NITROGEN MANAGEMENT OPTIONS FOR IRRIGATED AND RAIN-FED RICE (*Oryza sativa L.*) VARIETIES IN SUDAN SAVANNA OF NIGERIA

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BY

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A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES AHMADU BELLO UNIVERSITY, ZARIA, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF DOCTOR OF PHILOSOPHY IN SOIL SCIENCE

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JUNE, 2017

DECLARATION

I hereby declare that the work in this thesis titled "Nitrogen Management Options for Irrigated and Rain-fed Rice (*Oryza sativa L.*) Varieties in sudan savanna of Nigeria" was performed by me in the Department of Soil Science, under the supervision of Prof. B.D. Tarfa, Prof. I.Y. Amapu and Prof. E.O. Uyovbisere. The information derived from literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another Degree or Diploma at this or any other higher institution.

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The above declaration is confirmed by me

_____
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CERTIFICATION

This thesis entitled "Nitrogen Management Options for Irrigated and Rain-fed Rice (*Oryza sativa L.*) Varieties in sudan savanna of Nigeria" by Mustapha YAHQUB meets the regulations governing the award of the degree of Doctor of Philosophy of Soil Science in the Department of Soil Science, Faculty of Agriculture, Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This work is dedicated to my mother Hadjia Halimat Awele Yahqub, my heartthrob Nafisat (Temi), Y'aqub (Baba), Khaleel-Rahman , Abdul Shakur and Haw'au (Ummi) for their patience and understanding throughout the course of this study.

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ABSTRACT

Rice is one of the main staple food crops and its demand is rapidly increasing in West Africa, hence there is need to increase its production at lower production costs through adequate N management with appropriate varieties.Nitrogen (N) management is one of the key inputs in rice production, especially in the savanna soils which is usually associated with widespread N deficiency. The focus of this research was to evaluate the performance of rice under different N fertilizer management options. Field experiments were conducted in 2012 and 2013 at the research farm of the Institute for Agricultural Research, Talata Mafara (irrigated) and Kadawa (rain-fed). The treatment combinations included two granular forms of N as Urea Super Granule (USG) and Granular Urea (GU) at different rates [0, 45.1, 72.2, 117.3 kg N/ha and a rate based on leaf colour chart (LCC)] with three varieties of rice (FARO 55, FARO 57 and FARO 52) as the test crops. The experimental design was Randomized Complete Block Design (RCBD) and replicated thrice. The second phase of the study involved the use of Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) model to simulate rice performance as a decision support tool for site-specific fertilizer recommendation in the study areas. Crop growth attributes generally increased with increased N application for both USG and GU, but with delay in days to heading. Application of USG at 117.3 kg N/ha significantly ($p<0.01$) increased yield and yield attributes, except for grain-, phosphorus- and potassium- harvest indices where application of GU based on LCC gave the highest values. Interaction between N management and varieties indicated that application of USG at 117.3 kg N/ha on FARO 52 resulted in significant rice yield increase.Paddy yield was highly and positively correlated with total biomass (r= 0.883**), straw yield (0.733**), dry matter (0.351**), plant height (0.158**) and N uptake (0.701**); but weak and non-significant negative relationship existed between soil pH (- 0.021) and available P (- 0.055). The indigenous soil nutrients supplies (INS, IPS and IKS) were 25.26 – 94.50 kg N ha^{-1}, 5.78 – 28.84 kg P ha^{-1} and 47.48 – 156.30 kg K $ha^{-1}$with fertilizer recovery fractions of 0.25 – 0.61, 0.09 – 0.48 and 0.27 – 0.69 for N, P and K respectively at both locations. The recommended fertilizer dosage modeled by QUEFTS were 104 – 140 kg N ha^{-1}, 69 – 94 kg P ha^{-1} and 23 – 46 kg K $ha^{-1}$for dry season (Talata Mafara) and 92 – 130 kg N ha^{-1}, 34 – 56 kg P ha^{-1} and 10 – 19 kg K ha^{-1} for wet season (Kadawa). It was higher than the conventional 'blanket fertilizer' rate recommended over the years. The model also recommends higher N with lower K for FARO 55, but lower K for FARO 57 and FARO 52; thereby advocating for site specific nutrient management (SSNM) through the use of different fertilizer combinations for different soil conditions. Field validation of the QUEFTS model showed a good agreement between observed and simulated yields (R^2 = 0.85, RSME = 0.93, RSMEn =< 30% and d-stat = 0.71), thus confirming better performance of QUEFTS in the rice ecosystem under different nitrogen regimes. Partial economic analysis of rice production at both locations revealed that application of USG at 117.3 kg N/ha with FARO 52 gave the highest gross margin of ₦237,907.22k/ha and a profit of ₦2.81k per naira invested. Results obtained from this study revealed that FARO 52 using USG had better paddy yields and highest NUE.Further studies are also required to establish the appropriate use of leaf colour chart in the study areas.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Rice (*Oryza sativa L.)* is the main food crop of an estimated 40% of the world's population (Liu, 2013; FAO, 2008). The World's more than three billion people depend on rice as their staple food and the demand for rice is rapidly increasing in West Africa (FAO, 2003). Manypeople in the major rice consuming countries are living at sub‑optimal nutritional levels, there is need to increase rice productionby as much as 70% in order to raise nutritional levels to satisfy current dietary needs (Greenland, 1997).Annually, about 5 million metric tons of rice is consumed in Nigeria and over 80% is imported costing the country a humongous amount of money (Onu *et al.,* 2015).Local productionis low and efforts to increase production are hindered by high input costs, low prices for riceespecially under rain-fed conditions.

Fertilizer nitrogen (N) has become one of the key inputs in food production and despite numerous research investigations; our understanding of N management for rice grown under diverse agro-ecological situations is still inadequate. Cereals including rice, wheat and maize, accounts for more than half of the total fertilizer N used in the world. Research has also shown that about 50 – 70 % more cereal grain will be required by 2050 to feed over 9 billion world population (Yadvinde-Singh *et al.,* 2011) and this will further increase demand for fertilizer N at greater magnitude

unless fertilizer recovery efficiency in cereals is improved.In addition, rice production in the Nigerian savanna showed that the soils are generally low in organic carbon with widespread deficiency in nitrogen (Olaleye *et al*., 2008).

1. 2 Statement of Research Problem

Traditionally, farmers apply fertilizer N in several split applications, but the number of splits, amount of N applied per split, and the time of applications vary substantially.The nature and magnitude of N loss largely depends on the sources and methods of N fertilizer application. The conventional granular urea (GU) is a fast releasing nitrogen fertilizer which is usually broadcasted in splits thatcould cause considerable loss through ammonia volatilization, immobilization, de-nitrification and surface run off.Fertilizer N loss as ammonia volatilization from the flooded rice field could be as high as 40 – 60 % (Jena *et al.,* 2003).Another major constraint to rice production in dryland savanna is lack of adoption of appropriate improved varieties where the commonly grown varieties are late-maturing and usually susceptible to pests and diseases.

1.3 Justification of the study

The deep placement of slow releasing nitrogenous fertilizer such as urea super granule (USG) reduces the N loss as well as increases N use efficiency in wetland rice (Crasswell *et al.,* 1985). Therefore, to minimize the losses of nitrogen, slow release of nitrogenous fertilizer such as urea super granules (USG)has been advocated with deep placement (Jaiswal and Singh, 2001; IFDC, 2007).The

apparent flexibility of rice farmers in adjusting the time and amount of fertilizer application offers potential to synchronize N application with the real-time demand of the rice crop. This therefore necessitates the use of leaf colour chart (LCC) for guiding real-time N top dressings in rice as an efficient N management (Furuya, 1987). However, critical LCC values vary considerably among different rice genotypes having different genetic background, plant type and leaf colour (Balasubramanian *et al*., 2003) and this critical colour shade on the LCC needs to be determined to guide N application (Bijay *et al*., 2002).

Theuse of N efficient genotypes in conjunction with use of chemical fertilizers is an important complementary strategy in improving rice yield and reducing cost of production. It therefore, becomes imperative to investigate the response of newly developed improved rice varieties commonly grown in the northern savanna, to different forms of urea fertilizer and modes of its application under irrigated and rain-fed conditions.

Decision support tools (DSTs) are simulation models used to explicitly describe the relationships between the various components of complex systems (Jones *et al*., 2003; Keating *etal*., 2003). Modeling increases insight into relevant processes, allows study of the effects of crop management, and exploration of possible consequences of management modifications. In this study therefore, a decision support systems, Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS), was used to generate site-tailored recommendation for nitrogen management.

1.4 Objectives of the Study

The objectives of the research are:

i. To determine rice varietal response to the application of two N sources under irrigated and rain-fed conditions in the study areas.

ii. To evaluate specific differences in nutrients (N, P and K) uptake and N- use efficiencies of the rice varieties under investigation.

iii. To assess the economic benefit of N-management options under irrigated and rain-fed rice production in the study areas.

iv. To estimate the indigenous nutrients (N, P and K) supplies in the study areas.

v. To develop alternative fertilizer recommendation (AFR) for rice varieties evaluated in the study areas.

CHAPTER TWO

2.0 REVIEW OF RELATED LITERATURES

2.1 Agronomic Practices of Rice

2.1.1 Origin, botany and life cycle of rice

Rice (*Oryza sativa L.*) was domesticated in Africa (*Oryza glaberrima*) and Asia (*Oryza sativa*). Although several centres of origin have been proposed including India and northern Thailand, evidence points to the Yangzi Valley in southern China as one site of origin for domesticated rice (BCI, 2002). Rice is the most widely grown and widely consumed cereal in the world and its production on world basis is second to that of wheat (Agbato, 2003).

Rice is a grass (*Gramineae*) and belongs to the genus *Oryza* (meaning oriental). *Oryza sativa i*s grown in a wide range of environments from the equatorial tropics to sub-tropical mid-latitudes; and from lowland paddy fields to swamps and to upland rice fields (BCI, 2002). Rice has a fibrous root system that does not penetrate deep into the soil while the shoot consists of a main stem and several tillers. The stem is cylindrical smooth, 35 – 150 cm long with solid nodes and hollow inter nodes; and the node are slightly fatter than the inter nodes. The leaf consists of a leaf sheath and a long narrow blade which is arranged alternately with a single leaf at each node.

The inflorescence is a panicle and borne at the tip of the main stem. Each tiller on the stem consists of about 50 – 500 spikelet and each spikelet contain a single hermaphrodite flower borne on a sheet pedicel; this therefore ensure self-fertilization.

The growing season of most traditional varieties takes longer times (about 260 days) while majority of modern varieties matures between 90 to 110 days (BCI, 2002). Shortening the growing season resulted in increasing cropping intensity (number of crops/ha/yr.).

2.1.2 Planting density and canopy management

This depends on the crop establishment method and variety (i.e. tillering capacity). In transplanted rice, a plant spacing of 0.2 x 0.2 m gives 250, 000 hills/ha; in direct seeded paddy rice, seed rates range from 60 to 80 kg/ha. On the other hand, in upland rice, lower seed rates (30 to 35 kg/ha) is usually dibbled into evenly spaced planting points. From seeding/transplanting to early tillering, excessive early canopy development may result in a very leafy canopy that is more susceptible to pest and disease infestation (BCI, 2002). Proper splitting and timing of N fertilizer applications are required to produce an optimal canopy without incurring pest and disease damage.

2.1.3 Climatic requirements

Rice is a warm weather crop and the average temperature during the growing season varies from 20 – 30 ^{0}C. Generally,low temperature during early growth retards seedling development and long periods of sunshine are essential for high yield (Agbato, 2003). Production of paddy rice is at its maximum yields in the dry season, when cloud cover is less and photosynthetic active radiation (PAR) is greater (BCI, 2002). In irrigated rice, rainfall is not important, provided the irrigation water supply is reliable and sufficient in quantity; whereas in rain-fed and upland rice, rainfall is a major yield determinant, especially in coarse textured soils with poor water retention capacity.

2.1.4 Soil requirements

In both upland and rain-fed rice, soil structure and fertility are major yield determinants (BCI, 2002). This is because the amount of mineral fertilizer used is often small. In irrigated rice, soil structure is usually destroyed during land preparation and effect of flooding generally improves nutrient availability (BCI, 2002).Recent research showed that, the soils on which rice grows varied as the climatic regime to which the crop is exposed. The soil texture ranges from sand to clay, pH from 3 to 10; organic matter content from 1 to 50 % and nutrient availability from acute deficiencies to surplus (George and Oswald, 2004).

2.2 Nutritional Importance of Nitrogen (N) in crop plants

Nitrogen is one of the most limiting nutrients and its deficiency is the most commonly detected nutrient disorder observed in rice production (Fairhurst *et al*., 2007). Research has shown that adequate supply of N stimulate plant growth, development and uptake of other nutrient elements (Brady and Weil, 2002).Nitrogen is needed for vigorous vegetative leaf, dark green leaf colour and stem growth apart from feeding soil microorganisms as decomposed organic matter. It also forms part of enzymes, chlorophyll and growth regulators. Recent research shows that supply of adequate N promotes rapid growth especially in plant height, tiller number, size of leaves, and number of spikelet per panicle and hence may enhance grain yield (Bedmar *et al.,* 2005).

It has been observed that the old leaves and sometimes all leaves become light green and chlorotic (pale yellowish green) at the tip (Dobermann and Cassman, 1996). The N deficiency symptom is obvious especially at the critical growth stages such as tillering and

panicle initiation, when the demand for N is large (Fairhurst *et al*., 2007). Generally, rice leaves may die under severe N deficiency except for young leaves, which are greener; others are narrow, short, and erect; and lemon- yellowish(BCI, 2002). Production of proteins and other substances essential for vital metabolic activities in N deficient crop is low. Moreover, excessive N supplies produce leaves that are susceptible to pests and diseases (Fairhurst *et al*., 2007). In most ecosystems, the use of N fertilizers has been essential to keep or increase the productivity of the soil. A large increase in global food production hasbeen linked to increased fertilizer N use and better N management (Smil, 2001).

2.3 Sources of Nitrogen for Crop Nutrition

2.3.1 Organic Manure

Organic manure was the most popular and commonly source of N in the past and because of their low N content, they must be applied at high rates (several tons per hectare). The use of organic N through animal manure or crop residues can be of important particularly in developing countries, when inorganic fertilizers are not readily available or unaffordable. Farmyard manure and composts usually release their N slowly, avoiding excessive uptake and reducing potential losses by leaching and de-nitrification(George and Oswald, 2004).

2.3.2 Inorganic Fertilizers

Among the inorganic N fertilizer, anhydrous ammonia, although contain the highest concentration of N (> 80 %) but it requires specialized equipment for storage, handling and application. Ammonium nitrate (NH_4NO_3) is also another excellent N fertilizer due to its combination of two different N forms but its low N content compared to other sources makes

the transportation, storage and application more expensive per unit of N (Fuerte-Mendizal et al., 2013). Again, ammonium sulphate ($(NH_4)_2SO_4$) is a source of N and S that can be of advantageous for acid-requiring crops and in high pH soils but due to its relatively low N content (21% N) compared to other sources. Ammonium chloride (NH_4Cl) and ammonium bicarbonate (NH_4HCO_3) are also good source of N but with low N content.

