clay(g/kg)	110		363	
Silt (g/kg)	150		325	
11Sand (g/kg)	740		312	
Texture	Sandy loam		Clay loam	
pH water (1:2.5)	7.8	Slightly alkaline	6.6	Neutral
pH $CaCl_2$ (1:2.5)	6.8	Neutral	5.9	Slightly acidic
Organic carbon (g/kg)	5	Low	17	High
Total N (g/kg)	1.1	Low	2.6	High
Bray 1 P (mg/kg)	10.2	Moderate	13.6	Moderate
Ca (cmol kg^{-1})	6.31	High	15.2	High
Mg (cmol kg^{-1})	2.9	High	5.1	High
K (cmol kg^{-1})	0.45	High	0.28	Moderate
Na (cmol kg^{-1})	1.8	High	0.12	Moderate
H + Al (cmol kg^{-1})	0.11		0.2	
ECEC (cmol kg^{-1})	11.57	High	17.9	High
EC (dSm^{-1})	0.13	Non-saline	0.07	Non-saline
ESP (%)	15.56		0.7	

ECEC=Effective Cation Exchange Capacity. EC= Electrical Conductivity. ESP= Exchangeable Sodium Percentage. *(FMNAR, 1990) acceptors such as ferric iron or sulphate. Moreover, alternate electron-acceptors (ferric hydroxides or sulphate) are inefficient in the destruction of organic matter compared to oxygen (Fageria *et al*., 2011). Consequently, the decomposition of organic matter is comparatively slow, inefficient and incomplete under flooded or anaerobic soil conditions.

The pH of the soils measured in 0.01M $CaCl_2$ was neutral (6.8) for Kadawa and slightly acidic (5.9) for Wushishi and are adequate for lowland rice cultivation (Havlin *et al.,* 2014). Bray 1 available phosphorus in Kadawa was 10.2 mg/kg while 13.6 mg/kg was measured in Wushishi. Excheangeable potassium was high in Kadawa (0.45cmol/kg) and moderate in Wushishi (0.28cmol/kg). Exchangeable calcium was 6.31cmol/kg in Kadawa and 15.2cmol/kg in Wushishi. Exchangeable magnesium was 2.9cmol/kg in Kadawa and 5.1cmol/kg in Wushishi. Sodium was higher (1.8 cmol/kg) in Kadawa while Wushishi had moderate level (0.12cmol/kg).

The exchangeable bases of both locations were dominated by Ca^{2+} and Mg^{2+} which is typical of most savanna soil. In Kadawa, the high sodium content, which is also reflected in the high ESP of the soil suggests the soil is prone to sodicity. High sodium can equally be toxic to plants. The electrical conductivity (EC) is a good indicator of the extent or degree of salinity of the soils. Values for EC for both locations were below levels considered to be saline. The EC values are very much within safe limits as they are much lower than the $4dsm^{-1}$ prescribed for alkaline and salt-affected soils (Landon, 1991).

4.2 Paddy Yield Response to Applied Nitrogen averaged across Phosphorus Rates

The main effect of nitrogen fertilization on paddy yield presented in Table 4.2 shows that yield without nitrogen application in Kadawa and Wushishi were 2.60 and 5.05 tons/ha respectively. There were significant increases in yield with N application in both locations.

Table 4.2 Paddy yield response to applied Nitrogen averaged across Phosphorus rates

Treatment	Wushishi	Kadawa
N (kg ha^{-1})	**——— tons ha^{-1}**	**———**
0	5.05c	2.60b
40	7.05b	3.55a
80	8.05a	3.42a
120	6.97b	3.91a
160	7.63ab	3.51a
Mean	6.95	3.4
SE±	0.41	0.32

Means followed by same letter(s) within the same column and treatment group are not significantly different at 5% level of probability. SE= Standard Error

In Wushishi, application of 80 kg/ha of N produced maximum yield of 8.05 tons/ha. Similarly, yield significantly increased by 0.95 tons/ha with the application of 40kg/ha of N in Kadawa. The interaction between nitrogen and phosphorus on paddy yield was not significant in both locations. The predicted optimum N rates from response curve (Fig. 4.1) were 114 kg/ha and 106 kg/ha for Wushishi and Kadawa respectively. The resulting asymptotic yield response functions for each location were expressed as follows:

Wushishi; $Y = 7.53 – 2.04 (0.955)^N$ $R^2 = 0.65$ ---------------------------------- 4.1

Kadawa; $Y = 3.63 – 1.03 (0.946)^N$ $R^2 = 0.71$ --------------------------------- 4.2

4.3 Straw Yield Response to Applied Nitrogen averaged across Phosphorus rates

Yield without applied nitrogen in Wushishi was 7 tons/ha and was significantly increased to a maximum value of 9.91 tons/ha with the application of 80kg N/ha (Table 4.3). Nitrogen application did not have any significant effect on straw yield in Kadawa. Nitrogen and phosphorus rates interaction was not significant on straw yield in both locations. Average straw yield (8.8 tons/ha) of Wushishi was significantly higher than Kadawa (2.4 tons/ha)

4.4 Effect of applied nitrogen on harvest index averaged across phosphorus rates

Harvest index was not significantly affected by nitrogen application in both locations (Table 4.3). Average harvest index in Kadawa (0.59) was significantly higher than in Wushishi (0.44). There was no significant interaction between nitrogen and phosphorus on harvest index in both locations.

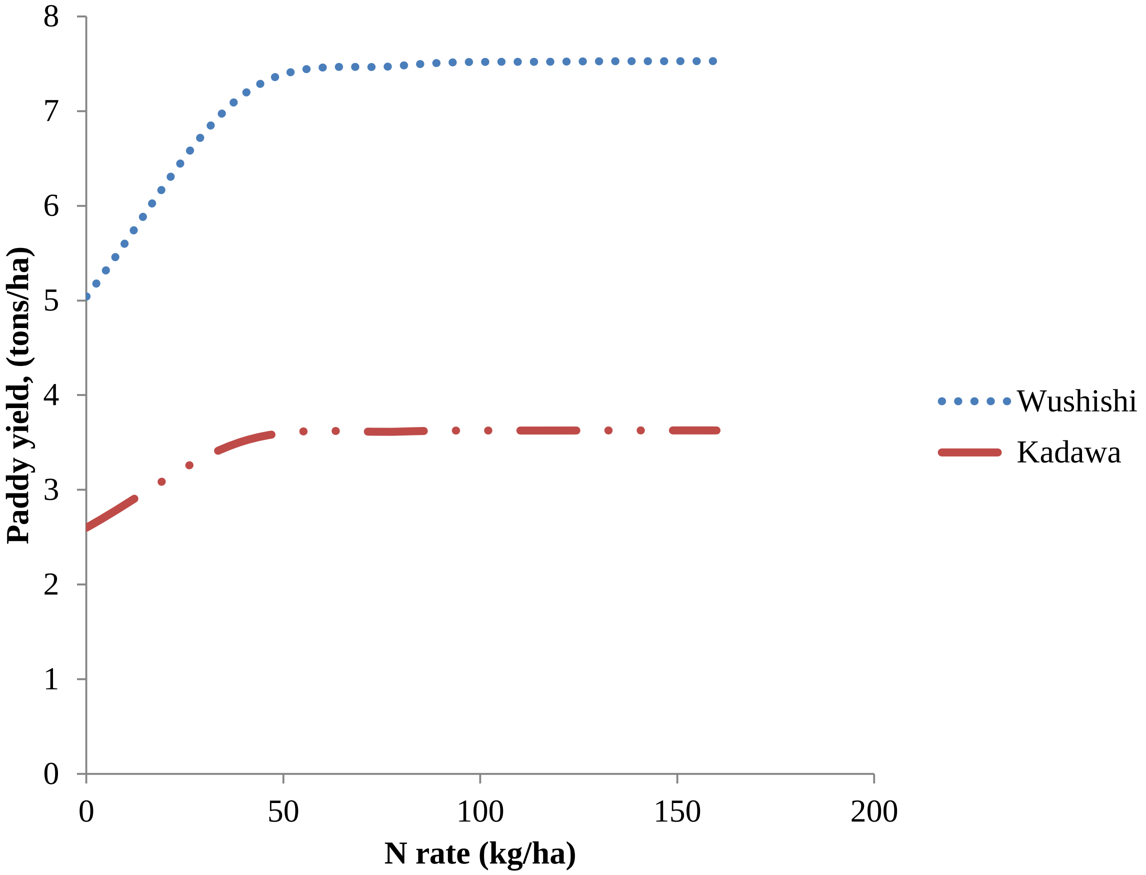

Figure 4.1. Paddy yield response to applied Nitrogen averaged across phosphorus rates in both locations

Table 4.3 Influence of nitrogen on straw yield, harvest index and biomass yield averaged across phosphorus rates

	Straw yield (tons ha^{-1})		**Harvest index**		**Biomass yield (tons ha^{-1})**	
Treatment	**Wushishi**	**Kadawa**	**Wushishi**	**Kadawa**	**Wushishi**	**Kadawa**
N (kg ha^{-1})						
0	7.0c	2.0	0.42	0.57	12.1c	4.6b
40	8.2bc	2.4	0.47	0.59	15.2b	5.95a
80	9.91a	2.4	0.45	0.58	18a	5.87a
120	8.76ab	2.6	0.45	0.60	15.7b	6.47a
160	10.09a	2.4	0.43	0.59	17.7a	5.96a
Mean	8.8	2.4	0.44	0.59	15.74	5.77
SE±	0.79	0.24	0.028	0.012	0.89	0.54

Means followed by same letter(s) within the same column and treatment group are not significantly different at 5% level of probability. SE= Standard Error

4.5 Biomass Yield response to applied Nitrogen averaged across Phosphorus Rates

Nitrogen had significant effect on crop biomass in both locations (Table 4.3). Application of 80 kg N/ha produced the highest biomass yield (18 tons/ha) in Wushishi while Kadawa had highest biomass yield of 5.95 tons/ha when 40 kg/ha of N was applied. Averaged across treatments rates, Wushishi had significant higher crop biomass (15.74 tons/ha) than Kadawa (5.77 tons/ha). There was however no significant interaction between nitrogen and phosphorus rates in both locations.

4.6 Effect of applied Nitrogen on Plant Height averaged across Phosphorus Rates

As presented in figure 4.2, plant height without application of nitrogen in Wushishi was 70.3cm and was significantly increased to a maximum height of 105cm with the application of 80kg N/ha. Conversely, no significant increase in plant height was observed in Kadawa. There was no significant interaction between nitrogen and phosphorus on plant height in both locations.

4.7 Effect of applied Nitrogen on Panicle Length averaged across Phosphorus Rates

As shown in Figure 4.3, application of 80 kg/ha of N significantly produced maximum panicle length of 29.5cm in Wushishi. Application of Nitrogen did not significantly increase panicle length in Kadawa. There was no significant interaction between nitrogen and phosphorus on panicle length in both locations.

4.8 Effect of applied Nitrogen on Number of Panicle averaged across Phosphorus Rates

Figure 4.4 shows that a significant increase in panicle number was recorded in Wushishi. Panicle number in the absence of applied fertilizer N was 202 m^{-2} which was increased to a maximum value of 322 m^{-2} when 80kg N/ha was applied. There was no significant interaction between nitrogen and phosphorus on number of panicles in both locations.

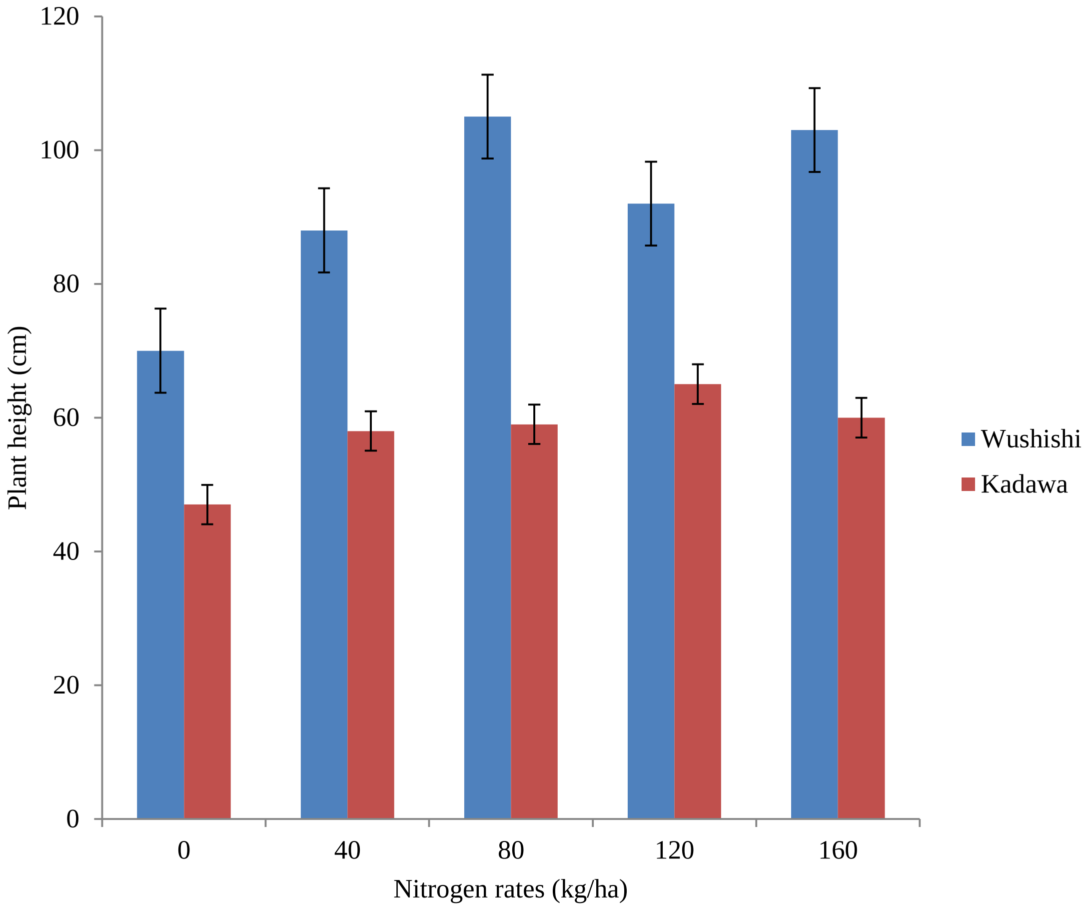

Figure 4.2 Effect of nitrogen application on plant height averaged across phosphorus rates

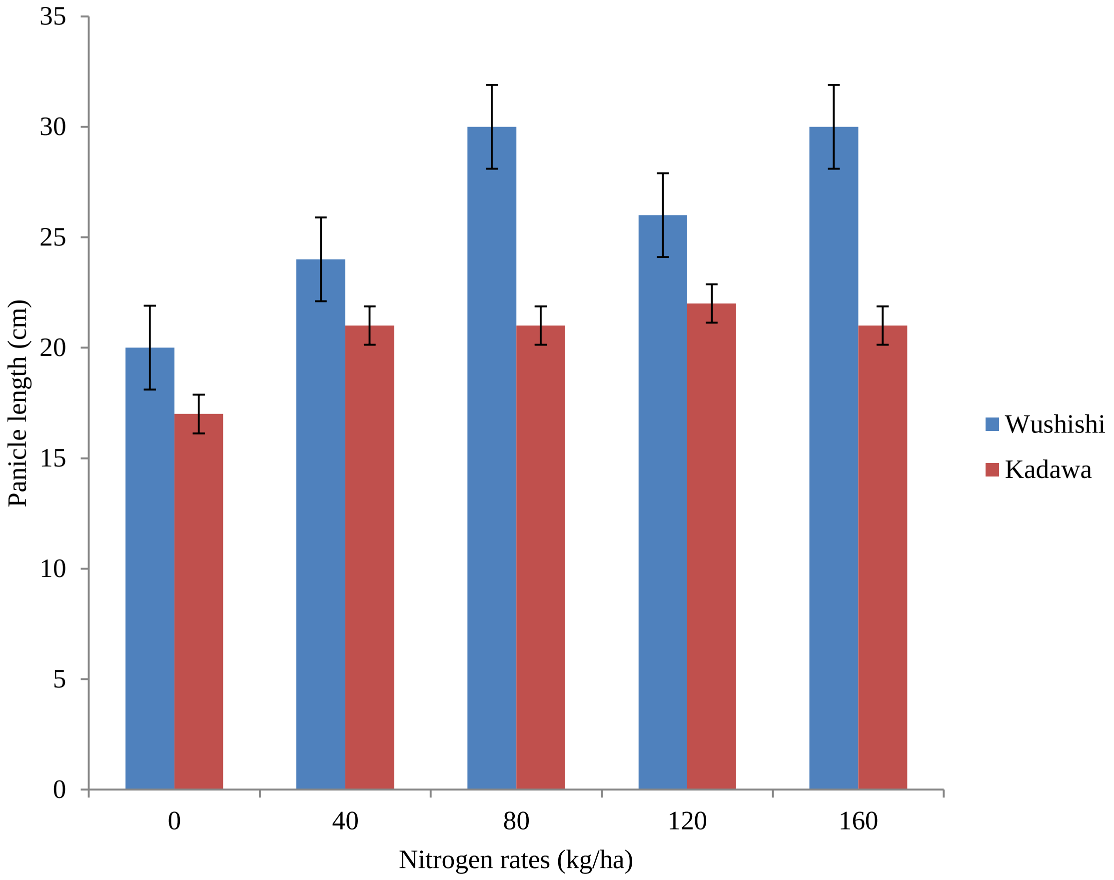

Figure 4.3 Effect of nitrogen application on length of panicle averaged across phosphorus rates

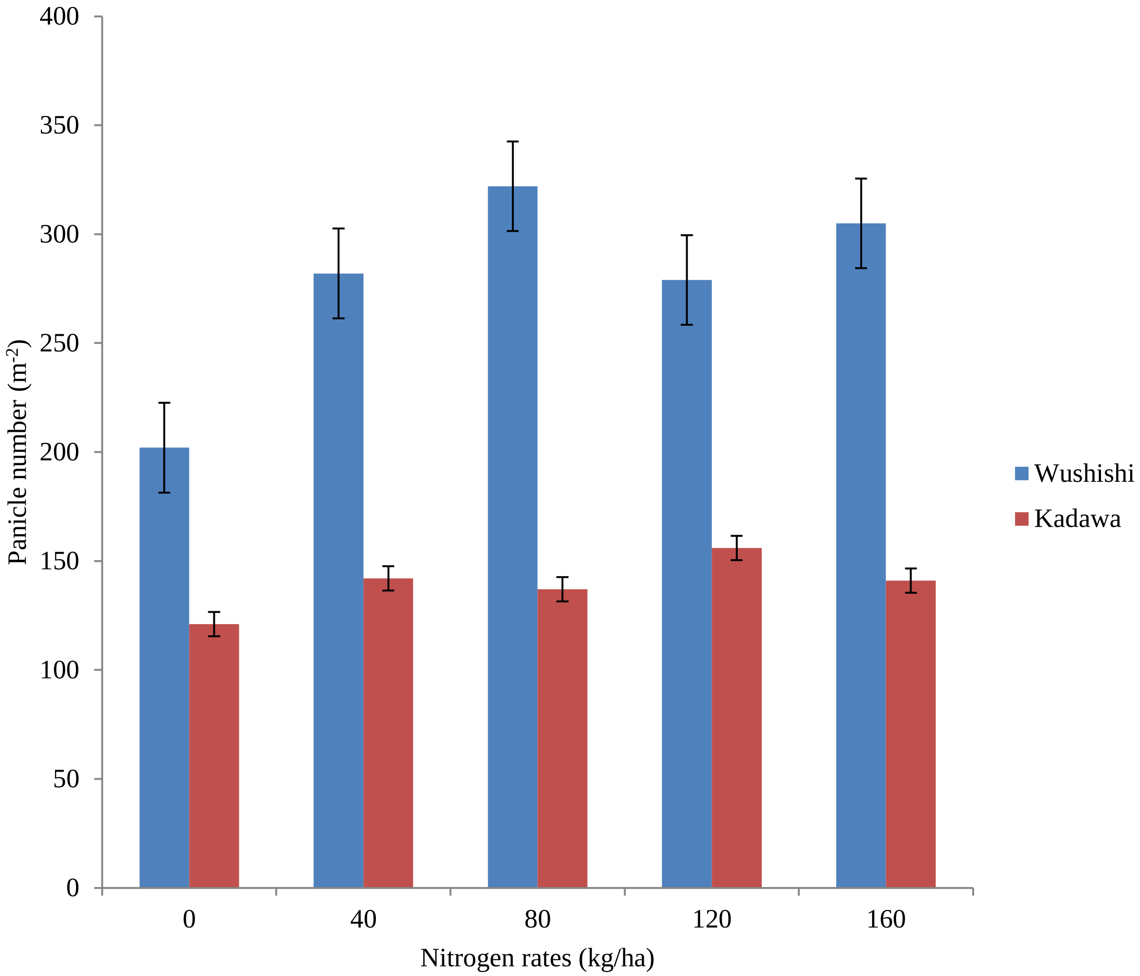

Figure 4.4.Effect of nitrogen application on panicle number averaged across phosphorus rates

4.9 Paddy Yield Response to applied Phosphorus under high Nitrogen Levels

Table 4.4 shows that yield without fertilizer P in Wushishi was 7.64 tons/ha and application of fertilizer P did not lead to any significant increase in yield relative to the control. No significant response of paddy yield to P application was recorded in Kadawa.

4.10 Effect of applied Phosphorus on Straw Yield under high Nitrogen Levels

No significant effect of P on straw yield in both locations was observed (Fig. 4.5). Average straw yield was significantly higher in Wushishi (8.9 tons/ha) than they were in Kadawa (2.6 tons/ha).

4.11 Effect of applied Phosphorus on Harvest Index under high Nitrogen levels

As shown in Figure 4.6, harvest index without application of fertilizer P in Wushishi was 0.48 and application of fertilizer P did not lead to any significant increase in harvest index relative to the control. Fertilizer P had no significant effect on harvest index in Kadawa. Average harvest index in Kadawa (0.6) was higher than values observed in Wushishi (0.46).

4.12 Effect of applied Phosphorus on Biomass Yield under high Nitrogen Levels

Application of P did not exert any significant effect on biomass yield in both locations (Fig. 4.7). Average biomass yield in Wushishi (16.5 tons/ha) was higher than Kadawa (6.5 tons/ha).