Urea ($CO(NH_2)_2$) is the most widely used N source worldwide and its favourable characteristics of manufacturing, costs, handling, storage and transport make it a very competitive N source (Herrera *et al.*, 2016). Problems encountered with urea are ammonia volatilization losses (Ni *et al.,* 2015), production of biuret (phytotoxic compound); and production of free $NH_3$by urea hydrolysis which has toxic effects on germinating seedlings. Other N fertilizers are urea-ammonium nitrate solution which may salt-out during cold weather (Herrera *et al.*, 2016), sodium nitrate ($NaNO_3$), potassium nitrate (KNO_3) and calcium nitrate ($Ca(NO_3)_2$) etc.

2.3.3 Controlled and Slow N-Release Fertilizers

Controlled- release and slow N- release fertilizers are similar because of their ability to minimize N losses through volatilization and leaching. They have been identified as promising tools to mitigate the negative effects of nitrous oxide (N_2O) and methane (CH_4) emissions on global climate (Bedmar *et al.*, 2005). They also serve as sources that increase the recovery of applied N fertilizer (Shaviv, 2000) by improving the synchronization between N availability and crop demand; in addition to the release of soluble N (NH4 and/or NO_3) over several weeks or months.

Some authors (Bedmar *et al.*, 2005; Chien *et al.*, 2009) argued that controlled-release differs from slow release because they release nutrients by physical processes such as diffusion, while slow N-release are those that release nutrients by chemical or biochemical processes such as aldehyde. Shoji et al. (2001) discovered that controlled release of fertilizers and a nitrification inhibitor showed the highest potential in increasing N use efficiency and thereby reduced N-fertilization rate.

2.3.3 Urea Deep Placement

This is usually done using compacted urea super granules (USG) with 1 – 3 g granules. One or more USG are deep placed (7 – 10 cm depth) by hand at the center of every four rice seedling hills in rice soils during or after transplanting. Generally, USG is applied only one-time, whereas surface application of Granular urea (GU) requires two or three split application. It has also been confirmed by many researchers that N loss is significantly reduced under USG (IFDC, 2007; Savant and Stangel, 1998). This is because the deep placement of USG essentially cuts off NH_3 volatilization and also reduces de-nitrification N loss.

2.3.4 Microorganisms used for Crop N Nutrition

Several microorganisms are also used in agriculture. Genus *Rhizobium sp.*is currently used because of their ability to fix N_2 in symbiosis with leguminous crops. The inoculation of soybean with the optimal species/strain has a significant impact on the yield and quality (Bindraben *et al.*, 2015).

2.3.5 Natural Sources of soil Nitrogen

These are other sources of N available for crop nutrition. It includes atmospheric N deposition, N input by irrigation water and N availability from mineralization of soil organic matter (Georges and Oswald, 2004).

2.4 Nitrogen Problems in Agricultural Systems

Generally, nitrogen goes through many transformations in the soil and this is usually grouped into a system called "nitrogen cycle". The nitrogen cycle contains several routes by which plant-available nitrogen can be lost from the soil. Nitrate-nitrogen (NO_3-N) is usually more subject to loss than is ammonium-nitrogen (NH_4-N). Significant loss mechanisms include leaching, de-nitrification, volatilization, and crop removal (Bedmar *et al.,* 2005).

The N deficiency in upland rice is related to low organic matter content of rice growing soils, soil acidity, soil erosion, use of low level of N fertilizers by farmers due to high cost of these fertilizers. Nitrogen deficiency is also related to low N use efficiency by the crop due to loss by leaching, volatilization, de-nitrification and erosion (Fageria and Baligar, 2005).

With the green revolution, the use of chemical fertilizer increases several folds and the inefficient use of these fertilizers have resulted in serious environmental consequences. The most adverse environmental impacts in field crops is the depletion of stratospheric ozone due to NO and NO_2 emission. It is known that

among the global warming gasses the contribution of NO_2 is 9% and within this percentage about 88% comes from the agricultural sector (FAO, 2007).

It is a well-known fact that rice crop requires large amounts of N for its growth and grain production. The estimated amount of N removal ranges from 16 to 17 kg for the production of one ton of rough rice, including straw (Ponnamperuma and Deturck, 1993; Sahrawat, 2000; Dobermann *et al*., 2002).

2.5 Nitrogen use efficiency

Nitrogen use efficiency (NUE) is defined as the production of grain per unit of N absorbed from the soil. It is usually calculated by taking the difference in the N uptake by the above ground parts of fertilized plants with that of the unfertilized plants (Fageria *et al.,* 2010). NUE is commonly studied in terms of the amount of fertilizer N applied and hence referred to as fertilizer N use efficiency which is the percentage recovery of fertilizer N by a crop (Maria, 2002).

2.5.1 Improving the Efficiency of Nitrogen Fertilizers

Nitrogen use efficiency is usually low and N recovery may even lower under certain management conditions (Dobermann *et al.,* 2004). Loss of N to the environmentusually takes place when high concentrations of soluble N forms are present in the soil solution in excess compared to the amount that plants can take up (Fageria and Baligar, 2005).

These problems can be largely overcome with good management practices such as applying rate of fertilizer commeasurable with the crop needs, placing the fertilizer where the plants can easily reach the nutrients, and choosing the right application time. Upland rice genotypes differ significantly in N uptake and utilization efficiency (Fageria, 2007) and it is known that the response of crops to nitrogen varies due to genetic makeup of crops.

2.6 Effects of Nitrogen Fertilizers on Growth and Yield Components of Rice

Nitrogen has been found to have tremendous effect on the vegetative growth of cereal crops in general and rice plant in particular. Anon (2001) indicates that elongation ability in rice depends on cultivar and nutrient availability and those modern cultivars need higher fertilizer rate than traditional cultivars and are more responsive to nitrogen fertilizer. The work of Reddy *et al.*(2007) and Lee and Bee (2007) showed that height of rice plant generally increases with increase in nitrogen rate. In another report, rice cultivars OS6, IR20 and BIKOM were given top dressing of 37.8 kgN/ha at 15 days after emergence, early tillering, late tillering, booting or early heading were found with no significant effect on plant height (Onochie, 2004). However, Tanaka *et al.* (2004), Gaballah (2000), Singh (2001) and Attia *et al.* (2009) reported that nitrogen was found to have significant effect on rice plant height. Abubakar (2010) observed an increase in plant height with the application of nitrogen up to the rate of 150 kg/ha.

Favourable effects of nitrogen fertilizer on tillering of rice plants were reported by many workers (Attia *et al.*, 2009 and Reddy *et al.*, 2007). The total leaf area of rice population is a

factor closely related to grain production, because the total leaf area at flowering greatly influences the amount of photosynthetic N content available to the panicle. Generally, the Leaf Area Index of most rice cultivars was increased with increase in nitrogen level (Chang, 2008). Attia *et al.* (2009) also found that rice cultivars Gura 171 responded to 25.2 kg N/ha and accumulated more dry matter, whereas cultivars IR579 responded only to 12.6 kg N/ha. Abubakar (2010) and Adamu (2011) reported that dry matter accumulation showed positive correlation and linearly increased by the application of nitrogen fertilizer. Chang *et al.*(2005) indicated that although yield increased with increasing nitrogen rate, the effect of nitrogen fertilizer on 1000- grain weight was negative. Adamu (2011) reported that the effect of nitrogenous fertilizer on 1000 - grain weight was negative and that application of 120 kg N/ha gave significantly lower 1000-grain weight than application on 60 kg N/ha.

Rice yield was reported to increase with increase in nitrogen rate up to 120 kg N/ha (Lakhdiva and Prasad, 2000). Further increase of up to 200 kg N/ha was found to increase yield (Anon, 2001; Mijindadi, 2003). However, applying nitrogen of up to 125 kg N/ha produced no significant yield increase in rice cultivars. Paddy yield of early maturing cultivars Ratna was found to increase from 7.3 – 9.2 t/ha in response to increasing nitrogen rates from 50 – 200 kg N/ha (Rao, 2008). In Nigeria, Fagade and Ojo (2006) showed that the optimum nitrogenresponse for the lodging variety is 75 kg N/ha, while improved varieties can respond to 120 kg N/ha in sandy Badeggi soils.

2.7 Response of Rice to Urea Super Granules (USG)

Savant and Stangel (1998) have shown that N loss is significantly reduced under USG as compared with split-applied Granular urea, which results in a significant

increase in rice grain yield under flooded conditions Deep placement of USG essentially cuts off NH_3 volatilization and also significantly reduces de-nitrification N loss compared to surface application of GU.

It has been noted that broadcast application of urea on the surface soil causes loss of up to 50% N Crasswell and De Datta (1980) while point placement of USG in 10 cm depth can save 30% nitrogen as Granular urea, increase absorption rate, improve soil health and ultimately increase rice yield (Savant andStangel,1990).

2.8 Effects of Deep Placement of Nitrogen Fertilizers on Soil

Deep placement of N fertilizers into the anaerobic soil zone is an effective method to reduce volatilization loss. Field experimental results using the ^{15}N as tracer at IRRI demonstrated that N use efficiency was higher when fertilizer was placed at 10 cm soil depth. Urea can be placed deep into the reduced soil layer at 8 – 10 cm soil depth by an instrument called "pneumatic urea injector" developed in the Netherlands. Field experimental result conducted at Bangladesh Rice Research Institute (BRRI) showed the superiority of this method of urea application over the conventional split broadcast method.

Different sources and forms of N fertilizer are now available in the market for commercial use. The most commonly used N fertilizer of rice crop is Granular urea (GU). Mean diameter of GU is 1.5 mm. Urea Super Granule (USG) is a modified form of urea having an average diameter of 11.5 mm. It has been developed at the International Fertilizer Development Centre, United States. Increased agronomic efficiency of urea-N due to reduce ammonia

volatilization loss in flooded rice soils was noted by Abdel-Bary and Metwally(2001). Freney(1997) found that application of an algae inhibitor (Copper sulfate + terbutryn) decreased ammonia volatilization loss resulting an increase in rice yield by 0.3 – 0.6 t/ha. Experimental results at the International Rice Institute (IRRI) revealed that addition of the urease inhibitor along with urea reduced the ammonia loss by 12 – 22 kg N/ha (De Datta, 1987).

2.9 Effects of Nitrogen Fertilization on Rice Cultivars

In sustainable agricultural practices, nutrient management practices include both crop and soil fertilization. Crop fertilization refers to fertilizer application according to the crop demands, while soil fertilization is targeted to replenish its fertility level. The strategy of efficient fertilizer management programme involves precise decision on the right rate, source, time and place of fertilizer application (Bruulsema *et al*., 2009). The amount of fertilizers to be applied for a target yield may be determined by soil testing, nutrient response or missing element trial techniques. As noted by Oikeh *et al*. (2009), nutrient deficiency in rice is a major constraint to rice production in West Africa.

Several factors can cause the differences in N acquisition among rice genotypes (Ladha *et al.,* 1998). Genotypic differences exist in N uptake from various soil depths (Kundu and Ladha, 1995). Rice genotypes differ in their ability to stimulate plant associative N_2 fixation (Ladha *et al.,* 1998). Rice genotypes have different rhizosphere effects on the extent and pattern of soil N mineralization (Kundu and

Ladha, 1997). These differences could be related to differences in rooting characteristics such as root surface area, root mass, root depth, root number and root length density (Kirk and Bouldin, 1991).

In rice, genotypic variation in NUE has been reported by many researchers. Broadbent *et al.* (1987) studied NUE of 24 genotypes with and without fertilizer-N application. They estimated NUE using the ratio of panicle weight to total N uptake (WP/TN) and reported that there were significant differences in WP/TN among the genotypes. WP/TN was well correlated with other NUE-related parameters and provided genotypic rankings that did not differ greatly from multiple-parameter rankings.

Further increase in rice production is achieved with less N fertilizer by improving N use efficiency (NUE) through better N fertilizer management and new rice varieties. Research on improving NUE of the rice crop has been focused on the development of fertilizer management strategies in the past three decades and great progress has been achieved to reduce N losses by new application methods and modified N sources. Another important research area is optimizing the timing and rate of N application for better synchronization between the supply and demand of N by the crop (Cassman *et al.*, 1998). Some efforts have been devoted to germplasm improvement in NUE, but the impact has not been as great as for the first two approaches.

2.10 Real Time N-management of Rice using Leaf Colour Chart (LCC)

Farmers generally apply fertilizer N in several split applications, but the number of splits, amount of N applied per split, and the time of applications vary substantially. The apparent flexibility of rice farmers in adjusting the time and amount of fertilizer application offers potential to synchronize N application with the real-time demand of the rice crop (Dobermann *et al.,* 2004). Monitoring of plant N status is important in improving the balance between crop N demand and N supply from soil and applied fertilizer (Cassman *et al.,* 1998). The direct measure of leaf N concentration by laboratory procedures is time consuming and costly. Such procedures have limited use as a diagnostic tool for optimizing N topdressing because of the extensive time delay between sampling and obtaining results.

It is an inexpensive, simple, easy to use tool for measuring the leaf greenness, developed from a Japanese prototype and was devised by "Fuji Film Co" especially for rice leaf colour (Furuya, 1987). Leaf colour chart measures the green colour intensity of rice leaves. Leaf greenness was calibrated very precisely to the leaf nitrogen content and the first leaf colour chart was developed in Japan. Chinese researchers at Zheijang Agricultural University developed a much improved LCC and calibrated it for indica, japonica and hybrid rice.

Leaf colour charts (LCC) offer substantial opportunities for farmers to estimate plant nitrogen (N) demand in real time for efficient fertilizer use and high rice yields. It has been calibrated with the chlorophyll meter and is used to guide nitrogen top dressing for rice.The LCC is used to rapidly assess leaf N status and

thereby guide the application of fertilizer N to maintain an optimal leaf N content, which can be vital for achieving high rice yield with effective N management.

The real-time option is generally preferred when farmers lack sufficient understanding of the critical stages for optimal timing of fertilizer N. Since farmers generally prefer to keep leaves of the crop dark green and this usually leads to over application of fertilizers N resulting in low recovery efficiency. Thus, the spectral property of leaves has been advocated as a more rational manner to guide need based fertilizer N applications (Jund and Turner, 1990; Peng *et al*., 1993).

2.10.1 The Use of Leaf Colour Chart (LCC) on the Field

The leaf colour chart (LCC) is used to assess the canopy green as well as green colour of a single leaf. The colour of a single leaf is measured by holding the LCC vertically and placing the middle part of the leaf 1cm in front of a colour strip for comparison. Tanno *et al*. (1982) reported that the reading by colour scale of canopy green was more closely correlated with average chlorophyll content of the three (3) top most leaves than reading on a single leaf. The leaf should not be detached and should be shielded with the body as the LCC reading is affected by sun's angle and light intensity. As nitrogen supply matches with crop demand, there is considerable yield increase under LCC nitrogen management and because of the optimum nitrogen supply (Alam *et al.*, 2006).

2.11 Decision Support Tools (DSTs) for Agricultural Sustainability

The complex nature of relationships between components present in agricultural systems suggests the use of simulation techniques to study those systems rather than

directly experimenting continuously on the systems themselves. Simulation models can assist with assessing alternatives and making decisions that would consume the entire career of an agronomist (StruifBontkes and Wopereis, 2003). The tools are meant to help improve the lives of the smallholder farmer and his/her family in sub-Saharan Africa (StruifBontkes and Wopereis, 2003). Once a model has been parameterized and validated, it can be used in support of analysis, interpretation of field experiments and for extrapolation of experimental results over a wider range of management practices and weather conditions (Bouman *et al*., 1996).

2.11.1 Features and Application of some Decision Support Tools

2.11.1.1 Decision Support System for Agro-technology Transfer (DSSAT)

DSSAT means Decision Support Systems for Agro technology Transfer. It is a MS-DOS-based software package integrating the effects of soil, crop phenotype, weather, and management options. DSSAT simulate probable outcomes of crop management strategies and allow user to compare simulated outcomes with observed results. It also serves as a business tool to enhance profitability and improve input marketing (Jones *et al.,* 2003). It is a research tool for deriving recommendations concerning crop management and also to investigate environmental and sustainability issues (StruifBontkes and Wopereis, 2003).

2.11.1.2 Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS)

QUEFTS is a system for Quantitative Evaluation of the Fertility of Tropical Soils. It is a static model that runs under MS-DOS. It is a simple tool to analyze the effectiveness of the N, P, and K ratios used when applying mineral fertilizers; it requires limited number of soil fertility parameters (Janssen *et al.,* 1990). In the system, chemical soil fertility is conceived as the capacity of a soil to provide plants with nutrients and the pivot of QUEFTS is formed by the relations between nutrient uptake and yield. QUEFTS can be employed to develop fertilizer recommendations for the various combinations, including the capacity of a farmer to purchase fertilizer (Haefele *et al.,* 2003a).

In addition, the tool allows conducting a simple economic analysis about the profitability of the use of fertilizer and to determine the optimal ratio between N, P, and K fertilizer.QUEFTS model is used to test possible interactions among N, P and K and determine their effect on internal efficiency. Witt *et al.* (1999) also confirmed the application of QUEFTS in studying the relationship between grain yield and nutrient supply. It also takes into account limitations in supply, acquisition and utilization of N, P and K.

2.11.1.3 Nutrient Management Support Systems (NuMaSS)

NuMaSS is an acronym for Nutrient Management Support Systems. It is compatible software that helps in soil acidity, nitrogen (N), and phosphorus (P) management decisions for crops in tropical regions of Africa, Asia, and Latin America. It

operates on three software modules- Diagnosis, Prediction, and Economics. It requires more data than QUEFTS due to its ability to include an extensive database, such as pictures of crops suffering from nutritional disorders, nutrient contents of crops and soil data.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Sites and Locations

The trials were conducted during the 2012 and 2013 cropping seasons (irrigated and rain-fed). The two dry season experiment were conducted at the Irrigation Research Stations, Institute for Agricultural Research (IAR) – TalataMafara (12.6219^{O} – 12.6223^{O}N, 006.0252^{O} – 006.0255^{O}E and 305 m above sea level), while the two wet season trials were conducted at the Institute for Agricultural Research (IAR) farm, Kadawa (11.6437^{O} – 11.6439^{O}N, 008.4335^{O} – 008.4336^{O}E and 488 m above sea level) respectively. The two Irrigation Research Stations were located in the sudansavannah ecological zone of Nigeria. Talata Mafara station is under Sokoto Rima River Basin Development Authority, while Kadawa station is under Hadeija-Jama're River Basin Development Authority. These areas usually received about 660 mm rainfall annually between May and September, the rest of the period being dry. Monthly mean maximum air temperature during the dry period varies between 26 and 36°C, while the monthly minimum is between 12 and 19°C.

3.2 Meteorological Data

Detailed weather data on rainfall and air temperature (maximum and minimum) were obtained on the experimental sites using rain-gauge and thermometer. Other meteorological data such as relative humidity, solar radiation, wind speed, wind

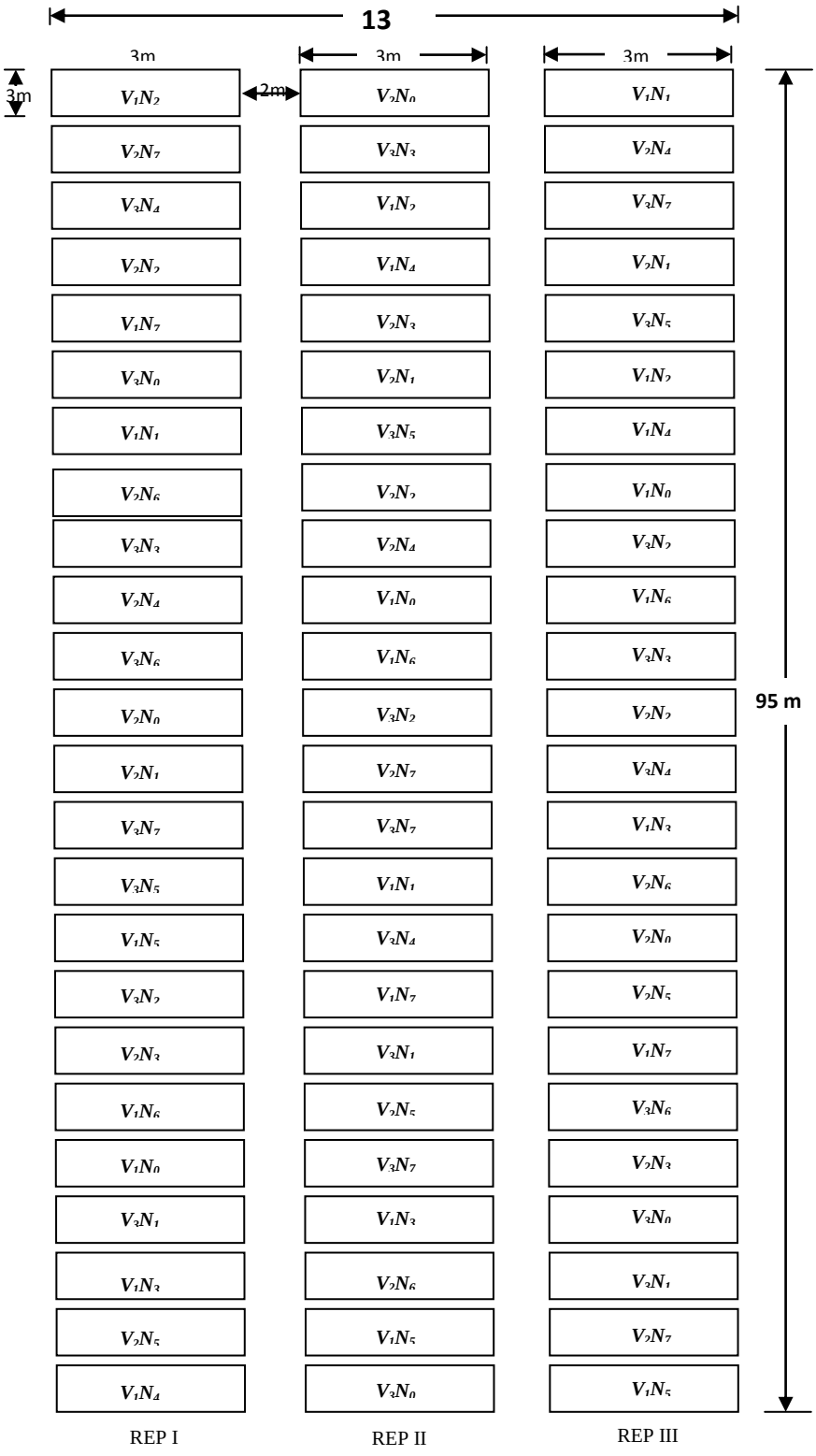
direction and near soil temperature were obtained from weather station located close to the experimental sites.

3.3 Treatment Combinations and Experimental Design

The treatments consisted of four factors. Factor one was the rice varieties (V_1 = FARO 55 (NERICA 1), V_2= FARO 57 (TOX 4004)and V_3= FARO 52 (WITA 4), while factor two consisted of USG at 45.08 kgNha^{-1} (N_1), 72.22 kgNha^{-1} (N_2); and 117.30 kgNha^{-1} (N_3); and GU at 45.08 kgNha^{-1} (N_4), 72.22 kg N ha^{-1} (N_5) and 117.30 kgNha^{-1} (N_6); The Granular Urea (GU) were applied in two equal halves (at 2 weeks after transplanting and at panicle initiation); and N management based on Leaf Colour Chart (LCC) at critical level (N_7). The LCC reading is taken randomly on ten rice stands selected per plot, once per week. If the average value obtained is below or at the critical value of 3, 35 kg N/ha is applied immediately. A control, unfertilized plot (N_0) was also included. The experiments were laid down as a randomized complete block design (RCBD) in a factorial arrangement and replicated three times. Each block consisted of 24 treatment combinations (plots) as shown in Figure 3.1.

3.3.1 Nutrient Omission Trials (“NOT”)

The indigenous nutrient supply (INS) of N, P, and K was determined by setting up a nutrient omission trials (NOT) besides the experimental site. The indigenous N supply was measured as plant N uptake at harvest in a small 0-N plot (3 x 3 m) located beside the trial, where P, and K are supplied in sufficient amounts so that



Legend:

V1	FARO 55
V2	FARO 57
V3	FARO 52
N0	0 kg Nha^{-1}
N1	USG at 45.08 $kgNha^{-1}$
N2	USG at 72.22 $kgNha^{-1}$
N3	USG at 117.30 $kgNha^{-1}$
N4	GU at 45.08 $kgNha^{-1}$
N5	GU at 72.22 $kgNha^{-1}$
N6	GU at 117.30 $kgNha^{-1}$
N7	GU based on LCC

Figure 3.1: Field Experimental Layout

plant growth is limited only by the indigenous N supply (i.e. plot that receives fertilizer P and K, but no fertilizer N). The same trial was set up for P and K-limited yield. The "NOT" was established separately for each variety as shown in Figure 3.2

3.4 Agronomic Management Practices

3.4.1 Land preparation

The land was ploughed, harrowed and leveled manually. After land preparation, the field was dyked into basins of 3 m by 3 m (9 m^2) each, as the plot size. The blocks were separated by an alley of 2 m and the plots were demarcated with high bunds of 20 cm so as to minimize lateral movement of fertilizer nitrogen from one plot to another, in-addition to conservation of water within the plot.

3.4.2 Pre-planting soil sampling

The soil samples were collected using auger at two sampling depths (0 – 15 cm and 15 – 30 cm). The samples collected were bulked to obtain a composite sample (20 cores for each of the three replicates), air-dried, crushed, screened through a 2-mm sieve and stored for soil characterization.

3.4.3 Nurseries and transplanting of seedlings

Nurseries were raised by drilling each rice variety (35 kg/ha) on a 4 m x 4 m plot.NPK 15-15-15 fertilizer (80 kg/ha) was applied to the soil immediately after planting. Each plot was watered regularly to maintain optimum moisture using

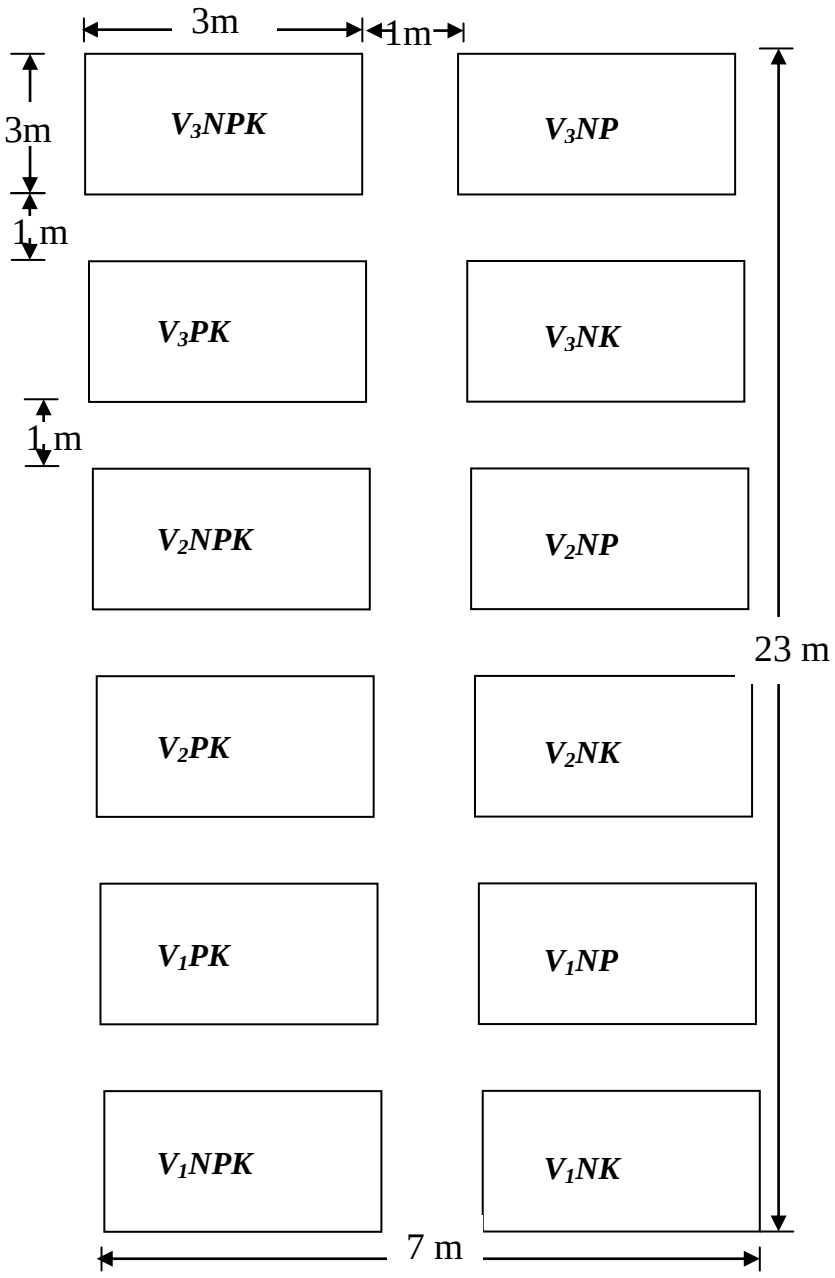


Figure 3.2: Nutrient Omission Trial plots

furrow irrigation method. Rice seedlings raised from the nurseries for three weeks were later transplanted at 2 seedlings per hill and at a spacing of 0.2 m × 0.2 m to give a total population of 500, 000 plants ha^{-1}.

3.4.4 Fertilizer application

Each plot received basal application of 50 kg P_20_5 ha^{-1} and 40 kg K_2O during land preparation. These fertilizer rates were based on the recommendations of FMARD (2012). Each capsule of USG (1.8 g, 2.7 g)and addition of (1.8 + 2.7) = 4.5 g size) was inserted between four hills of rice one week after transplanting (1WAT) as shown in Plate 3.1 – 3.3.Thegranular urea (GU) was applied in two equal halves (at 1 week after transplanting and at panicle initiation) by broadcasting.