4.13 Effect of applied phosphorus on panicle number under high nitrogen levels

Results on the effect of P fertilizer application on panicle number are presented in Figure 4.8. In Kadawa, panicle number with no fertilizer P was 163 m^{-2} and no significant increase in panicle number was observed with application of fertilizer P. Similarly in Wushishi, panicle number

Table. 4.4 Paddy yield response to applied phosphorus under high nitrogen levels

	P rate (kg ha^{-1})				Mean	SE±
	0	7.5	15	22.5		
Location	tons ha^{-1}					
Wushishi	7.64ab	8.91a	6.27b	7.40cb	7.56	0.33
Kadawa	4.08	3.35	3.74	4.39	3.89	0.33

Means followed by same letter(s) within the same rows and treatment group are not significantly different at 5% level of probability. SE= Standard Error.

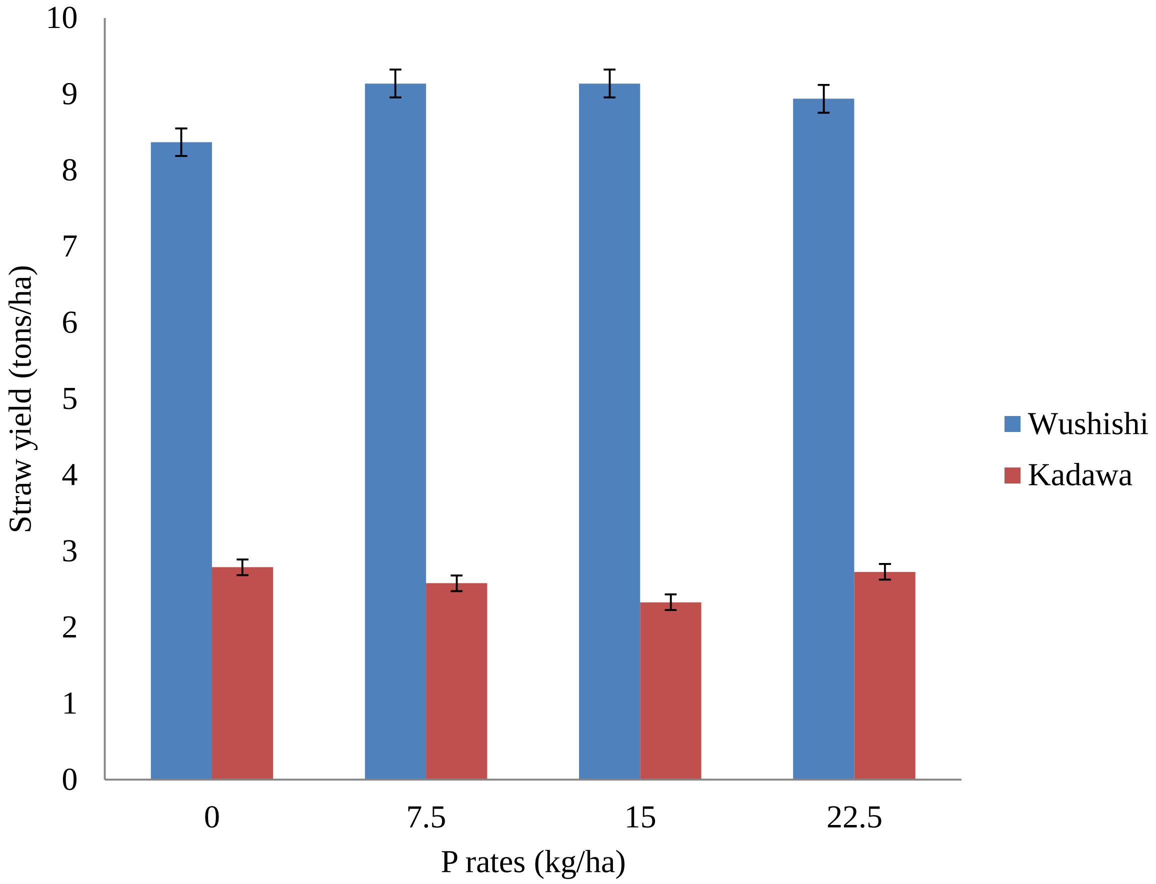

Figure 4.5 Effect of applied phosphorus on straw yield under high nitrogen levels

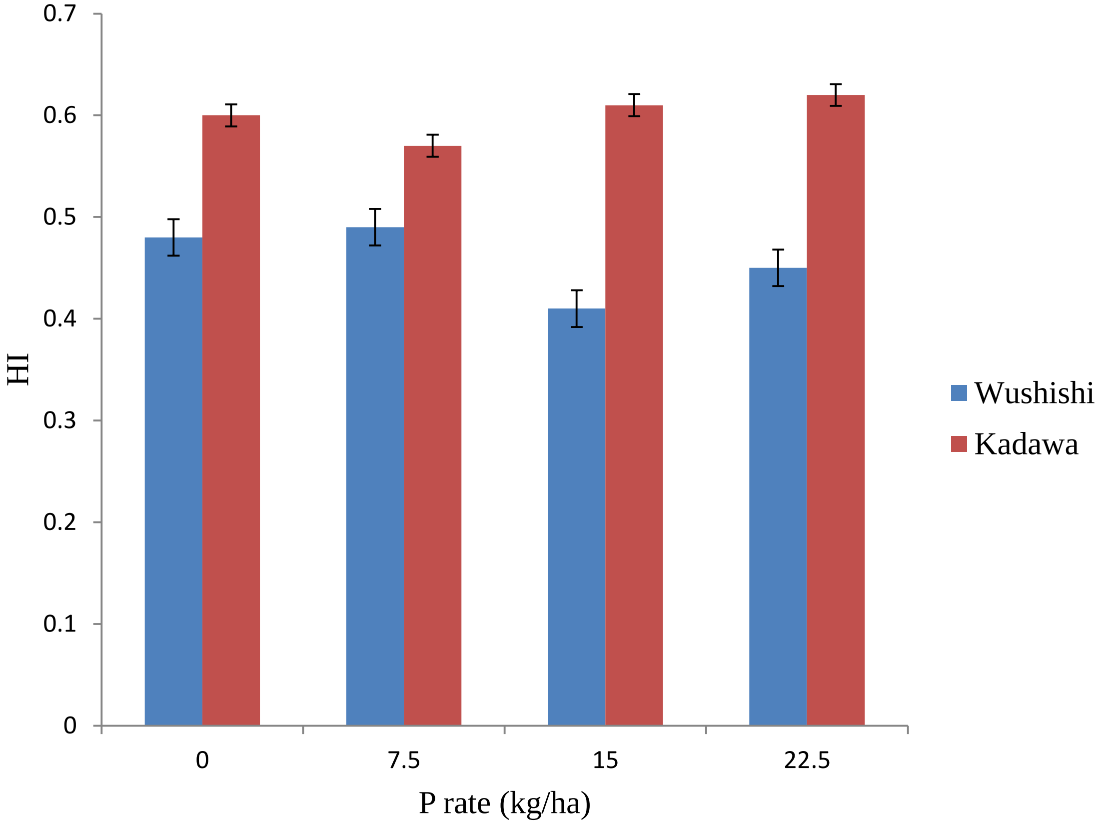

Figure 4.6 Effect of applied phosphorus on harvest index (HI) under high nitrogen levels

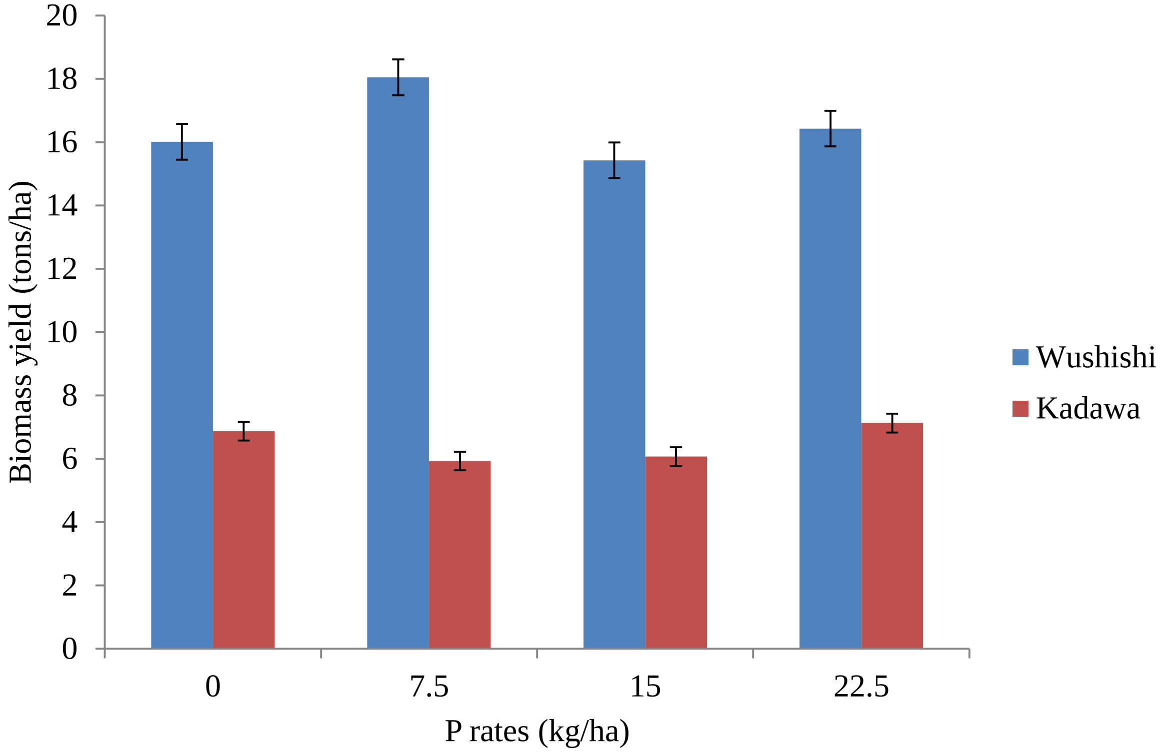

Figure 4.7 Effect of applied phosphorus on biomass yield under high nitrogen values