3.4.4.1 Application of granularurea (GU) based on leaf colour chart (LCC)

The leaf colour chart (LCC) readings are taken between 8 – 10 am once in a week, starting from fourteen days after transplanting (14 DAT). Readings are taken once every seven to twenty days (7 – 20 Days) until the first flowering. The critical value is three (3) and when the critical value of the leaf falls below the threshold value, 35 kg N/ha from granular urea (GU) is applied to the crop plot immediately.

3.4.5 Irrigation

Irrigation was carried out at Talata Mafara, using furrow method at 3 days intervals and was later supplemented with rain water.

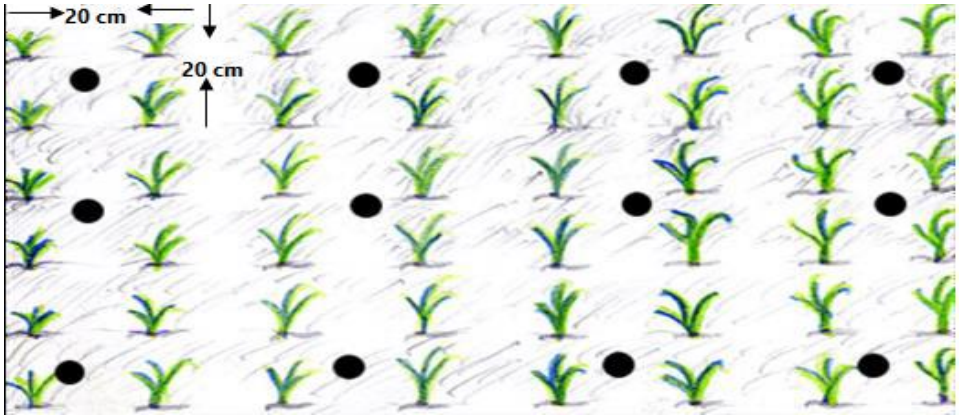


Plate3.1**:**Placement of USG within 4 hills of rice plant

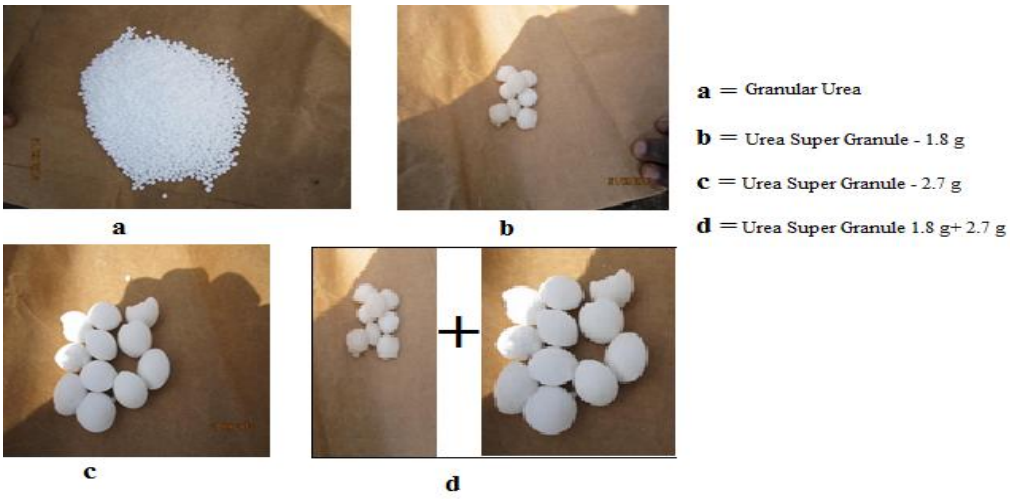


Plate 3.2**:** Photographs of forms of Urea used in the Experiment

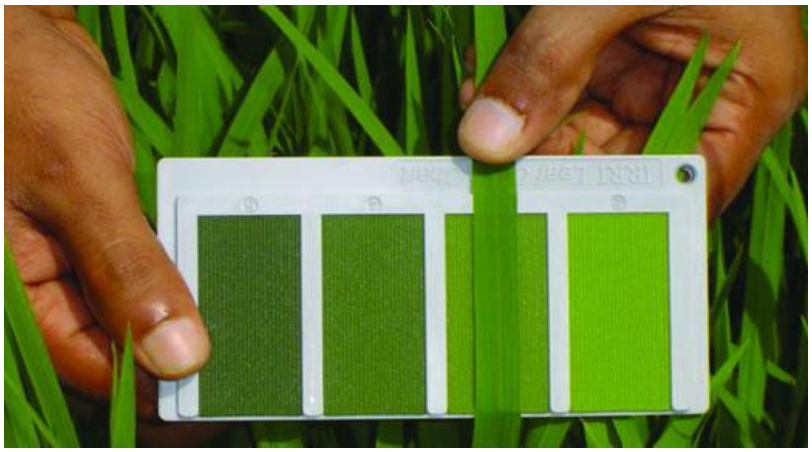


Plate 3.3**:**The LCC reading is between panels 3 and 4, which is the critical range formost transplanted rice.

3.4.6 Other cultural practices and management

Pre-emergent herbicide, Pendi-menthaline was applied at the rate of 2 – 4 l/ha and post-emergent herbicide (Rice Fox) was applied at the rate of 5 l/ha. Subsequently, weeds were controlled by hand pulling.

3.5 Crop Observation and Data Collection

Field observations were made on five (5) stands selected at random and tagged in each plot. The response of the crop to the various treatments was evaluated by measuring the following physiological characteristics and yield components:

3.5.1 Plant height (cm)

The plant height of each of the five randomly tagged stands in each plot was measured at 3, 6 and 9 WAT using a metre rule from the ground level to the tip of the topmost leaf. The average was then determined and recorded. During the reproductive stage, height was measured from the ground level to the tip of the tallest panicle.

3.5.2 Number of leaves per plant

The number of leaves per plant was obtained at 3, 6 and 9 WAT by counting number of leaves from five tillers in each tagged stand and taking their means.

3.5.3 Number of tillers per plant

Five plants from the tagged hills were selected at random and non-biodegradable plastic rings were fixed at the base of each plant such that every tiller from that plant will emerge within the ring fixed. Number of tillers per plant was determined at 3, 6 and 9 WAT by counting the number of tillers found in each plastic ring and then divided by five to get average number of tillers per plot.

3.5.4 Number of panicles per plant

Number of panicles per plant was determined by manual counting of the panicles on each plant from the five tagged plants sampled at 3, 6 and 9 WAT. The values obtained were added and divided by five to get average number of panicle per plant.

3.5.5 Panicle length

Panicle length was measured at harvest by using the five tagged plants in the net plots and measuring the panicle from the base of the inflorescence to its tip with a metre rule. Values obtained were divided by five to get average panicle length per plot.

3.6 Harvesting

Harvesting was made at maturity (when the entire plants have turned golden brown and rachilla have dried). Harvesting was done with the help of a sickle at ground level. The total above ground biomass was bounded in heaves, dried for three days before threshing.

3.6.1 Straw yield (kg/ha)

The straw yield (kg/ha) was determined three days after harvest by weighing the bundled net plot straw left in the fields to sundry using weighing balance.

3.6.2 Grain yield (kg/ha)

The grain yield was determined at harvest. The harvested net plots were threshed, winnowed and sun-dried, and the clean grains weighed per plot and were later expressed in kilogram per hectare.

3.6.3 1000 - grain Weight (g)

One thousand grains were counted from each net plot and weighed with weighing balance and recorded.

3.7 Post-harvest soil sampling

Soilsamples were randomly taken from each plot after harvest with an auger at two depths (0 – 15 and 15 – 30 cm). A composite sample was obtained for each depth, and the samples were air dried, crushed and sieved through 2 mm sieve. Sub samples were later analyzed for physical and chemical properties.

3.8 Soil Analysis

3.8.1 Soil physical parameters

Bulk density was determined using the core cylinder method (Anderson and Ingram, 1993), while particle size distribution was determined by hydrometer method as modified by Gee and Or(2002).

3.8.2 Soil chemical properties

Soil pH was determined using a digital pH metre, organic carbon (C) by wet oxidation method of Walkley and Black as described by Nelson and Sommers (1982), total N was determined by macro-Kjeldahl oxidation method (Bremner and Mulvaney, 1982). Available phosphorus (P) was extracted by the Bray-1 method (Bray and Kurtz, 1945) and also by the Olsen's method with bicarbonate extractant for the P used in the QUEFTS model (Olsen *et al*., 1954) and the P determined using colorimeter. Cation exchange capacity (CEC) was also determined by ammonium acetate saturation method while exchange acidity was determined by the methods described by Okalebo *et al.* (2002).

Electrical conductivity of the saturated soil paste was determined using conductivity meter (Anderson and Ingram, 1993). Soil exchangeable bases (K, Na, Mg and Ca) were extracted from soil with ammonium acetate at pH 7, the Mg and Ca concentrations were determined with atomic absorption spectrophotometer (AAS) while the Na and K content were read on flame photometer. Theexchangeable 'acidic' cations (Al + H)were extracted with an un-buffered potassium chloride

solution and the ions were measured by titrating with weak NaOH. The micronutrients (Fe, Cu and Mn) content of the soil was determined using the methods described by Juo (1979) and Page *et al*. (1982).

3.8.3 Plant sampling and analysis

Harvested plant samples (shoot and grain) from the net plot (2 m x 2 m) were shredded, sub-sampled placed in large envelopes and oven-dried at 65^0C to a constant weight. The oven-dried samples were ground in an electric stainless steel mill using 0.5 mm sieve and stored in plastic bags for tissue analysis.

The concentrations of P, K, Ca and Mg in paddy rice were determined by flame and spectrophotometric analysis as appropriate, following the tri-acid (sulphuric acid + nitric acid + perchloric acid) wet digestion. The digest was used for P – determination by colorimetric (Vanado - molybdate) method, K by flame emission method; Ca and Mg by Atomic Absorption Spectrophotometer.Total N in plant samples were estimated by complete oxidation using micro-kjeldahl procedures (Okalebo *et al.,* 2002).

Plant tissue analysis for both grains and straw were used to determine nutrient content and uptake of the crop, nitrogen use efficiencies and other harvest indices as shown in Table 3.1 following Fageria *et al.*(2010) method.

3.9 Varietal Description

FARO 55 (NERICA 1) is upland rice, medium maturing variety (100 – 105 days) with a paddy yield potential of 3 – 4 tons/ha. It competes well with weed and has a good cooking and aroma qualities. It is resistant to diseases, especially rice blast.

Table 3.1: Formulae for Calculating Nitrogen Use Efficiencies

S/No.	Use Efficiency	Formula
1.	Agronomic Efficiency (AE)	$\frac{Gy_f - Gy_u}{N_a}$ = kg /kg
2.	Physiological Efficiency (PE)	$\frac{Y_f - Y_u}{N_f - N_u}$ = kg /kg
3.	Agro Physiological Efficiency (APE)	$\frac{Gy_f - Gy_u}{N_f - N_u}$ = kg /kg
4.	Apparent Recovery Efficiency (ARE)	$\frac{N_f - N_u}{N_a} X\ 100$
5.	Nitrogen Utilization Efficiency (NUE)	PE X ARE = kg/ kg
6.	Grain harvest index (GHI)	$\frac{\text{Grain yield}}{\text{(grain + shoot) yield}}$
7.	Nitrogen harvest index (NHI)	$\frac{\text{N-uptake in grain}}{\text{N-uptake in (grain + shoot)}}$

Source: Fageria *et al.,* 2010

Where: Gy_f = grain yield of the fertilized plot (kg), Y_f= total biological yield (grain plus straw) of the fertilized plot (kg), Y_u = total biological yield of the unfertilized plot (kg), N_f = nutrient accumulation of the fertilized plot (kg), N_u = nutrient accumulation of the unfertilized plot (kg), Gy_u = grain yield of the unfertilized plot (kg), N_a = quantity of N applied (kg).

FARO 57 (TOX 4) is shallow irrigated swampy rice, late maturing variety (120 – 135 days) with a paddy yield potential of 4.5 – 6.0 tons/ha. It has high resistant to diseases.

FARO 52 (WITA 4) is irrigated swampy rice, late maturing variety (125 – 130 days) with a paddy yield potential of 4.5 – 6.0 tons/ha. It has tolerant ability to drought and iron toxicity (USAID, 2010).

3.10 Estimating Soil Indigenous Nutrient Supplies

Soil indigenous N, P, K supply was used as input in QUEFTS designed to estimate fertilizer requirements. Soil indigenous nutrient supply is defined as plant nutrient uptake with above-ground biomass in a nutrient omission plot in which only the nutrient of interest is limiting. Thus, total N uptake in a PK plot estimates the indigenous N supply while total P uptake in NK plot estimates indigenous P supply and total K uptake in an NP plot estimates the indigenous K supply.

The N-limited yield was measured from rice crop grown in N omission plot. The plot receives sufficiently large amount of fertilizer P and K. Similarly, the P-limited yield was measured from rice crop grown in P omission plot and the K-limited yield was measured from rice crop grown in K omission plot.

3.10.1 Estimating fertilizer N, P, K requirement of rice

The QUEFTS model outlook as shown in Plate 3.4 is a generic approach to estimate crop nutrient uptake requirements (Witt *et al.,* 1999). It accounts for interactions among macro-nutrients affecting the internal efficiencies (i.e. kg grain produced per kg plant nutrient) of N, P and K and allows differentiation according to different yield levels targeted. The recovery

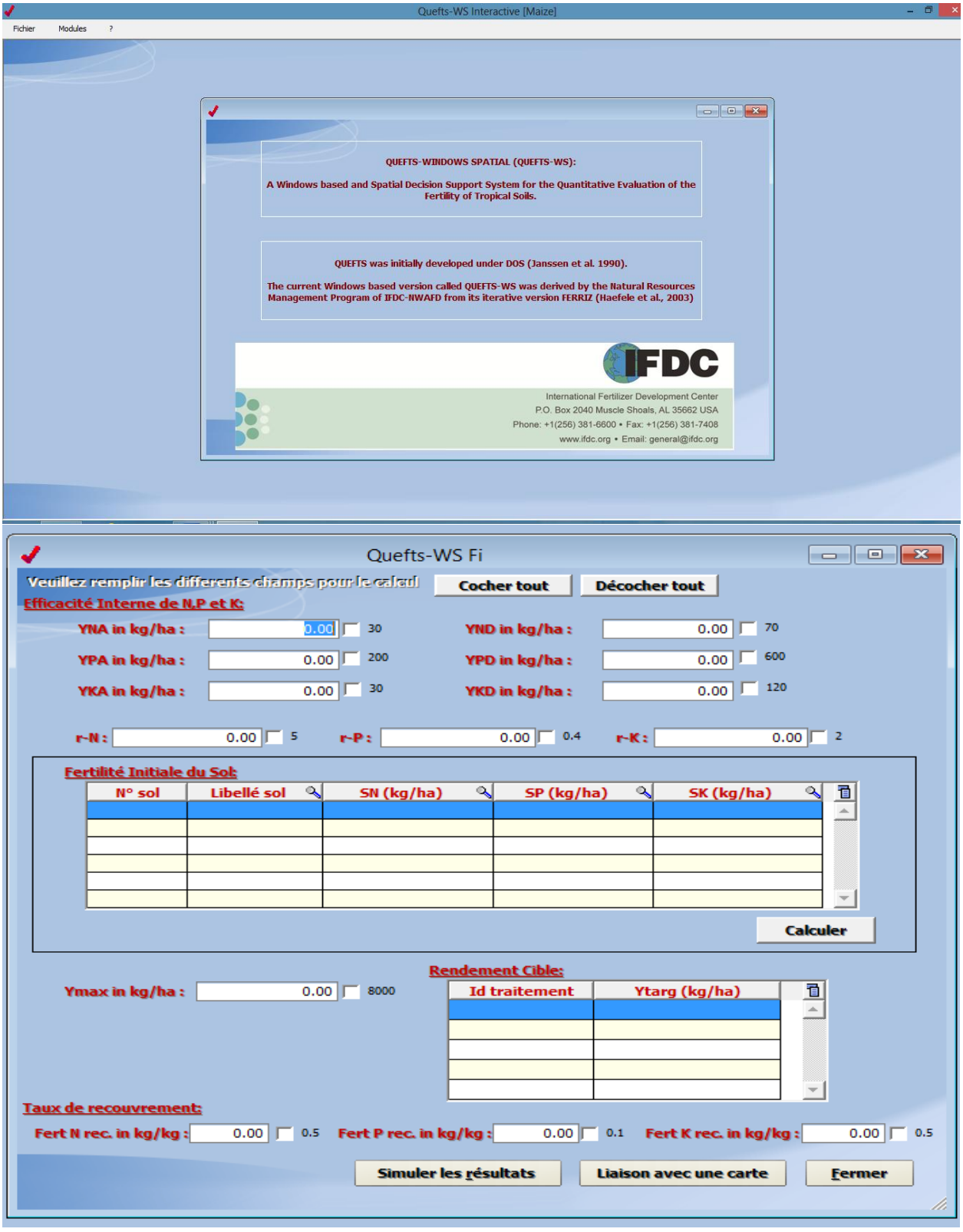


Plate 3.4: QUEFTS model outlook

fractions (RFN, RFPand RFK) and internal efficiencies (IEN, IEP and IEK) were computed for each plot fromthe above ground uptake at maturity in plots where specific nutrient element was applied and plots where it was not applied (Janssen *et al.,* 1990) using the following equations:

$$(\mathrm{RF})\mathrm{N} = \frac{\mathrm{Nupt\ (NPK)} - \mathrm{Nupt(PK)}}{amount\ of\ N\ applied\ \left(\frac{\mathrm{kg}}{\mathrm{ha}}\right)}$$

and

$$(\mathrm{IE})\mathrm{N} = \frac{\mathrm{Grain\ yield}\ \left(\frac{\mathrm{kg}}{\mathrm{ha}}\right)\ \mathrm{from\ Nplot}}{Nupt(NPK)}$$

Where:

(RF) N= Refractory Fraction for nitrogen (N)

$\mathrm{Nupt\ (NPK)} =$ Nutrient Uptake for plot NPK

$\mathrm{Nupt(PK)} =$ Nutrient Uptake for plot PK

$(\mathrm{IE})\mathrm{N} =$ Internal Efficiency for nitrogen (N)

3.11 Statistical Analysis:

All data (both soil and plant) collected were subjected to analysis of variance (ANOVA) using the mixed model procedure of SAS (Littell *et al*., 1996). Differences between treatment means were compared using Duncan Multiple Range Test (DMRT). Pearson correlation coefficients (r) and regression analyses were performed between relevant soil and plant parameters (SAS, 2001).

In addition, factorial analysis of variance were conducted using General Linear Model procedure in the SAS package (SAS, 2001) to determine the significance of the effects of N fertilization, rice varieties, year and their interactions on N uptake, and NUE indices. Factor analysis was performed with reference to the whole dataset and estimates of the initial factors obtained from principal component analysis. The number of factors to be retained was chosen on the basis of the relative proportions of the variance explained by the Eigenvalue (standardized variance associated with a particular factor). To simplify the interpretation of the results, varimax rotation was used. On the basis of the rotated component matrix, it was possible to identify the most significant variables within the group of components and the degree of inter-relationship between them.

Coefficient of multiple determinations (R^2), the root mean square error (RMSE), normalize root mean square error ($RMSE_n$) and an index of agreement (d) were computed to assess the goodness –of- fit statistics of the QUEFTS model using the following relationship:

$$\mathrm{RMSE} = \left[\sum_{i=1}^{n} (S_i - Ob_i)^2/n\right]^{0.5}$$

$$\mathrm{RMSE_n} = 100\left[\sum_{i=1}^{n} (S_i - Ob_i)^2/n\right]^{0.5} /Ob_{avg}$$

$$d = 1 - \frac{\sum_{i=1}^{n} (S_i - Ob_i)^2}{\sum_{i=1}^{n} \left(|S_i - Ob_{avg}| + |Ob_i - Ob_{avg}|\right)^2}$$

Where: $\mathbf{S_i}$ = simulated values

Ob_i = Observed values

n = observed data points

3.12 Partial Economic Analysis

Data on costs and returns from paddy production were obtained during the trials and results obtained was used to estimate which of the treatment combinations was profitable using gross margin analysis and return per naira invested (Olukosi and Erhabor, 1988). Gross margin analysis employed used the following relationship:

$$GM = TR - TVC$$

$$TR = Yr * Pr$$

$$RPNI = GM/TVC$$

Where:

GM = Gross margin (₦/ha)

TR = Total revenue (₦/ha)

TVC = Total variable cost (₦/ha)

RPNI = return per naira invested (₦)

Yr = Output of rice crop (kg/ha)

Pr = Unit price of rice (₦/kg)

$$\text{and } TVC = \sum_{i-j}^{n} P_i X_i$$

Where:

P_i = unit price of the i^{th} input (₦/kg)

X_i = quantity of the i^{th} input (/ha)

The cost incurred (input/ha) for the inputs like land preparation, seeds, fertilizers, labour, water application under irrigation, herbicides and others were noted and recorded.

CHAPTER FOUR

4.0 RESULTS

4.1 Characterization of the Study Sites

4.1.1 Soil characteristics

Soils of the experimental locations have been classified as Alfisol in the USDA soil taxonomy system (FMARD, 2012). Initial physical and chemical properties of the experimental soils in 2012 and 2013 are presented in Table 4.1. The soils were sandy loam texture in both locations (Talata Mafara and Kadawa IAR stations). They were generally low in clay content 60 – 80 and 80 – 120 gkg^{-1} for Talata Mafara and Kadawa respectively. Total N for the two locations were low (0.28 – 0.84 gkg^{-1}) and decreases with cropping season i.e. lower for the second cropping season. The soil reaction (pH) in water was moderately acidic to neutral (5.9 to 6.7) in both locations based on rating (FMARD, 2012). The soils were generally low in organic carbon content (1.38 - 2.53 gkg^{-1}). The available phosphorus werelow (3.3 to 7.28 $mgkg^{-1}$) in both locations. Theexchangeable bases were also low for both locations: potassium (0.14 - 8.31$cmolkg^{-1}$), calcium (2.28 to 5.2 $cmolkg^{-1}$), magnesium (0.83 – 1.42 $cmolkg^{-1}$) and sodium (0.22 – 0.47 $cmolkg^{-1}$). The CEC was low with Kadawa soil having slightly higher CEC than Talata Mafara (3.5 – 5.9 $cmolkg^{-1}$).The electrical conductivity (EC)values were low for the two years under study ranging from 0.28 – 0.42 dSm^{-1} indicating low salinity status at both locations. The available micronutrientscations were generally above the critical levels in the savanna soils as shown in Table 4.1.

Table 4.1: Initial Physical and Chemical Properties of Soils atExperimental Locations (Talata Mafara and Kadawa) in 2012and 2013 cropping seasons.

Soil Properties	Talata Mafara		Kadawa	
	2012	2013	2012	2013
Physical properties:				
Bulk density (Mg cm^{-3})	1.23	1.17	1.45	1.31
Particle size distribution (g kg^{-1}):				
Clay	120	80	90	80
Silt	180	160	160	180
Sand	700	760	750	740
Textural class (USDA)	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam
Chemical properties:				
pH water	5.90	6.10	6.10	6.70
pH $CaCl_2$	4.80	5.80	5.80	6.50
E.C (dS m^{-1})	0.42	0.39	0.35	0.28
Organic carbon (g kg^{-1})	2.42	1.38	2.53	2.17
Total Nitrogen (g kg^{-1})	0.84	0.35	0.35	0.28
Available phosphorus (mg kg^{-1})	5.43	7.28	3.33	3.68
Exchangeable bases (cmol kg^{-1}):				
K^{+}	0.31	0.28	0.14	0.21
Ca^{++}	3.20	2.80	5.20	3.00
Mg^{++}	0.86	0.83	1.42	0.84
Na^{+}	0.32	0.22	0.47	0.34
Exchangeable acidity	0.10	0.10	0.10	0.10
CEC	4.2	3.5	5.9	4.3
Extractable micronutrients (mg kg^{-1}):				
Fe^{++}	330.72	320.73	332.60	370.23
Cu^{++}	6.64	13.74	9.36	5.71
Mn^{++}	89.64	74.61	79.10	65.90

Source: Department of Soil Science, Faculty of Agriculture, Ahmadu Bello University, Zaria.

4.1.2 Climatic conditions of the study periods

The total rainfall distribution for the two years at both locations were moderate ranging from 927.4 to 1,193.4 mm and 720.2 to 832.5 mm for Talata Mafara and Kadawa respectively as presented in Figure 4.1. For the two years under study, Talata Mafara had more rainfall than Kadawa.The rainfall decreases from the 1st year to the 2nd year for both locations. Therelative humidityranged from 57 to 60% for the two locations. The minimum and maximum temperatures for the two locations also ranged from 19.5 to 23.7 ^{0}C for Talata Mafara and 32 to 34 ^{0}C for Kadawa. The climatic conditionswere moderate for rice production in both sites.

4.2 Crop Growth Components

4.2.1 Plant height (cm)

The effect of N application on plant height of three rice varieties at 6 WAT in 2012, 2013 and combined at both Talata Mafara and Kadawa is shown in Table 4.2. Application of GU at 72.2 kg N/ha significantly produced taller plant (60.43 cm) and was closely followed by USG at 72.2 kg N/ha (57.34 cm). The control had the shortest plant (50.58 cm).At Kadawa, application of USG at 117.3 kg N/ha had the tallest plant (59.83 cm) which was closely followed by USG at 45.1 kg N/ha (55.59 cm). Under combined analysis, application of GU at 72.2 kg N/ha at Talata Mafara increased plant height by 19.47% over the control. On the other hand, application of USG at 117.3 kg N/ha at Kadawa increased plant height by 7.28% over the control.

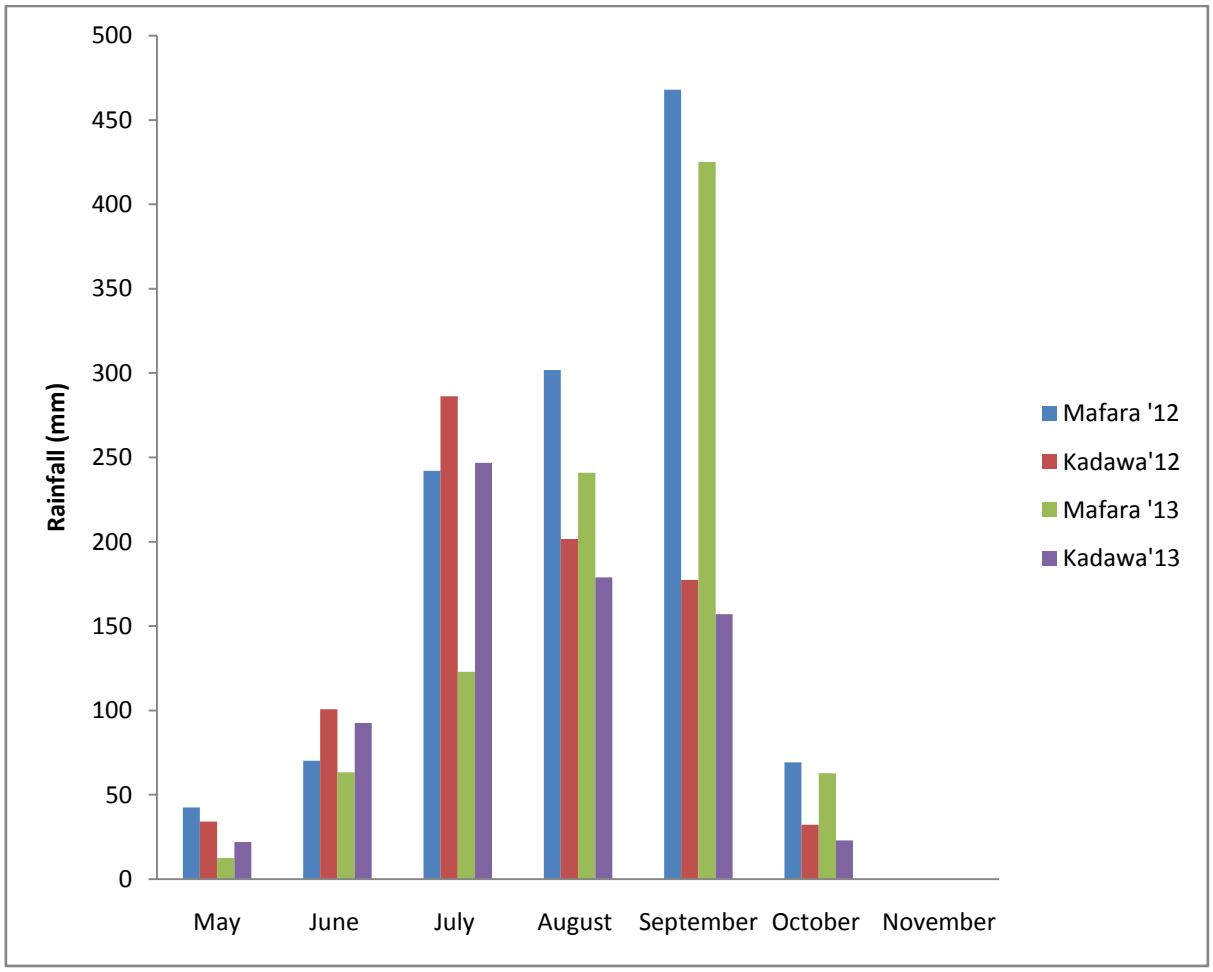


Figure 4.1: Rainfall distribution at Talata Mafara and Kadawa in 2012 and2013cropping seasons.