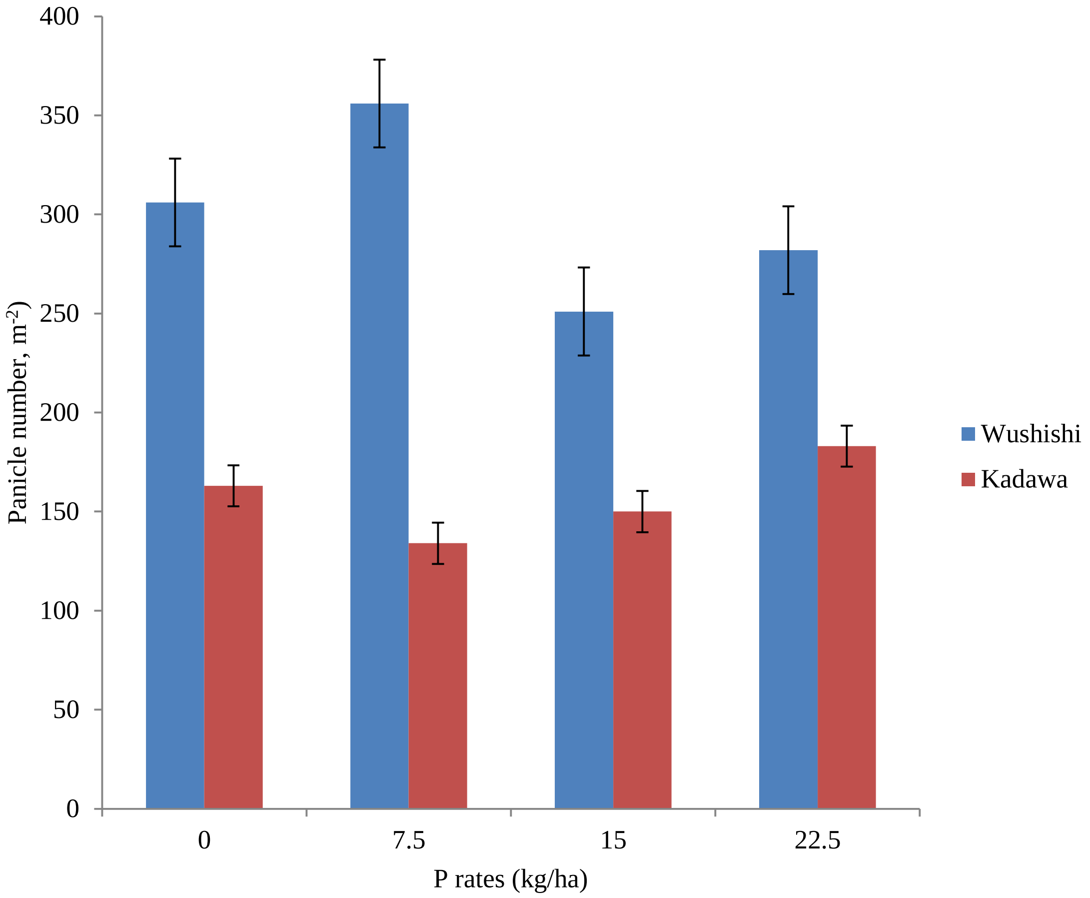

Figure 4.8 Effect of phosphorus application on panicle number under high nitrogen levels

without fertilizer P was 306m^{-2} and application of P did not differ significantly with the control.

4.14 Effect of applied Phosphorus on Plant Height under high Nitrogen levels

In both Wushishi and Kadawa, application of P had no significant effect on plant height (Fig. 4.9). Average across treatment levels, plant height in Wushishi (96.2 cm) was significantly higher than plant heights in Kadawa (64.9 cm).

4.15 Effect of applied Phosphorus on Panicle Length under high Nitrogen levels

The result in Figure 4.10 showed that P application did to have any significant effect on panicle length in both locations. However, average across treatment levels, panicle length in Wushishi (26.5cm) was higher than panicle length in Kadawa (22cm).

4.16 Paddy Yield response to applied Potassium under high Nitrogen and Phosphorus levels

Paddy yield response to applied K was not significant in both locations (Fig. 4.11). Averaged across treatment levels, Wushishi had significant higher paddy yield (7.6 tons/ha) than Kadawa (4 tons/ha).

4.17 Straw Yield response to applied Potassium under high Nitrogen and Phosphorus levels

Applied K did not appear to have any significant effect on straw yield in both locations (Table 4.5). Average straw yield in Wushishi (11.51 tons/ha) was higher than for Kadawa (2.26 tons/ha).

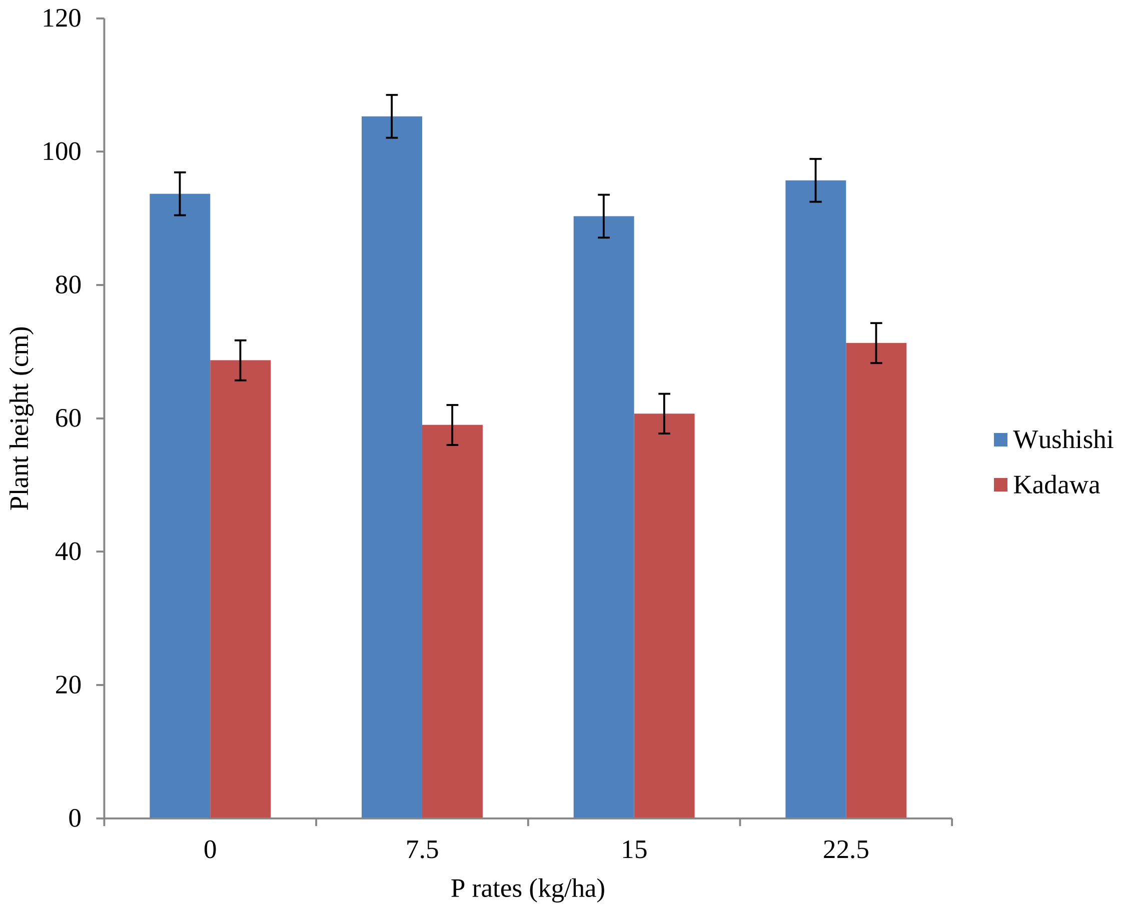

Figure 4.9 Effect of applied phosphorus on plant height under high nitrogen levels

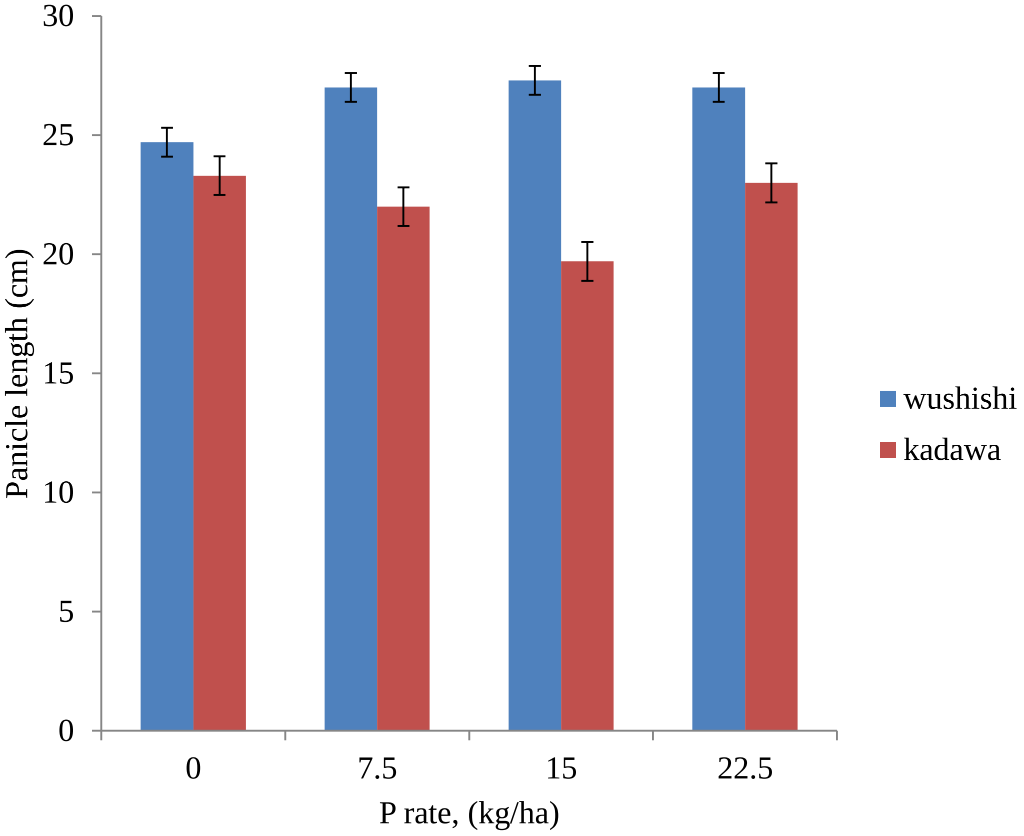

Figure 4.10 Effect of phosphorus application on panicle length under high nitrogen levels

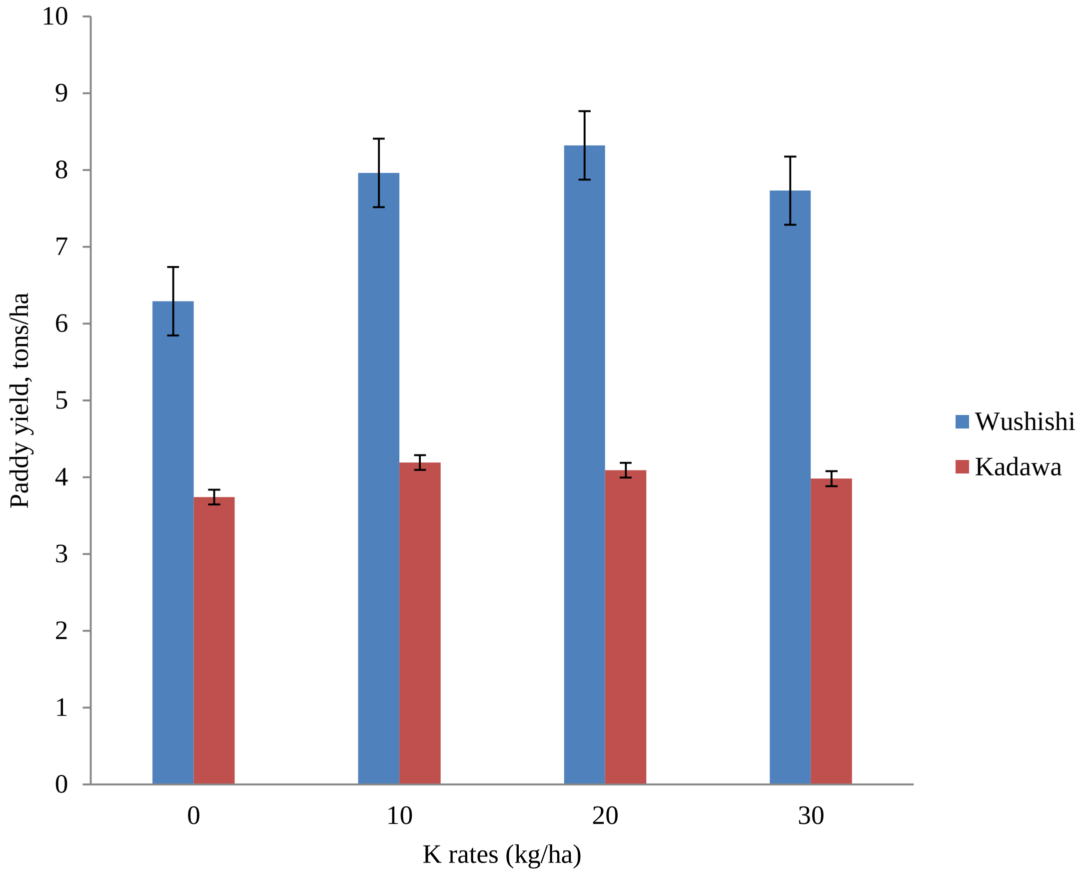

Figure 4.11 Effect of applied potassium on paddy yield under high nitrogen and phosphorus levels