Table 4.2: Effectsof N-fertilizers, rates and varietyon Plant height (cm) of rice at Talata Mafara and Kadawa at 6 WAT in 2012, 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	48.13c	53.02c	50.58e	55.69b	43.76d	49.72b
USG at 45.1	54.24ab	59.24ab	56.74bc	58.75ab	52.43ab	55.59ab
USG at 72.2	54.48ab	59.84ab	57.34b	56.44b	50.37abc	53.41b
USG at 117.3	54.64ab	55.63bc	55.63bcd	66.06a	53.59a	59.83a
GU at 45.1	51.11bc	56.11bc	53.61cde	60.84ab	45.49cd	53.17b
GU at 72.2	57.93a	65.93a	60.43a	51.89b	46.99bcd	49.44b
GU at 117.3	52.87b	52.84c	52.87de	57.00ab	46.69abcd	53.34b
GU based on LCC	53.98ab	58.98ab	56.48bc	58.97ab	45.22cd	52.09b
S.E $\pm$	1.573	1.452	1.033	2.945	1.899	1.921
Variety (V)						
FARO 55	60.78a	64.86a	63.38a	55.29b	49.30a	52.30
FARO 57	45.91c	49.66c	47.75c	62.18a	45.07b	53.62
FARO 52	53.72b	57.47b	55.77b	57.15ab	50.97a	54.06
S.E $\pm$	1.112	0.889	0.633	1.804	1.163	1.177
Interaction						
N x V	*	*	**	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. *, ** = significant at 5% & 1% levels of probability; NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

The varieties under study exhibited significant differences with respect to plant height. At Talata Mafara, FARO 55 had the tallest (63.38 cm) plants while FARO 57 was the shortest (47.75 cm). At Kadawa, there was no significant difference for plant height at 6WAT. The interaction of the three rice varieties and N-management was significant only at Talata Mafara in 2012, 2013 and combined as presented in Table 4.3.

The interaction of N- management and rice varieties on plant height at 6WAT is presented in Table 4.3. In the year 2012, 2013 and combined; application of USG at 72.2 kg N/ha on FARO 55 gave the tallest (70.30 cm) plants, while FARO 57 had the shortest (40.43 cm).

Plant height at 9WAT was significantly influenced by the effect of N forms and rates in 2012, 2013 and combined at Talata Mafara. There were no significant differences in plant heights for both years at Kadawa. At Talata Mafara, application of USG at 117.3 kg N/ha had the tallest (64.06 cm) plant and was at par with the application of GU at 117.3 kg N/ha (63.42 cm). The control (0 kg N/ha) had the shortest plant (51.46 cm). As for the varietal response, FARO 55 had the tallest plants. The plant heights were 65.59 cm and 65.29 cm in Talata Mafara and Kadawa respectively as shown in Table 4.4.

As shown in Table 4.5, the interaction of N-fertilizer and variety on plant height at 9WAT in 2012 and 2013 combined showed significant differences with applications of USG at 117.3 kg N/ha to FARO 55 recorded the tallest (74.97 cm) plants. Plants

Table 4.3: Interaction of N-management and variety on plant height (cm) at 6 WAT at Talata Mafara in 2012 and 2013.

Treatment	Variety								
	2012			2013			Combined		
N-fertilizer (kg/ha)	FARO 55	FARO57	FARO 52	FARO 55	FARO 57	FARO 52	FARO 55	FARO 57	FARO 52
Control	45.32c	53.06b	50.79b	60.80bc	42.93e	55.33c	58.47a	40.43c	52.83b
USG at 45.1	56.48ab	54.89b	55.41b	68.07a	50.20d	59.47c	65.57a	47.70b	56.97ab
USG at 72.2	50.42bc	54.01b	55.79b	72.80a	51.73d	55.00cd	70.30a	49.23b	52.50b
USG at 117.3	58.42a	63.87a	57.20a	69.33a	45.90e	51.64d	69.33a	45.90bc	51.64b
GU at 45.1	51.92b	51.63b	55.95b	57.27c	50.00de	61.07b	54.77b	47.50b	58.57a
GU at 72.2	46.66c	51.01b	50.67b	71.80a	56.07c	60.94b	69.30a	53.57b	58.44a
GU at 117.3	51.66b	54.31b	54.06b	51.47d	50.08d	57.05c	51.47b	50.08b	57.05a
GU based on LCC	57.48a	46.22c	52.58b	67.33ab	50.33d	59.27bc	64.83a	47.83b	56.77b
SE+/-		2.640			2.513			4.706	

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

Table 4.4: Effects of N-fertilizers, rates and varietyon Plant height (cm) of rice at Talata Mafara and Kadawa at 6 WAT in 2012, 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	48.96c	53.96c	51.46d	64.56	54.21	59.38
USG at 45.1	56.11bc	60.33ab	58.22c	70.77	58.93	64.85
USG at 72.2	55.71bc	60.71ab	58.21c	67.22	60.91	64.06
USG at 117.3	62.50a	64.06a	64.06a	67.89	62.19	65.04
GU at 45.1	51.91cd	56.91bc	54.41d	70.87	54.58	62.73
GU at 72.2	58.02b	63.02a	60.52bc	66.08	59.25	62.67
GU at 117.3	63.42a	63.42a	63.42ab	64.82	62.17	63.50
GU based on LCC	55.51bc	60.51ab	58.01c	68.98	56.74	62.86
S.E $\pm$	1.631	1.545	1.089	2.990	2.477	2.011
Variety (V)						
FARO 55	64.06a	68.10a	65.59a	66.81	63.77a	65.29a
FARO 57	49.92c	53.67c	50.75c	67.32	52.91c	60.12b
FARO 52	55.57b	59.32b	57.05b	68.82	59.18b	64.00a
S.E $\pm$	1.153	0.946	0.667	1.831	1.517	1.232
Interaction						
N x V	NS	NS	**	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. ** = significant at 1% levels of probability; NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

Table 4.5: Interaction of N-management and variety on plant height (cm) at 9WAT at Talata Mafara in 2012 and 2013 cropping seasons.

Treatment	Variety		
N-fertilizer (kg/ha)	FARO 55	FARO 57	FARO 52
Control	58.23b	42.03c	54.10b
USG at 45.1	68.13a	49.57bc	56.97b
USG at 72.2	71.37a	50.50b	52.77b
USG at 117.3	74.97a	59.53b	57.67b
GU at 45.1	55.17b	50.03b	58.03b
GU at 72.2	66.63a	55.77b	59.17b
GU at 117.3	68.73a	58.77b	62.77ab
GU based on LCC	67.77a	48.17c	58.10b
SE(±)		4.927	

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

in this treatment was statistically similar to those obtained with the application of USG at 72.2, USG at 45.1 and GU at 45.1, GU at 72.2 and GU based on LCC recommendation.

4.2.2 Number of tillers per plant

The effect of N management on number of tillers per plant at 6WAT of three rice varieties in 2012, 2013 and combined at Talata Mafara and Kadawa is shown in Table 4.6. The result showed that application of GU at 117.3 kg N/ha produced the highest (24.10) number of tillers. This was at par with application of USG at 117.3 kg N/ha (22.18). There were no significant differences at Kadawa, except in 2013 where USG applied at 72.2 kg N/ha had the highest (10.96) and the control had the least (8.18).

Varietal response also showed that varieties differ in their number of tillers per plant as presented in Table 4.7. FARO 57 had more number of tillers than FARO 55. However, the number of tillers was at par with that of FARO 52 at Talata Mafara in 2012 and 2013 combined. There were no significant differences in number of tillers per plant at Kadawa.

At9WAT, the significant differences were observed in number of tillers at Talata Mafara where application of USG at 117.3 kg N/ha produced the highest (24.56) number of tillers. This was closely followed by the application of GU at 117.3 kg N/ha (23.30) while the application of USG at 45.1 kg N/ha had the least (15.59). As for the varietal response, FARO 57 had the highest (20.85) number of tillers. This was statistically similar to that of FARO 52.FARO 55 had the least number of

Table 4.6: Effects ofN-fertilizers, ratesand varietyon Number of tillers per plant at Talata Mafara and Kadawa at6 WAT in 2012, 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	13.62b	18.62b	16.12b	16.06	8.18ab	12.12
USG at 45.1	13.93b	18.62b	16.38b	18.17	10.11ab	14.14
USG at 72.2	15.69b	20.69ab	18.19b	18.00	10.96a	14.48
USG at 117.3	23.32a	22.18ab	22.18a	18.53	9.67ab	14.09
GU at 45.1	14.29b	19.29b	16.79b	18.64	8.22ab	13.43
GU at 72.2	16.31b	21.31ab	18.81b	15.61	9.00ab	12.31
GU at 117.3	24.10a	24.10a	24.10a	17.94	10.04ab	13.99
GU based on LCC	14.98b	19.98b	17.48b	20.28	6.85b	13.56
S.E $\pm$	1.354	1.201	0.871	2.297	1.089	1.365
Variety (V)						
FARO 55	14.45b	17.78b	15.19b	18.47	5.46b	11.96b
FARO 57	19.15a	22.86a	20.24a	16.31	10.59a	13.46ab
FARO 52	17.49a	21.24a	18.96a	18.93	11.33a	15.13a
S.E $\pm$	0.957	0.735	0.533	1.406	0.667	0.836
Interaction						
N x V	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. NS = not significant.
USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

Table 4.7: Effects of N-fertilizers, ratesand varietyon Number of tillers per plant at 9 WAT at Talata Mafara andKadawa in 2012, 2013 cropping seasons.

	Talata Mafara			Kadawa		
Treatment	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	15.47b	20.47ab	17.97bc	31.33	7.41	19.37
USG at 45.1	13.09b	18.09b	15.59c	33.28	7.33	20.31
USG at 72.2	17.09b	22.09ab	19.59b	36.39	8.96	22.68
USG at 117.3	25.46a	24.56a	24.56a	31.72	8.18	19.95
GU at 45.1	15.27b	20.27ab	17.77bc	34.72	6.82	20.77
GU at 72.2	17.40b	22.40ab	19.90b	36.06	9.48	22.77
GU at 117.3	23.30a	23.30a	23.30a	32.41	7.55	19.98
GU based on LCC	16.47b	21.47ab	18.97b	34.44	6.33	20.39
S.E $\pm$	1.506	1.395	0.991	2.982	1.159	1.534
Variety (V)						
FARO 55	15.04b	18.45b	15.93b	34.10	5.69b	19.89
FARO 57	19.64a	23.39a	20.85a	31.85	8.47a	20.16
FARO 52	19.15a	22.90a	20.51a	35.43	9.11a	22.27
S.E $\pm$	1.065	0.854	0.607	1.826	0.710	0.939
Interaction						
N x V	NS	NS	*	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. * = significant at 5% levels of probability; NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

tillers. There were no significant differences in the number of tillers at Kadawa as shown in Table 4.7.

Interaction of N-management and variety on number of tillers was only significant at Talata Mafara in 2012 and 2013 combined analysis (Table 4.8). Application of USG at 117.3 kg N/ha to FARO 57 had the highest (27.13) number of tillers. This was at par to that of FARO 52, FARO 57 with application of GU at 117.3 kg N/ha and FARO 55 and FARO 52 with USG application at 117.3 kg N/ha. Application of USG at 45.1 kgN/ha to FARO 57 variety recorded the least (13.17) number of tillers as presented in Table 4.8.

4.2.3 Crop dry matter per plant (g)

The effect of N-management on crop dry matter (g) per plant at 6WAT for the three rice varieties in 2012, 2013 and combined at Talata Mafara and Kadawa is presented in Table 4.9. Results of 2012 and 2013 combined at Talata Mafara showed that application of GU at 72.2 kg N/ha recorded the highest (6.48 g) crop dry matter and was closely followed by application of USG at 45.1 kg N/ha. The least (3.39 g) was obtained with the application of GU at 117.3 kg N/ha.

The combined analysis for Kadawa showed that application of USG at 117.3 kg N/ha had the highest crop dry matter (5.22 g), while the least (2.66 g) was recorded with the application GU based on LCC (Table 4.9). The response of varieties to N management showed that FARO 52 had the highest crop dry matter (6.99 and 4.04 g) at Talata Mafara and Kadawa respectively in the combined analysis. At 6WAT,

Table 4.8: Interaction of N- fertilizer and variety on number of tillers perplant at 9 WAT at Talata Mafara in 2012 and 2013 cropping seasons.

Treatment	Variety		
N-fertilizer (kg/ha)	FARO 55	FARO 57	FARO 52
Control	14.17bc	20.70ab	19.03b
USG at 45.1	13.90c	13.17c	19.70b
USG at 72.2	16.57b	23.90a	18.30b
USG at 117.3	24.85a	27.13a	23.03a
GU at 45.1	14.77b	19.90b	18.63b
GU at 72.2	15.63b	21.97a	22.10a
GU at 117.3	18.63b	25.10a	26.17a
GU based on LCC	15.43b	20.23b	21.23a
SE(±)		2.319	

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

Table 4.9: Effects ofN-fertilizers, ratesand variety on Crop dry matter (g) per plant at Talata Mafara and Kadawa at 6 WATin 2012, 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	8.30a	2.95	5.62a	2.05ab	4.03abc	3.04bc
USG at 45.1	8.54a	3.98	6.26a	2.07ab	5.23abc	3.65abc
USG at 72.2	8.11a	3.56	5.83a	2.55ab	4.66abc	3.61abc
USG at 117.3	4.22b	3.86	3.86b	3.95a	6.48ab	5.22a
GU at 45.1	9.28a	3.08	6.18a	2.31ab	3.45c	2.88bc
GU at 72.2	9.50a	3.46	6.48a	2.31ab	3.66bc	4.55ab
GU at 117.3	3.39b	3.39	3.39b	2.12ab	5.17abc	3.64abc
GU based on LCC	8.55a	3.75	6.15a	1.65b	6.79a	2.66c
S.E $\pm$	0.878	0.373	0.505	0.632	0.086	0.555
Variety (V)						
FARO 55	5.87c	2.87b	4.50c	2.45ab	4.20	3.33
FARO 57	7.48b	3.52ab	5.72b	1.69b	5.51	3.60
FARO 52	9.11a	4.12a	6.99a	2.98a	5.09	4.04
S.E $\pm$	0.621	0.229	0.309	0.387	0.545	0.339
Interaction						
N x V	NS	*	NS	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT.* = significant at 5% levels of probability; NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

there was significant interaction of N-management and rice varieties on crop dry matter at Talata Mafara in 2013. The application of GU based on LCC to FARO 52 had the highest crop dry matter (5.93 g plant^{-1}) and was closely followed by FARO 57 with application of USG at 45.1 kg N/ha (5.78 g plant^{-1}) as presented in Table 4.10. The least (1.81 g plant^{-1}) crop dry matter was observed in the control plot of FARO 55 as presented in Table 4.10. The effect of N-management and rice varieties on crop dry matter at 9WAT in 2012, 2013 and combined at both locations is presented in Table 4.11. The combined analysis showed significant effect at Talata Mafara, while there was no significant difference at Kadawa. At Talata Mafara, GU applied at 72.2 kg N/ha had the highest (26.88 g plant^{-1}) crop dry matter, while GU applied at 117.3 kg N/ha recorded the least (11.04 g plant^{-1}).

As for the varietal response at both locations, FARO 52 produced crop dry matter that was statistically similar to FARO 57. For both locations, the interactions of N-management and rice varieties on crop dry matter were not significant.

4.2.4 Days to 50% heading

The effect of N-management on number of days to 50% heading of three rice varieties in 2012, 2013 and combined at Talata Mafara and Kadawa is presented in Table 4.12. Application of USG at 117.3 kg N/ha gave the longest number of days to 50% heading (68.89 and 64.39) at both Talata Mafara and Kadawa respectively, while the control result gave the shortest (61.56 and 62.28) days to flowering at both Talata Mafara and Kadawa respectively. The varieties under study exhibited significant differences with respect to days to 50% heading. FARO 52 had the

Table 4.10: Interaction of N-management and variety on crop dry matter(g) per plant at 6WAT at Talata Mafara in 2013 cropping season.

Treatment	Variety		
N-fertilizer (kg/ha)	FARO 55	FARO 57	FARO 52
Control	1.81c	3.13b	3.92b
USG at 45.1	2.73c	5.78a	3.42b
USG at 72.2	4.66a	2.73c	3.28b
USG at 117.3	2.93b	4.02b	4.63ab
GU at 45.1	2.79bc	2.71c	3.73b
GU at 72.2	2.40c	3.28b	4.70a
GU at 117.3	2.86b	3.95b	3.36b
GU based on LCC	2.78c	2.55c	5.93a
SE(±)		0.646	

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

Table 4.11: Effectsof N-fertilizers, rates and varietyon Crop dry matter (g) per plant at Talata Mafara and Kadawaat 9 WAT in 2012, 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	26.40cd	11.58	18.99bc	15.52b	7.25c	11.39
USG at 45.1	30.94bc	12.57	21.76abc	23.28a	12.29a	17.79
USG at 72.2	22.94d	12.00	17.47c	20.58a	11.43ab	16.01
USG at 117.3	12.03e	11.84	11.84d	21.53a	12.63a	17.08
GU at 45.1	37.65ab	10.53	24.09ab	21.08a	9.58b	15.33
GU at 72.2	42.82a	10.95	26.88a	21.65a	11.05ab	16.35
GU at 117.3	11.04e	11.04	11.04d	24.20a	12.17a	18.19
GU based on LCC	31.04bc	10.71	20.88bc	23.22a	7.57c	15.40
S.E ±	2.678	1.144	1.738	1.306	1.089	1.198
Variety(V)						
FARO 55	25.13	8.89b	17.95b	14.35b	11.34b	12.85b
FARO 57	27.29	12.70a	21.17a	20.95a	12.58a	16.77a
FARO 52	28.15	12.61a	21.53a	21.82a	10.15b	15.99a
S.E ±	1.893	0.701	1.064	0.8011	0.946	0.874
Interaction						
N x V	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

Table 4.12: Effects of N-fertilizers and rates on number of days to50% heading of rice variety at Talata Mafara and Kadawain 2012, 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	60.33b	62.78	61.56c	63.78	60.78	62.28b
USG at 45.1	61.33ab	63.78	62.56bc	65.11	62.11	63.6ab
USG at 72.2	61.67ab	64.11	62.89bc	65.11	62.11	63.61ab
USG at 117.3	63.56a	64.89	64.89a	65.89	62.89	64.39a
GU at 45.1	60.33b	63.22	61.78c	64.33	61.22	62.78b
GU at 72.2	61.11ab	63.89	62.50bc	65.00	62.00	63.50ab
GU at 117.3	63.44a	63.44	63.44ab	63.44	61.56	62.50b
GU based on LCC	61.44ab	64.22	62.83bc	65.11	62.11	63.621ab
S.E ±	0.565	0.804	0.494	0.745	2.446	0.502
Variety (V)						
FARO 55	62.83a	65.75a	64.50b	66.83a	63.79a	65.31a
FARO 57	56.33b	59.04b	57.88c	60.04b	57.04b	58.54b
FARO 52	63.94a	66.58a	65.45a	67.29a	64.71a	66.00a
S.E ±	0.399	0.493	0.302	0.456	0.499	0.307
Interaction						
N x V	NS	NS	NS	NS	NS	*

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. *= significant at 5% levels of probability; NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

longest days to heading (65.45 and 66.00) while FARO 57 recorded the shortest days to 50% heading (57.88 and 58.54) at both locations.

The interaction between N management and varieties on days to 50% heading indicated that combination of FARO 52 and USG applied at 45.1 kg N/ha recorded the longest (67.83) days to 50% heading, while the shortest (56.83) was recorded by FARO 57 underthe control treatment as presented in Table 4.13.

4.2.5 Number of panicles per plant

The effect of N-management on number of panicles per plant of three rice varieties in 2012, 2013 and combined at Talata Mafara and Kadawa is presented in Table 4.14. Results obtained showed that application of USG at 117.3 kg N/ha had the highest number of panicles (16.72).The least (11.13) number of panicles was recorded for GUapplied at 72.2 kg N/ha at Talata Mafara. At Kadawa the highest (14.17) and the least (10.58) number of panicles were recorded inGU at 45.1 kg N/ha and GU based on LCC treatments respectively.

The varietal response showed that FARO 52 had the highest (12.90 and 12.73)number of panicles at Talata Mafara and Kadawa respectively, while the least values of 11.29 and 11.63 were recorded for FARO 55 at both Talata Mafara and Kadawa respectively (Table 4.14). Interaction of N- forms of fertilizers and varieties significantly affected the number of panicles per plant in 2012 and 2013 combined at Talata Mafara as shown in Table 4.15. Application of GU at 117.3 kg

Table 4.13: Interaction of N-management and variety on days to 50 %heading at Kadawa in2012 and 2013cropping seasons.

Treatment	Variety		
N-fertilizer (kg/ha)	FARO 55	FARO 57	FARO 52
Control	64.17bc	56.83f	65.83a
USG at 45.1	65.17b	57.83ef	67.83a
USG at 72.2	66.17a	58.17e	66.50a
USG at 117.3	66.17a	60.17de	66.83a
GU at 45.1	65.00b	57.17f	66.17a
GU at 72.2	65.83a	58.17e	66.50a
GU at 117.3	64.50b	60.83d	62.17cd
GU based on LCC	65.50ab	59.17e	66.17a
SE(±)		0.869	

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

Table 4.14: Effects of N-fertilizers and rates on number ofpanicles per plant of rice variety at Talata Mafara andKadawain 2012, 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	9.36b	14.41bc	11.88b	10.67b	11.06b	10.87c
USG at 45.1	9.36b	14.36bc	11.86b	12.74ab	13.37ab	13.06ab
USG at 72.2	8.96b	13.92bc	11.44b	11.29ab	11.92ab	11.61bc
USG at 117.3	16.79a	16.50a	16.72a	12.37ab	13.27ab	12.82ab
GU at 45.1	9.73b	14.75abc	12.23b	14.29a	14.05a	14.17a
GU at 72.2	8.63b	13.63c	11.13b	11.91ab	12.40ab	12.16bc
GU at 117.3	15.76a	15.76ab	15.76a	10.32b	10.84b	10.81c
GU based on LCC	9.06b	14.06c	11.56b	10.32b	10.84b	10.58c
S.E ±	0.699	0.651	0.461	1.061	0.808	0.605
Variety (V)						
FARO 55	10.01b	13.67b	11.29b	11.27	11.99	11.63b
FARO 57	11.25a	15.00a	12.76a	11.36	11.96	11.66b
FARO 52	11.60a	13.67a	12.90a	12.62	12.85	12.73a
S.E ±	0.494	0.398	0.282	0.649	0.495	0.371
Interaction						
N x V	*	*	*	NS	NS	*

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DNMRT. * = significant at 5% levels of probability; NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart

Table 4.15: Interaction of N-management and variety on number of panicles at Talata Mafara in 2012, 2013 croppingseasons.

Treatment	2012			2013			Combined		
	Variety								
N-fertilizer (kg/ha)	FARO 55	FARO 57	FARO 52	FARO 55	FARO 57	FARO 52	FARO 55	FARO 57	FARO 52
Control	10.33c	11.76b	10.51c	12.47	17.27	13.50	9.88b	14.77a	11.00b
USG at 45.1	10.03c	11.83b	17.32a	12.93	14.27	15.87	10.43b	11.77b	13.37ab
USG at 72.2	11.36b	10.96bc	12.51b	12.60	13.73	15.43	10.10b	11.23b	12.98b
USG at 117.3	12.03c	14.11ab	12.31b	17.00	15.13	17.37	17.00a	15.13a	17.37a
GU at 45.1	16.58a	11.75b	14.20a	15.98	12.80	15.40	13.48a	10.30b	12.90b
GU at 72.2	12.72b	11.55b	12.20b	12.60	14.47	13.83	10.10b	11.97b	11.33b
GU at 117.3	10.37c	10.05c	12.02b	13.50	16.30	17.47	13.50a	16.30a	17.47a
GU based on LCC	9.67c	11.28b	10.80c	12.30	16.07	13.80	9.80b	13.57a	11.30b
SE(±)		1.135			1.127			1.482	

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

N/ha toFARO 52 had the highest value (17.47), while the least (9.80) was with the application of GU based on LCC toFARO 55 as presented in Table 4.15.

Interactionof N-management and variety at Kadawa showed that application of USG at 45.1 kg N/ha toFARO 52 recorded the highest (17.33) number of panicles, while the least (9.67) was recorded with the application of GU based on LCC as presented in Table 4.16.

4.2.6 Panicle length (cm)

The effect of N-management and rice varieties on panicle length in 2012, 2013 and combined at both Talata Mafara and Kadawa is presented in Table 4.17. At Talata Mafara, application of USG at 117.3 kg N/ha produced the longest (29.82 cm) panicle, while the least (23.68 cm) was recorded with the GU based on LCC. On the other hand, the combined analysis at Kadawa showed that application of USG at 117.3 kg N/ha had the longest panicle length (23.95 cm), while GUapplied based on LCC had the shortest (19.73 cm).

The varietal response showed thatFARO 52 had the longest panicle length (27.17 cm) and was at par with FARO 57(27.17) at Talata Mafara, while at Kadawa, FARO 55 had the longest length (32.14 cm) which is statistically similar to FARO 52 (Table 4.17).

Interaction of N-management and rice variety on panicle length was not significant except in combined analysis at Talata Mafara where application of GU at 117.3 kg/ha toFARO 52 had the longest (31.50 cm).Application of USG at 72.2 kg N/ha to FARO 55 recorded the least (19.80 cm) as presented in Table 4.18.

Table 4.16: Interaction of N-form of fertilizer and variety on number ofpanicle at Kadawa in 2012 and 2013 cropping seasons.

Treatment	Variety		
N-fertilizer ($kgha^{-1}$)	FARO 55	FARO 57	FARO 52
Control	10.33d	11.76c	10.51d
USG at 45.1	10.03d	11.83c	17.33a
USG at 72.2	11.36c	10.96d	12.51c
USG at 117.3	12.03c	14.11bc	12.31c
GU at 45.1	16.58ab	11.75c	14.19b
GU at 72.2	12.72c	11.55c	12.20c
GU at 117.3	10.37d	10.05d	12.02c
GU based on LCC	9.67d	11.28cd	10.79d
SE(±)		1.048	

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

Table 4.17: Effectsof N-fertilizers, rates, andvariety on Panicle length (cm) per plant at Talata Mafara and Kadawain 2012, 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	21.61bc	26.61a	24.11cd	20.23b	21.12ab	20.67bc
USG at 45.1	22.96b	27.96bc	25.46b	20.78ab	21.81ab	21.30bc
USG at 72.2	21.40bc	26.40cd	23.90cd	21.88ab	22.14ab	22.01b
USG at 117.3	30.51a	29.79a	29.82a	23.79a	24.09a	23.95a
GU at 45.1	22.24bc	27.24cd	24.74bc	21.42ab	21.81ab	21.61bc
GU at 72.2	20.96c	29.47ab	29.47a	20.58b	21.15ab	20.40bc
GU at 117.3	29.47a	29.47ab	29.47a	20.58b	21.15ab	20.87bc
GU based on LCC	21.24c	26.13d	23.68cd	19.31b	20.14b	19.73c
S.E ±	0.549	0.532	0.370	0.968	0.956	0.618
Variety (V)						
FARO 55	21.19c	24.67c	22.13c	21.76a	22.15a	22.14a
FARO 57	24.35b	28.10b	27.17a	19.91b	20.33b	20.12b
FARO 52	25.85a	29.56a	27.17a	21.37ab	22.03a	21.69a
S.E ±	0.388	0.326	0.227	0.604	0.585	0.378
Interaction						
N x V	NS	NS	*	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. * = significant at 5% levels of probability; NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

Table 4.18: Interaction of N-form of fertilizer and variety on paniclelength at Talata Mafara in 2012 and 2013 cropping seasons.

Treatment	Variety		
N-fertilizer (kgha^{-1})	FARO 55	FARO 57	FARO 52
Control	21.10c	24.93b	26.30b
USG at 45.1	22.09c	26.37b	27.93a
USG at 72.2	19.80c	25.20b	26.70b
USG at 117.3	27.87ab	30.07a	31.43a
GU at 45.1	22.37c	23.60bc	28.25a
GU at 72.2	21.43c	24.63b	24.31b
GU at 117.3	27.00b	29.90a	31.50a
GU based on LCC	20.72c	25.13b	25.20b
SE(±)		1.512	

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

4.3 Total biomass (t/ha)

The effect of N-management and rice varieties on total biomass in 2012, 2013 and combined at Talata Mafara and Kadawa is presented in Table 4.19. Application of GU at 117.3 kg N/ha had the highest (10.06 t/ha)total biomass(15% above USG) at the same rate.The control had the least (5.89 t/ha) in Talata Mafara. On the other hand, at Kadawa, USG at 117.3 kg N/ha recorded the highest (16.20 t/ha) which was 69% above GU at the same rate, while the control had the least (6.88 t/ha).

FARO 52 maintained the best performance at both location and was closely followed by FARO 57. There were no significant difference in the interaction of N-management and varieties on total biomass, except in 2013 at Kadawa where application of USG at 117.3 kg N/ha toFARO 57 had the highest (21.30 t/ha)total biomass (Table 4.20). This was closely followed by the application of USG at 117.3 kg N/ha toFARO 52 (17.81 t/ha), while the least (5.02 t/ha) was recorded withFARO 55 under control as presented in Table 4.20.

4.4 Grain yield (t/ha)

The effect of N-management on grain yield of three rice varieties in 2012, 2013 and combined at both Talata Mafara and Kadawa is presented in Table 4.21. At Talata Mafara, application of GU at 45.1 kg N/ha gave the highest (4.32 t/ha) grain yield which was 61% above the control.The control had the least (2.68 t/ha). On the other hand, application of USG at 117.3 kg N/ha produced the highest grain yield (4.81 t/ha) at Kadawa which was 130% above the control.