Table 4.5 Effect of applied potassium on straw yield, harvest index and biomass yield of lowland rice under high nitrogen and phosphorus levels

	Straw yield (tons/ha)		Harvest Index		Biomass yield (tons/ha)	
Treatment	**Wushishi**	**Kadawa**	**Wushishi**	**Kadawa**	**Wushishi**	**Kadawa**
K (kg/ha)						
0	9.14	2.33	0.41	0.61	15.43b	6.07
10	11.74	2.03	0.40	0.67	19.7a	6.22
20	12.32	2.20	0.41	0.65	20.63a	6.29
30	12.87	2.47	0.38	0.62	20.57a	6.44
Mean	11.51	2.26	0.40	0.64	19.08	6.26
SE±	1.51	0.21	0.06	0.03	1.06	0.34

Means followed by same letter(s) within the same column and treatment group are not significantly different at 5% level of probability. SE= Standard Error

4.18 Effect of applied Potassium on harvest index under high Nitrogen and Phosphorus level

Harvest indices were not significantly affected by the application of K fertilizer in both locations (Table 4.5). Average harvest index in Wushishi (0.40 kg/kg) was lower for than Kadawa (0.64 kg/kg).

4.19 Effect of applied Potassium on Biomass Yield under high Nitrogen and Phosphorus levels

Application of K fertilizer had significant effect on biomass yield in Wushishi only. Biomass yield without applied K in Wushishi was 15.43 tons/ha and was significantly increased to 19.74 tons/ha with the application of 10 kg K/ha (Table 4.5). Increase in K rates beyond 10kg/ha did not significantly increase biomass yield. There was no significant effect of applied K on biomass yield in Kadawa. Average yield in Wushishi (19.08 tons/ha) was more than for Kadawa (6.26 tons/ha) site.

4.20 Effect of applied Potassium on Panicle Length under high Nitrogen and Phosphorus Levels

No significant effect of K on panicle length was observed in both locations (Figure 4.12). Average across treatment levels, panicle length in Kadawa (18.9cm) was however shorter than Wushishi (34.2cm).

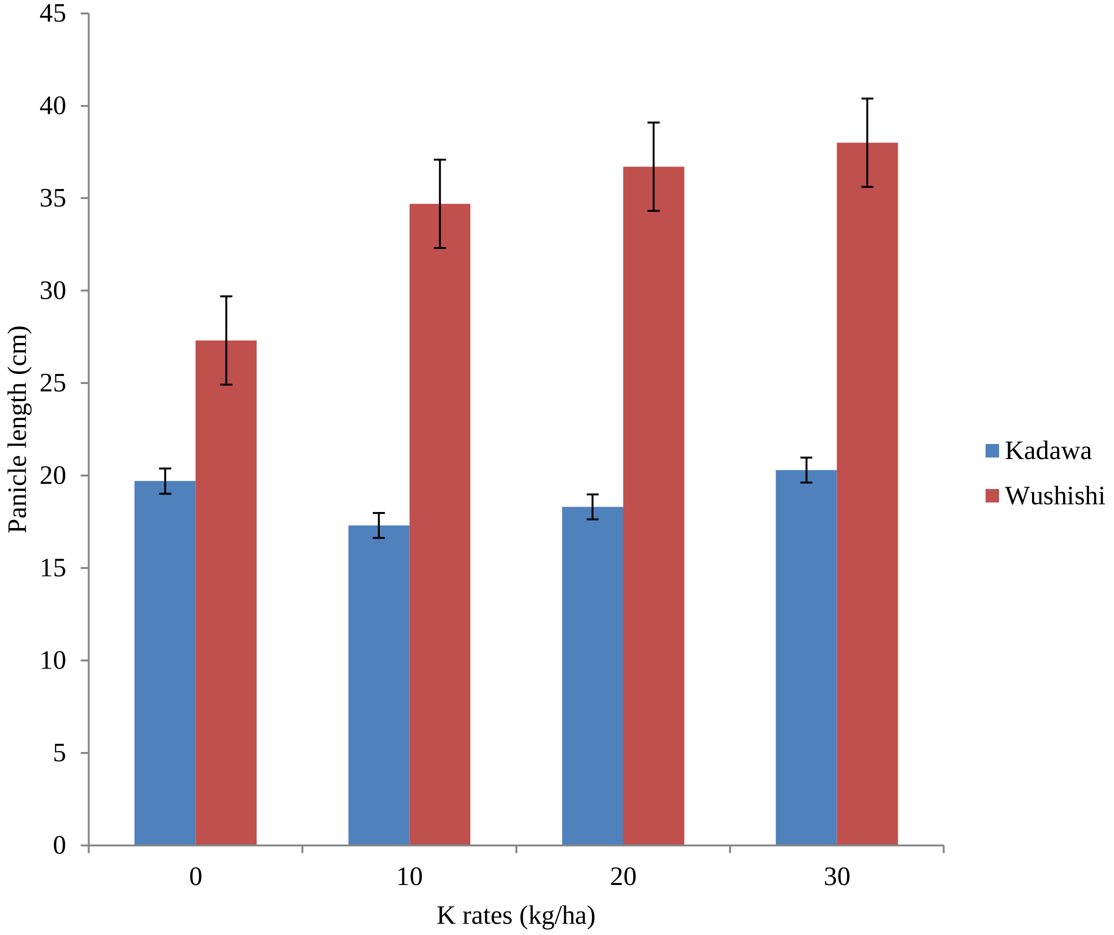

Figure 4.12 Effect of applied potassium on panicle length under high nitrogen and phosphorus levels

4.21 Effect of applied Potassium on Panicle Number under high Nitrogen and Phosphorus levels

Panicle number was not significantly affected by the application of K fertilizer in any of the two locations (Figure 4.13). Average across treatment rates, panicle number in Wushishi (293 m^{-2}) was higher than Kadawa (159 m^{-2}).

4.22 Effect of applied potassium on Plant Height under high Nitrogen and Phosphorus levels.

Application of K in Kadawa did not influence plant height significantly (Figure 4.14). Contrarily in Wushishi, significant increase in plant height was observed when 10kg/ha of K was applied. However, higher K rates did not appear to increase plant height. Average across treatment rates, rice were shorter in Kadawa than those from Wushishi

4.22 Economics of Nutrient Application

Figure 4.15 shows how variation in fertilizer cost to paddy price ratio (CP) influences fertilizer profitability. Similarly, figure 4.16 reveals how crop response to applied nutrient, as determined by location, affected fertilizer profitability. Nitrogen application was more profitable in Wushishi than Kadawa due to greater crop response to applied N. The EOR at different CPs were consistently lower than the optimal nutrient rate (Table. 4.12). Using a Paddy price value of ₦130/kg and nitrogen cost of ₦260/kg (which corresponds to ₦565/kg of urea), the EOR at Wushishi was 72% of optimal nutrient rate. 57% of the maximum nitrogen rate was the estimated EOR at Kadawa. EOR was found to be inversely proportional to CP for any given N rate. The variation in CP formed the basis for accurate prediction of EOR. Regression equations that related EOR to CP for both locations were expressed as.

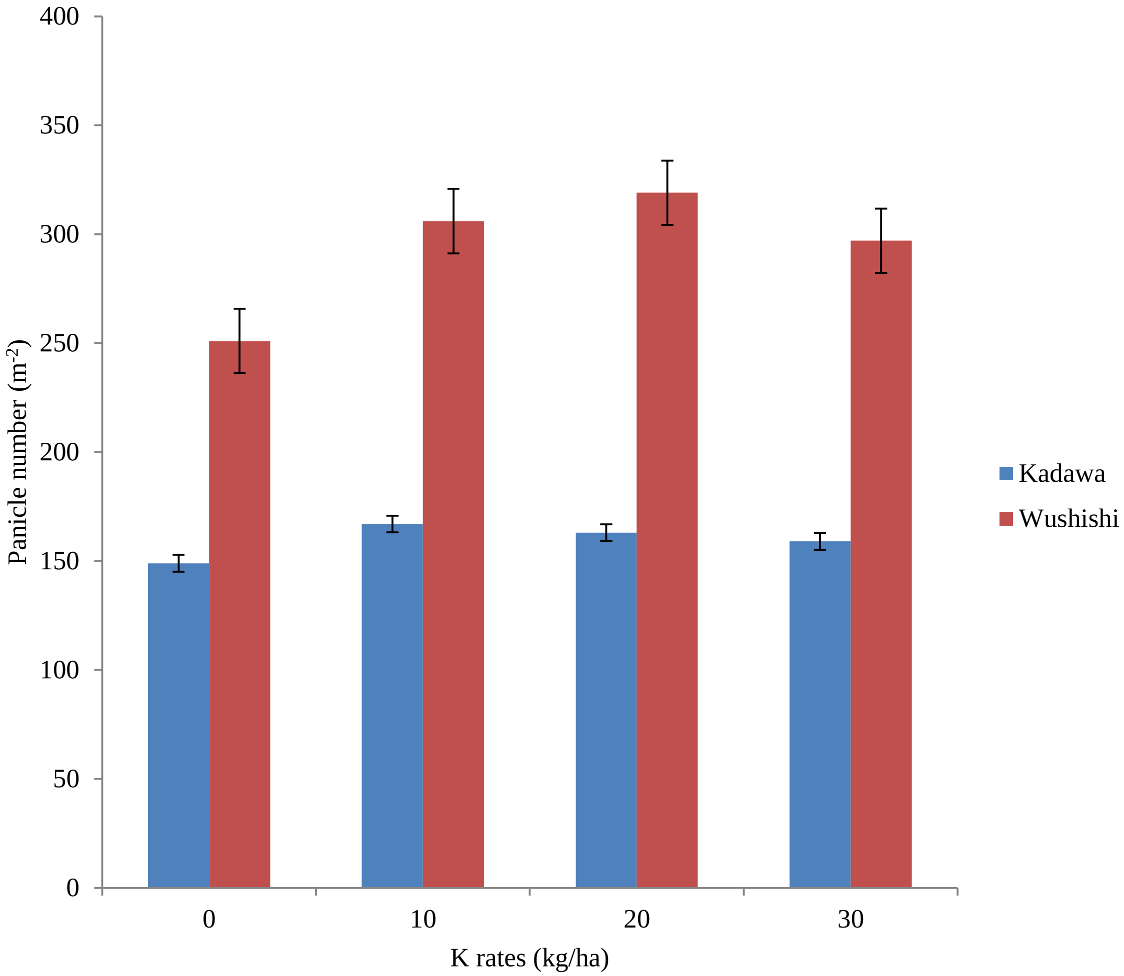

Figure 4.13 Effect of applied potassium on panicle number under high nitrogen and phosphorus levels

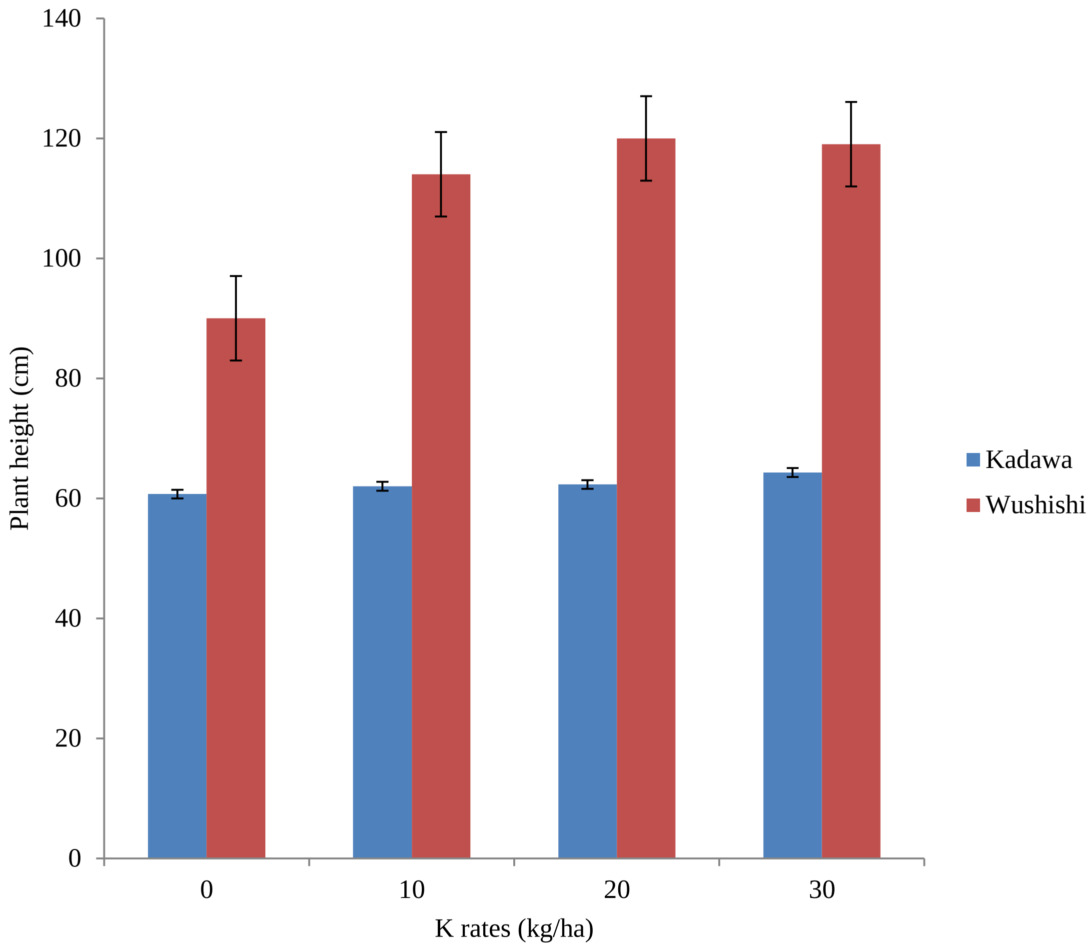

Figure 4.14 Effect of applied potassium on plant height under phosphorus and nitrogen levels

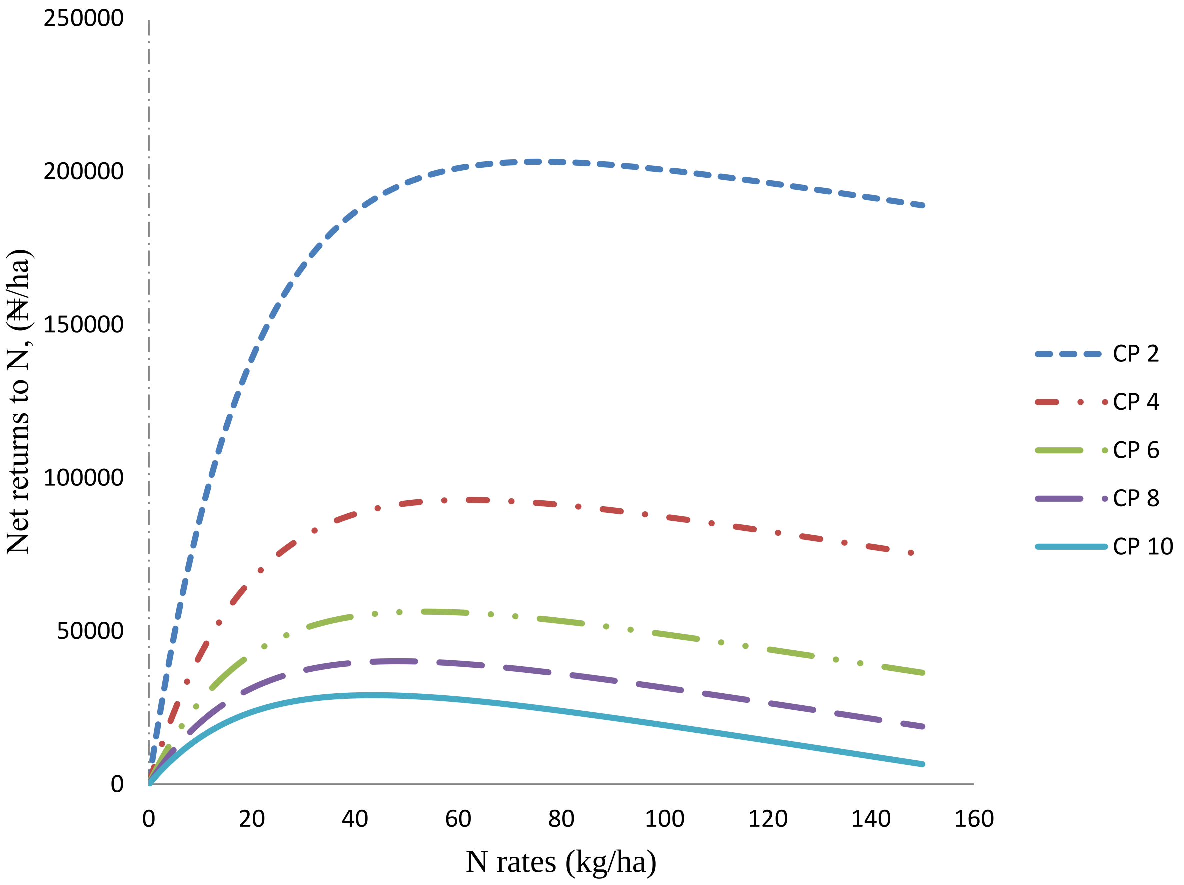

Figure 4.15 Mean effect of nitrogen rate on net return to nitrogen applied to rice for five nitrogen cost to paddy price ratio (CP)

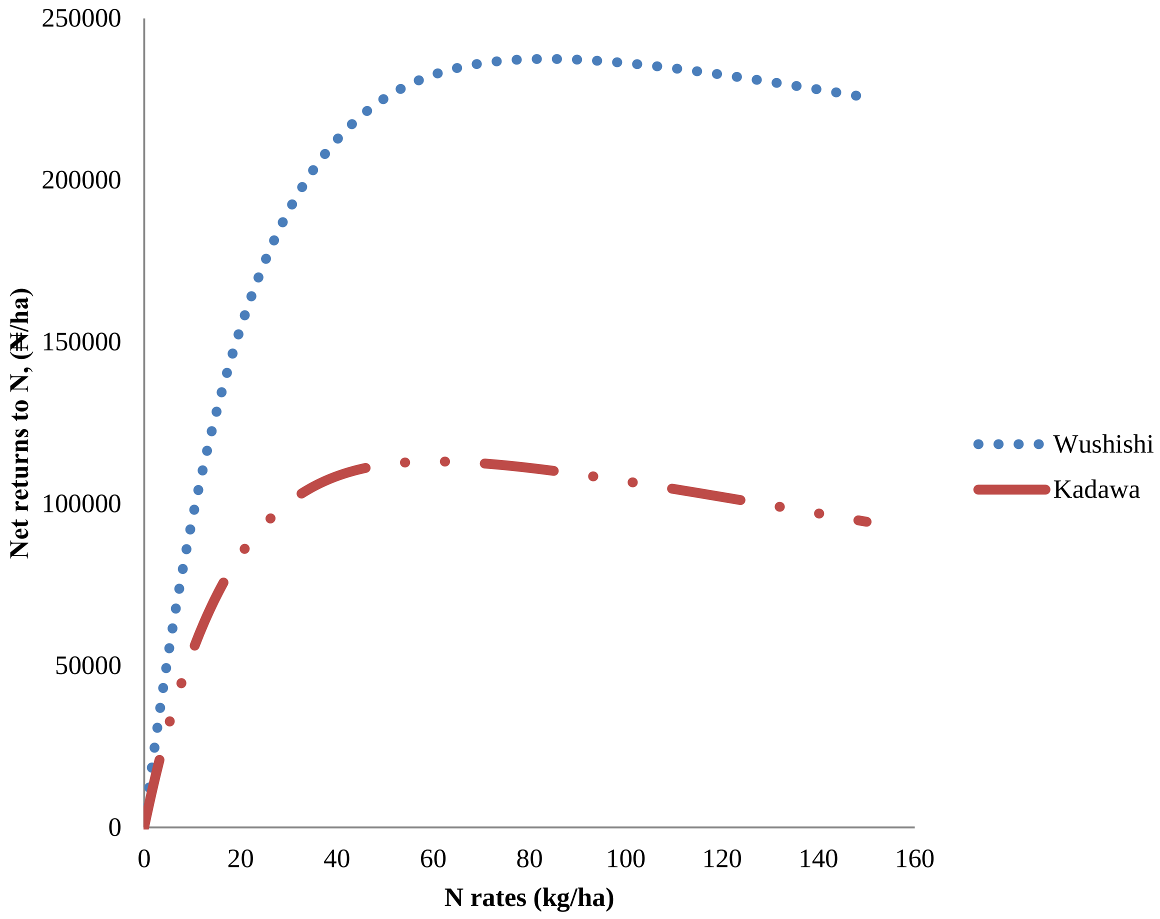

Figure 4.16 Effect of nitrogen rate on net return to nitrogen applied to rice for the two locations and combined analysis at CP of 2

Table 4.6 Economically optimal rates at five CP

Location		**EOR at five CP**				
	ONR*	**2**	**4**	**6**	**8**	**10**
	Kg ha^{-1}					
Wushishi	114	82	69	60	54	49
Kadawa	106	61	48	41	36	32

*ONR = Optimal Nutrient Rate

Wushishi; $EOR = 38.36 + 61.751 (0.8401)^{CP}$ $R^2 = 0.9995$ ---------------------------- 4.3

Kadawa; $EOR = 26.53 + 53.44 (0.801)^{CP}$ $R^2 = 0.9986$ --------------------------- 4.4

4.23 Nitrogen Use Efficiency

The Agronomic Efficiency (AE) of applied N was observed to significantly decline with increasing N rate in both locations (Fig. 4.17). Phosphorus did not exert any significant effect on AE of applied N as there was no significant Nitrogen-phosphorus interaction in both locations (Table 4.7). The AE, average across treatments levels was significantly greater in Wushishi. The AE at EOR for both locations were 15.1 and 32.6 Kg/kg for Kadawa and Wushishi respectively and were higher than AE at optimal nutrient rate. N rate effect on agronomic efficiency in both locations was expressed as:

Kadawa; $AE = 7.27 + 66.96 (0.9654)^{N}$ $R^2 = 0.9906$ ---------------------------------- 4.5

Wushishi; $AE = -1.87 + 79.25 (0.9899)^{N}$ $R^2 = 0.9962$ --------------------------------- 4.6

Similarly, PFP decline with increasing N rates (Fig. 4.18). There was no significant interaction between Nitrogen and phosphorus on PFP (Table 4.8). In Wushishi, PFP was 95.6 kg/kg at EOR. PFP at EOR in Kadawa was 59.6 kg/kg. Nitrogen rate effect on PFP in both locations was expressed as:

Kadawa; $PFP = 21.194 + 195.09 (0.9737)^{N}$ $R^2 = 0.9952$ ------------------------- 4.7

Wushishi; $PFP = 31.35 + 315.35 (0.9808)^{N}$ $R^2 = 0.9980$ ------------------------- 4.8

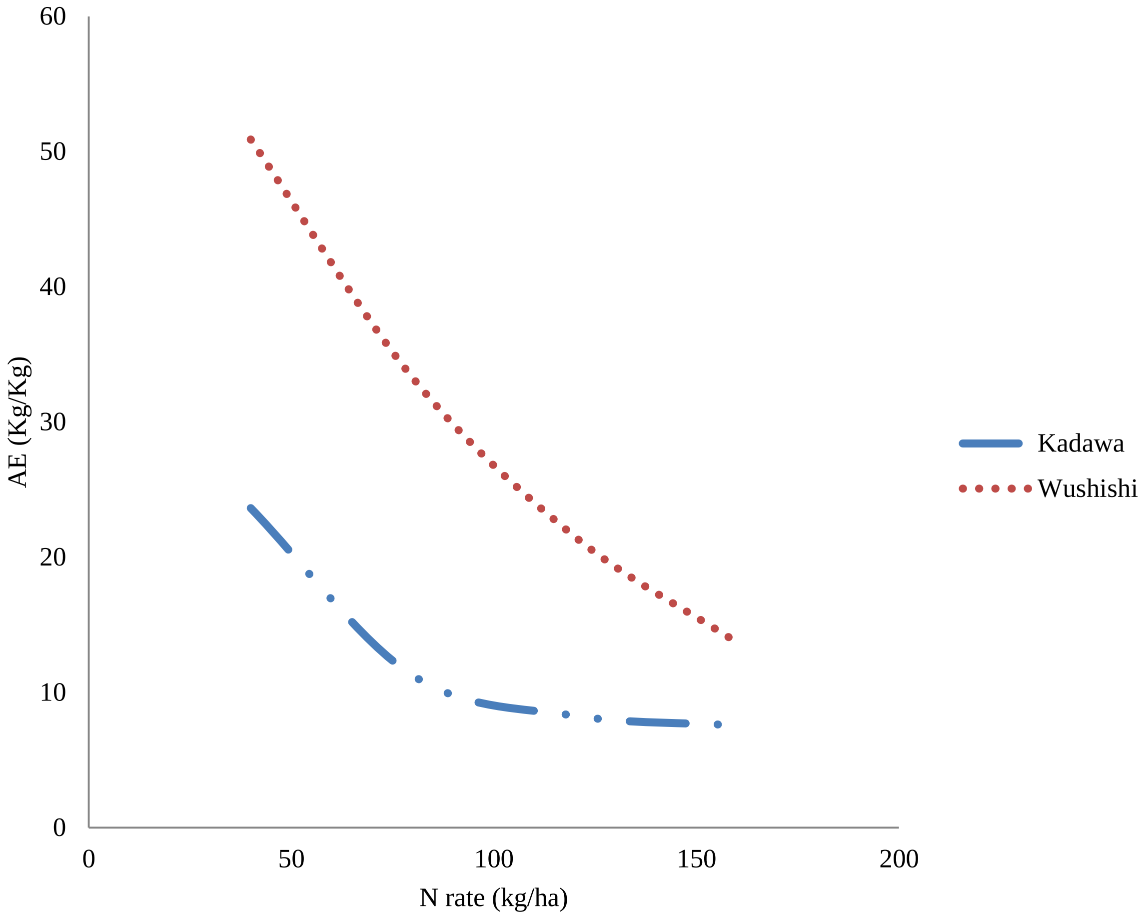

Figure 4.17 Effect of nitrogen rate on Agronomic Efficiency averaged across phosphorus rates

Table 4.7. Effect of nitrogen application on Agronomic Efficiency averaged across phosphorus rates

Location	N rate (kg/ha)									
	40	80	120	160	mean	Pr	N X P	AE at ^{2}EOR	AE at ONR	AE at NRR
	kg kg^{-1}							kg kg^{-1}		
Kadawa	23.72	10.28	10.91	5.72	12.66	**	NS	15.1	8.8	9.17
Wushishi	49.83	37.50	15.94	16.09	29.84	**	NS	32.6	23.28	27.09

[2] *The economic optimal rates at CP of 2 were 82 kg ha^{-1}and 61 kg ha^{-1} for Wushishi and Kadawa respectively. ONR= Optimum Nutrient Rates were 114kg/ha and 106kg/ha for Wushishi and Kadawa. NRR= National Recommended rate (100kg/ha). ** = significant effect at P≤ 0.01 level of probability.*

Table 4.8 Mean effect of N rate (kg ha^{-1}) on Partial factor Productivity (PFP) averaged across phosphorus rates

	N rate (kg/ha)									
Location	**40**	**80**	**120**	**160**	**Pr**	**mean**	**N X P**	**PFP at [1]EOR**	**PFP at ONR**	**PFP at NRR**
	kg kg^{-1}							**kg kg^{-1}**		
Kadawa	88.68	42.76	32.56	21.95	**	46.49	NS	59.6	33.14	35.19
Wushishi	176.12	100.65	58.04	47.67	**	95.62	NS	95.6	66.70	77.60

[1] *The economic optimal nutrient rates at CP of 2 were 82 kg ha^{-1}and 61 kg ha^{-1} for Wushishi, Kadawa. ONR (Optimum Nutrient Rates) were 114 and 106 kg/ha for Wushishi and Kadawa. NRR = National Recommended Rate (100kg/ha). **= significant effect at P≤ 0.01 level of probability.*

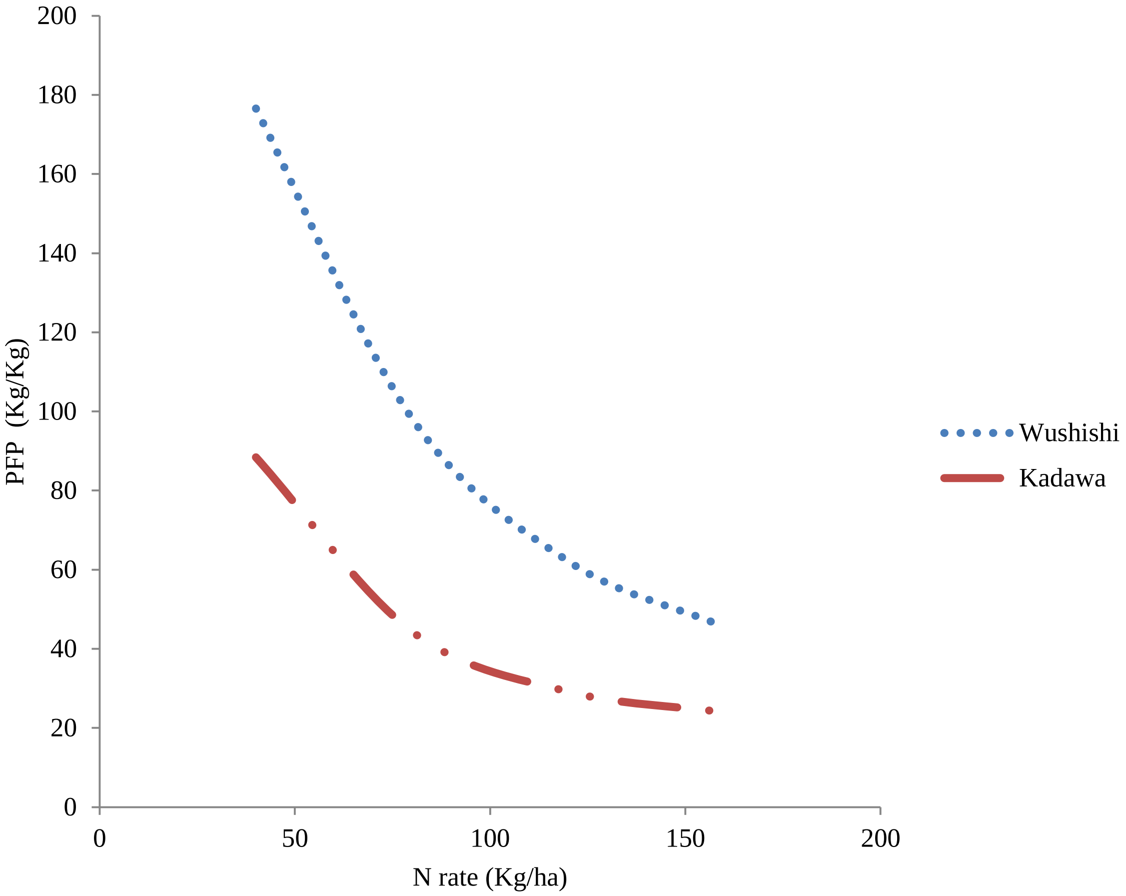

Figure 4.18 Effect of nitrogen rate on Partial Factor Productivity of Applied nitrogen averaged across phosphorus rates

CHAPTER FIVE

5.0 DISCUSSION

5.1 Paddy Yield Response to applied Nitrogen averaged across Phosphorus levels

The significant response of paddy yield to N application showed that N is a major limiting nutrient in lowland rice soils (Fairhust *et al*., 2007, Ishaya and Dauda., 2010). Similar yield increases have been reported by Jibrin *et al*., (2010) in the Sudan savannah ecological zone of Nigeria and Fagaria *et al* (2013) in Brazil. The estimated optimum N rate from regression model in both locations were higher than national recommendation (Chude, *et al.,* 2011., Nwilene, *et al.,* 2008) and lower than those reported by Fageria *et al*., (2013) and Jibrin *et al*., (2010). Nitrogen was limiting in Wushishi even though the soil organic matter and total nitrogen were high. Total N is not generally use as indicator of N availability to crop. Rather, soil levels of NH_4-N or/and NO_3-N are commonly employed due to the high mobility of N. Leaf Colour Chat (LCC) has been adopted in other settings as low-cost method of determining in-season N need (Nwilene *et al*., 2008). Moreover, high levels of soil organic matter do not necessarily translate into increased availability of soil N. Composition of soil organic matter such as high recalcitrant and low particulate fractions, coupled with low rate of mineralization (a major occurring process in anaerobic conditions) may lead to low levels of plant available N.

The greater crop response to applied nitrogen in Wushishi compared to Kadawa can also be attributed to soil physical properties. The soil texture in Wushishi was clay loam which is typical of lowland ecology. Kadawa however had much coarse soil texture that were highly drained and consequently prone to leaching of applied N and moisture stress. The effect of soil texture was so obvious that the control yield in Wushishi was more than highest yield with Nitrogen application in Kadawa. Moreover, the water level in Wushishi was at all times at least 5cm above the surface compared to Kadawa where no standing water could be maintained due to the soil texture. Even though straw yield, biomass yield, panicle number, panicle length and plant height were significantly higher in Wushishi, Kadawa appeared to have had significantly higher harvest index. Yang and Zhang (2010) attributed this phenomenon to moderate moisture stress during grain filling which promotes early plant senescence and remobilization of pre-stored carbon reserve from straw to grain provided the level of moisture stress would allow overnight rehydration of the plant and sufficient supply of nitrogen. The maintenance of standing water during grain filling in Wushishi may have delayed senescence and poor partitioning of photosynthates into grain there by leading to the relatively low harvest index.

5.2 Yield Response to Applied Phosphorus under high Nitrogen levels

The available soil P in Kadawa and Wushishi appeared to be moderate for rice production. This explains the non-significant yield response to applied P recorded in both locations. The result from Kadawa lends credence to the non-significant yield increased observe in the same location by Jibrin *et al* (2010). Under flooded conditions, as observed in Wushishi, phosphorus availability is increased because of the reduction of ferric phosphate to the more soluble ferrous form. Moisture stress may have limited yield in Kadawa. This may explain the significant lower yield recorded in Kadawa relative to Wushishi

5.3 Yield Response to Applied Potassium under high Nitrogen and Phosphorus levels

The soils of the experimental site indicated moderate exchangeable potassium suggesting little or no crop response to applied K. This can be attributed to adequate indigenous nutrient supply from sources such as irrigation water, sediment deposits or fertilizer application from previous trials. Moisture stress in Kadawa may have slowed diffusion of potassium to plant root due to the increase tortuosity of K movement in the soil (Havlin *et al*., 2014).

5.4 Nitrogen Use Efficiency

There was a general decline in AE and PFP with increasing N rates in both locations. The AE at EOR in Wushishi was higher than average of 25kg/kg for well-managed system as described by Dobermann (2007). In contrast, AE at EOR in Kadawa was below the AE in a well-managed system.. The PFP in Wushishi at EOR was higher than the 60 kg/kg of a well-managed system while that in Kadawa was lower. The high average AE and PFP in this study were due to their estimation at EOR. The components of NUE often showed more efficiency at EOR than at higher N rates. Application of Nitrogen at EOR may increase NUE and profitability while reducing environmental pollution commonly associated with high N use. Adoption of improved agronomic practice may increase the profitability of fertilizer through larger crop response or NUE.

5.5 Economically Optimal Rate

The EOR decreased from 82 to 49kg/ha of N as CP increased from 2 to 10 in Wushishi. In the same way, EOR decreased from 61 to 32kg/ha of N as CP increased from 2 to 10 in Kadawa. These demonstrate the variability of fertilizer application rate and profitability with CP. The mean loss in returns to N in Wushishi would be 1.5% and 24% at CP of 2 and 10 respectively if N is applied at estimated optimal nutrient rate (114 kg/ha). Similarly in Kadawa, The mean loss in returns to N would be 6.6% and 108% at CP of 2 and 10 respectively if N is applied at estimated optimal nutrient rate (106 kg/ha). Consideration of CP when developing fertilizer recommendation gives a clearer picture of the economic penalty of applying nutrient below or above EOR.

CHAPTER SIX

6.0 SUMMARY, CONCLUSION AND RECOMMENDATION

6.1 Summary

Field experiments were conducted in 2015 at irrigation sites in Wushishi and Kadawa to quantify the yield response of lowland rice to nitrogen, phosphorus and potassium applications; to determine the economically optimal nutrient rate for N, P, K at different fertilizer cost to paddy price ratios (CP); to evaluate the components of Nitrogen Use Efficiency (NUE). Treatments consisted of five rates of N (0, 40, 80, 120, 160 kg ha^{-1}), four rates of P (0, 7.5, 15, 22.5 kg ha^{-1}) and four rates of K (0, 10, 20, 30 kg ha^{-1}) laid out in an incomplete factorial arrangement in Randomized Complete Block Design in three replicates.

There was significant increase in paddy yield with nitrogen application in both locations. Application of 80 kg/ha of N significantly increased yield by 3 tons/ha in Wushishi. Yield of up to 3.55 tons/ha was produced in Kadawa with the application of 40 kg/ha of N. Average across treatment levels, Wushishi recorded more paddy yield than Kadawa. Estimated optimum nitrogen rates from asymptotic non-linear regression model were 114kg/ha and 106kg/ha for Wushishi and Kadawa respectively. As the fertilizer cost to paddy price ratio (CP) increased, the range of profitability and Economically Optimal Rate (EOR) decreased. In Kadawa, EOR ranged from 61 to 32 kg ha^{-1} of N at CP of 2 to 10. Values for EOR were between 82 and 49 kg/ha for CP of 2 to 10. Agronomic Efficiency (AE) and Partial Factor Productivity (PFP) decreased with increasing N rate in both locations. In Wushishi, AE and PFP at CP of 2 were 32.6 kg/kg and 95.6 kg/kg respectively. Similarly, AE and PFP at CP of 2 in Kadawa were 15.1 kg/kg and 59.6 kg/kg respectively. Nitrogen fertilization was observed to be more profitable in Wushishi due to greater crop response.

No significant yield increase to applied P and K was observed in this study which suggested that indigenous P and K were adequate to support optimum crop yield.

6.2 Conclusion

From the findings in this study, it can be concluded that:

1. Maximum paddy yield of 8.05 tons/ha was attained with the application of 80 kg/ha of Nitrogen in Wushishi. Application of 40 kg/ha of N produced maximum paddy yield of 3.55 tons/ha in Kadawa. Estimated optimum nitrogen rates from asymptotic non-linear regression model were 114kg/ha and 106kg/ha for Wushishi and Kadawa respectively. There were no significant response to potassium and phosphorus application by rice paddy yield in both locations
2. The economically optimum nitrogen rates in Wushishi ranged from 82kg/ha to 49 kg/ha for CP of 2 to 10. In Kadawa, economically optimum nitrogen rates were between 61 kg/ha and 32 kg/ha for CP of 2 to 10
3. Partial Factor Productivity (PFP) at CP of 2 was 59.6 kg/kg in Kadawa and 95.6 kg/kg in Wushishi. Agronomic Efficiency (AE) at CP of 2 was 32.6 kg/kg in Wushishi and 15.1 kg/kg in Kadawa.

6.3 Recommendations

Base on the findings from this study, the following are recommended

I. The major limiting nutrient for lowland rice production is nitrogen and high organic matter content or total nitrogen may not always serve as indicator for nitrogen sufficiency. Therefore, Nitrogen application should always be given priority above other nutrients. The use of Leaf Colour Chart (LCC) may serve as an important tool for predicting in-season crop nitrogen requirement

II. Withdrawal of irrigation water during grain filling, under adequate nitrogen fertilization, can lead to significant increase in yield and water use efficiency.

III. The use of regression models can serve as accurate means of relating variation in CP with EONR. This is important in fine-tuning fertilizer recommendation.

IV. Application of fertilizer at EONR is an important strategy for increasing NUE.

V. Crop management practices that increase NUE together with economic policies that reduce the cost of fertilizer and raise the selling price of grains could significantly increase profitability of fertilizer use.

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APPENDICES

Appendix 1.Ratings for soil data interpretation

Soil pH

Extreme acid	<4.5
Very strongly acid	4.5-5.0
Strongly acidic	5.1-5.5
Moderately acidic	5.6-6.0
Slightly acidic	6.1-6.5
Neutral	6.6-7.3
Slightly alkaline	7.4-7.8
Moderately alkaline	7.9-8.4
Strongly alkaline	8.5-9.0
Very strongly alkaline	>9.0

Organic Carbon (%)

Low	<1.5
Medium	1.5-2.0
High	>2.0

Total Nitrogen (g kg^{-1})

Low	<1.5			
Medium	1.5-2.0			
High	>2.0			
Bray 1 Available Phosphorus (mg kg^{-1})				
Low	<10			
Medium	10-20			
High	>20			
Exchangeable cations (cmol kg^{-1})	**Ca**	**Mg**	**K**	**Na**
Low	0-2	0-0.3	0-0.15	0-0.1
Medium	2-5	0.3-1.0	0.15-0.3	0.1-0.3
High	>5	>10	>0.3	>0.3
Cation Exchange Capacity (cmol kg^{-1})	**NH$_4$OAc**	**ECEC**		
Low	<50	<70		
Medium	50-80	70-90		
High	>80	>90		

Source: FMANR, 1990

Appendix 2. Indices of nutrient use efficiency, their calculation using the difference method, and their interpretation

Index	Calculation	Interpretation	Nitrogen in cereal
RE = Apparent crop recovery efficiency of applied nutrient (kg increase in N uptake per kg N applied	RE= $(U-U_o)/F$	RE depends on the congruence between plant demand and nutrient release from fertilizer. RE is affected by the application method (amount, timing, placement, N form) and the factors that determine the size of the crop nutrient sink, genotype, climate, plant density, abiotic and biotic stresses	0.3-0.5kg/kg: 0.5-0.8 kg/kg in well managed systems, at low levels of N use, or at low N supply
PE = Physiological efficiency of applied N (kg yield increase per kg increase in N uptake from fertilizer)	PE=(Y–Yo)/(U– Uo)	Ability of a plant to transform nutrients acquired from fertilizer into economic yield (Paddy). • Depends on genotype, environment and management. • Low PE suggests sub optimal growth (nutrient deficiencies, drought stress, heat stress, mineral toxicities, pests).	40–60 kg/kg; >50 kg/kg in well managed systems, at low levels of N use, or at low soil N supply
IE = Internal utilization efficiency of a nutrient (kg yield per kg nutrient Uptake	IE= Y/U	Ability of a plant to transform nutrients acquired from all sources (soil, fertilizer) into economic yield (Paddy). • Depends on genotype, environment and management. • A very high IE suggests deficiency of that nutrient. • Low IE suggests poor internal nutrient conversion due to other stresses (nutrient Deficiencies, drought stress,stress, mineral toxicities,pests).	30–90 kg/kg; 55-65 kg/kg is the optimal range for balanced nutrition at high yield levels

Indices of nutrient use efficiency, their calculation using the difference method, and their interpretation (continued)

Index	Calculation	Interpretation	Nitrogen in cereal
AE= Agronomic efficiency of applied nutrient (kg yield increase per kg nutrient applied)	AE= $(Y-Y_o)$	Product of nutrient recovery from mineral or organic fertilizer and the efficiency with which the plant uses each additional unit of nutrient.	10-30 kg/kg; >25 kg/kg in well managed systems, at low level of N use, or at low soil N supply
PFP= Partial Factor Productivity of Applied nutrient	PFP=Y/F or PFP=(Y_o/F)+AE	Most important for farmers because it integrates the use efficiency of both indigenous and applied nutrients. High indigenous soil nutrient supply and high AE and equally important for PFP.	40-80 kg/kg; >60 kg/kg in well-managed systems, al low levels of N use, or at low soil N supply

F = amount of (fertilizer) nutrient applied (kg/ha)
Y= crop yield with applied nutrients (kg/ha)
Y_o= crop yield (kg/ha) in a control treatment with no fertilizer
U= total plant nutrient uptake in aboveground biomass at maturity (kg/ha) in a plot that received fertilizer
U_o= total nutrient uptake in aboveground biomass at maturity (kg gain in a pot that received no fertilizer
Adapted from Dobermann (2009)