Table 4.19: Effects of N-fertilizers, rates and varietyon Total biomass (t/ha) of rice at Talata Mafara and Kadawa in 2012, 2013 cropping seasons.

Treatment	Talata Mafara				Kadawa			
	2012	2013	combined	%↑	2012	2013	combined	%↑
Nitrogen (N) kg/ha								
Control	6.53b	5.24d	5.89b	-	6.08d	7.68d	6.88d	-
USG at 45.1	8.62ab	8.87abc	8.74a	48.39	11.51bc	13.57b	12.54b	82.27
USG at 72.2	8.36ab	9.47ab	8.92a	51.44	12.56b	11.94bc	12.25bc	78.05
USG at 117.3	10.06a	9.13abc	9.13a	55.01	15.74a	16.67a	16.20a	135.47
GU at 45.1	10.41a	7.93bc	9.17a	55.69	9.09c	10.85c	9.98c	45.06
GU at 72.2	9.57a	7.21c	8.39a	42.44	9.85c	12.16bc	11.01bc	60.03
GU at 117.3	10.06a	10.06a	10.06a	70.79	10.69bc	12.21bc	11.45bc	66.42
GU based on LCC	8.75ab	7.58bc	8.16a	38.54	9.46c	10.63c	10.05c	46.08
S.E ±	0.840	0.638	0.869		0.769	0.649	1.124	
Variety (V)								
FARO 55	5.45c	4.62c	4.79c		12.13a	7.50c	9.82b	
FARO 57	11.32a	8.02b	9.53b		8.04b	14.81a	11.43a	
FARO 52	10.36b	11.92a	10.91a		11.70a	13.57b	12.64a	
S.E ±	0.516	0.392	0.534		0.472	0.398	0.189	
Interaction								
N x V	NS	NS	NS		NS	*	NS	

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. *= significant at 5% levels ofprobability; NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

Table 4.20: Interaction of N-form of fertilizerand variety on totalbiomass (t/ha) at Kadawa in 2013 cropping season.

Treatment	Variety		
N-fertilizer (kgha^{-1})	FARO 55	FARO 57	FARO 52
Control	5.02g	9.00e	9.01e
USG at 45.1	8.70e	16.52b	15.48b
USG at 72.2	6.67f	14.89bc	14.26c
USG at 117.3	10.89de	21.30a	17.81b
GU at 45.1	6.33fg	12.81cd	13.41c
GU at 72.2	7.44f	16.04b	13.00c
GU at 117.3	8.44ef	14.19c	14.00c
GU based on LCC	6.52f	13.78c	11.59d
SE(±)		1.125	

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

Table 4.21: Effects of N-fertilizers,rates and varietyon Grain yield (t/ha) of rice at Talata Mafara and Kadawa in 2012,2013 cropping seasons.

Treatment	Talata Mafara				Kadawa			
	2012	2013	combined	%↑	2012	2013	combined	%↑
Nitrogen (N) kg/ha								
Control	3.28b	2.08c	2.68b	-	2.15e	2.03c	2.09c	-
USG at 45.1	4.66a	3.77ab	4.22a	57.46	3.77bc	3.84ab	3.80b	81.82
USG at 72.2	4.39a	3.97ab	4.18a	55.97	4.12b	3.49b	3.81b	82.30
USG at 117.3	4.43a	4.19a	4.22a	56.34	4.98a	4.65a	4.81a	130.14
GU at 45.1	5.22a	3.42ab	4.32a	61.19	3.01d	3.25b	3.13b	49.76
GU at 72.2	5.05a	3.08b	4.06a	51.49	3.09cd	3.56b	3.33b	59.33
GU at 117.3	4.25ab	4.17a	4.16a	53.39	3.53bcd	3.55b	3.43b	68.89
GU based on LCC	4.73a	3.33ab	4.03a	50.37	3.19cd	3.15b	3.17b	51.67
S.E ±	0.341	0.289	0.397		0.237	0.298	0.407	
Variety (V)								
FARO 55	2.47c	2.09c	2.19b		4.18a	2.08b	3.13b	
FARO 57	5.86a	3.16b	4.69a		2.28b	4.18a	3.23b	
FARO 52	5.12b	4.78a	4.97a		3.98a	4.05a	4.02a	
S.E ±	0.209	0.178	0.243		0.145	0.183	0.249	
Interaction								
N x V	NS	*	NS		NS	NS	NS	

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DNMRT. *= significant at 5% levels of probability; NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

The varietal response showed that FARO 52 had the highest (4.97 t/ha and 4.02 t/ha) grain yield at Talata Mafara and Kadawa respectively (Table 4.21), while the least wasobtained with FARO 55. The significant interaction was observed only at Talata Mafara in 2013 (Table 4.22), where application of GU based on LCC on FARO 52 had the highest (6 t/ha); although the yield was statistically similar to FARO 52 treated with USG at 45.1 and at 72.2 kgN/ha as presented in Table 4.22.

4.5 Straw yield (t/ha)

The effect of N-management and rice varieties on straw yield in 2012, 2013 and combined at Talata Mafara and Kadawa is presented in Table 4.23. Application of GU at 117.3 kg N/ha had the highest (5.85 t/ha) straw yield at Talata Mafara (21% above USG 117.3 kg N/ha), while control had the least (3.21 t/ha). On the other hand, USG at 117.3 kg N/ha had the highest (11.39 t/ha) at Kadawa (72% above GU) at the same rate and the control had the least (4.79 t/ha).

Varietal response showed that FARO 52 had the highest (6.20 and 8.62 t/ha) straw yields at Talata Mafara and Kadawa respectively. There were no significant interactionsbetween N-management and varieties in all the yearsand locations as presented in Table 4.23

4.6 1000-grain weight (g)

The effect of N-management and rice varieties on weight of 1,000-grain in 2012, 2013and combined at Talata Mafara and Kadawa is presented in Table 4.24. The combined analysis results showed that there was significant effect at Talata Mafara

Table 4.22: Interaction of N-form of fertilizer, rates and variety on grain yield (t/ha) at Talata Mafara in 2013 cropping season.

Treatment	Variety		
N-fertilizer ($kgha^{-1}$)	FARO 55	FARO 57	FARO 52
Control	1.69d	1.77d	2.79c
USG at 45.1	2.13c	3.57b	5.60a
USG at 72.2	2.08cd	4.51b	5.33a
USG at 117.3	2.86c	5.48a	4.23b
PU at 45.1	1.95d	3.08c	5.22a
PU at 72.2	2.03d	3.49bc	3.72b
PU at 117.3	2.24c	4.77ab	5.32a
PU based on LCC	1.78d	2.19c	6.00a
SE(±)		0.502	

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

Table 4.23: Effects of N-fertilizers, Rates and Varieties on Straw yield (t/ha) of rice at Talata Mafara and Kadawa in 2012, 2013 cropping seasons.

Treatment	Talata Mafara				Kadawa			
	2012	2013	combined	%↑	2012	2013	combined	%↑
Nitrogen (N) kg/ha								
Control	3.26c	3.16c	3.21c	-	3.93d	5.65d	4.79d	-
USG at 45.1	3.96bc	5.10ab	4.53b	41.12	7.74bc	9.72b	8.73b	82.25
USG at 72.2	3.97bc	5.50ab	4.73ab	47.35	8.43b	8.45bc	8.44bc	76.20
USG at 117.3	5.63ab	4.94ab	5.28ab	64.49	10.77a	12.01a	11.39a	137.79
GU at 45.1	5.19abc	4.51abc	4.85ab	51.09	6.09c	7.61c	6.85c	43.01
GU at 72.2	4.52abc	4.13bc	4.33bc	34.89	6.75bc	8.60bc	7.68bc	60.33
GU at 117.3	5.95a	5.75a	5.85a	85.36	7.16bc	8.68bc	7.92bc	65.34
GU based on LCC	4.02bc	4.25bc	4.13bc	28.66	6.27c	7.48c	6.87c	43.42
S.E ±	0.608	0.514	0.609		0.586	0.489	0.774	
Variety (V)								
FARO 55	2.98b	2.52c	2.75c		7.95a	5.42c	6.68b	
FARO 57	5.45a	4.41b	4.93b		5.75b	10.64a	8.20a	
FARO 52	5.25a	7.15a	6.20a		7.72a	9.52b	8.62a	
S.E ±	0.373	0.315	0.374		0.359	0.300	0.475	
Interaction								
N x V	NS	NS	NS		NS	NS	NS	

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

Table 4.24: Effects of N-fertilizers, rates and varietyon 1000-grain weight (g) of paddy rice at Talata Mafara and Kadawa in 2012, 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	22.52bcd	25.41b	23.97ab	26.09	25.97	26.03
USG at 45.1	23.38abc	26.27ab	24.82ab	26.61	26.56	26.58
USG at 72.2	20.59cd	27.41ab	24.00ab	26.09	26.20	26.15
USG at 117.3	25.22ab	25.79ab	25.80ab	25.69	25.96	25.82
GU at 45.1	19.86d	26.44qb	23.15b	25.32	26.23	25.77
GU at 72.2	22.65bcd	26.76ab	24.70ab	27.28	26.79	27.04
GU at 117.3	26.42a	26.42ab	26.42a	25.84	26.42	26.13
GU based on LCC	20.36cd	27.93a	24.14ab	25.88	26.56	26.22
S.E ±	1.172	0.765	0.803	0.704	0.728	0.501
Variety (V)						
FARO 55	22.76	28.33a	25.17a	25.25b	26.69	25.97
FARO 57	23.49	27.70a	25.44a	26.68a	26.13	26.41
FARO 52	21.62	23.63b	22.58b	26.36ab	26.18	26.27
S.E ±	0.829	0.468	0.492	0.431	0.446	0.307
Interaction						
N x V	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

where application of GU at 117.3 kg N/ha recorded heaviest (26.42 g) grain weight, while GU applied at 45.1 kg N/ha recorded the least (23.15 g). However, there was no significant difference in the combined analysis at Kadawa. The varietal response showed that FARO 57 had the heaviest (25.44 g) grain weight, while FARO 52 recorded thelightest (22.58g). However, there were no significant interactions of N management and varieties at both locations as presented in Table 4.24.

4.7 Grain Harvest Index (%)

Table 4.25 showed the analysed result of grain harvest index (%) as affected by rice varieties, N-form of fertilizer and rates at Talata Mafara and Kadawa in 2012, 2013 and combined. There was significant difference ($p<0.5$) at Talata Mafara where application of GU based on LCC had the highest (49.57%) harvest index. Application of GU at 117.3 kg N/ha recorded the least (42.10%). There was no significant difference among treatments at Kadawa. Varietal response showed that FARO 57 had the highest (48.40%) harvest index at Talata Mafara, while FARO 55 recorded the highest (31.73%) harvest index at Kadawa. There were no significant interaction of N-management and rice varieties on grain harvest index in all the years and locations as shown in Table 4.25.

4.8 Nutrient Harvest Indices

4.8.1 Nitrogen (N) - Harvest Index (%)

Result of N-harvest index as affected by rice varieties and N-management is shown in Table 4.26. Result showed that application of USG at 45.1 kg N/ha recorded the

Table 4.25: Effects of forms of N-fertilizers, rates and varietyon Grain harvest index (%) of paddy rice at Talata Mafara andKadawa in 2012, 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	50.43ab	42.42	46.43ab	36.96	27.19	32.07
USG at 45.1	52.57ab	43.72	48.14ab	31.94	28.47	30.21
USG at 72.2	51.24ab	43.06	47.15ab	34.91	30.31	32.61
USG at 117.3	45.20bc	46.67	46.67ab	31.13	27.36	29.24
GU at 45.1	49.30abc	42.12	45.71ab	32.46	29.24	30.85
GU at 72.2	52.44ab	44.74	48.59ab	30.79	29.07	29.93
GU at 117.3	42.10c	42.10	42.10b	32.62	28.36	30.49
GU based on LCC	55.02a	44.11	49.57a	33.47	29.64	31.56
S.E ±	2.228	3.130	2.151	2.118	1.873	1.398
Variety (V)						
FARO 55	46.23b	45.98a	46.20	35.16a	28.29	31.73a
FARO 57	52.07a	44.78ab	48.40	29.87b	28.40	28.96b
FARO 52	51.06a	40.09b	46.81	34.07a	29.78	31.29a
S.E ±	1.576	1.920	1.317	1.297	1.147	0.856
Interaction						
N x V	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

Table 4.26: Effects of N-fertilizers, rates and varietyon Nitrogen harvest index (%) of paddy rice at Talata Mafara and Kadawa in 2012, 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	63.99ab	71.22abc	67.61ab	36.96	31.75ab	34.36ab
USG at 45.1	69.08a	78.30a	73.69a	31.94	35.81a	33.88ab
USG at 72.2	61.69ab	70.79abc	66.33abc	34.91	39.23a	37.07a
USG at 117.3	63.98ab	65.03bc	65.03abc	31.13	36.66a	33.89ab
GU at 45.1	50.08b	64.30bc	57.19c	32.46	23.87b	28.17b
GU at 72.2	64.61ab	72.23ab	68.42ab	30.79	34.36a	32.58ab
GU at 117.3	60.19ab	60.19c	60.19bc	32.62	33.32a	32.97ab
GU based on LCC	61.50ab	66.68bc	64.09abc	33.47	34.86a	34.17ab
S.E ±	4.652	3.446	3.129	2.118	3.029	2.055
Variety (V)						
FARO 55	61.65	72.87a	67.14	35.16a	38.64a	36.89a
FARO 57	66.03	68.41ab	67.44	29.87b	32.30b	31.09b
FARO 52	57.99	64.57b	62.53	34.07a	30.26b	32.17b
S.E ±	3.289	2.110	1.916	1.297	1.855	1.258
Interaction						
N x V	NS	NS	NS	NS	*	*

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. *= significant at 5% levels of probability; NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

highest (73.69%) nitrogen harvest index, while GU at 45.1 kg N/ha had the least (57.19%) at Talata Mafara. Resultfor the Kadawa site showed that USG applied at 72.2kgN/ha had the highest (37.07%) nitrogen harvest index, while GU at 45.1 had the least (28.17%).

Varietal response showed that FARO 57 had the highest (67.44%) nitrogen harvest index at Talata Mafara (Table 4.26), while FARO 55 had the highest (36.89%) nitrogen harvest index at Kadawa. The interaction of N-management and rice varieties was not significant at Talata Mafara but significant at Kadawa.FARO 55 under control at Kadawa had the highest (42.65%) nitrogen harvest index, although it gave similar result with the application of GU at 72.2 kg N/ha as presented in Table 4.27.

4.8.2 Phosphorus (P) - Harvest Index (%)

The effect of N-management on P-harvest index of three rice varieties in 2012, 2013 and combined at Talata Mafara and Kadawa is presented in Table 4.28. Results revealed that application of GU based on LCC had the highest (51.56%)P-harvest index, while GU at 117.3 kg N/ha had the least (36.46%)P-harvest index at Talata Mafara.For the Kadawa site, application of GU based on LCC also recorded the highest (40.34%)P-harvest index, while the USG applied at 45.1 kg N/ha had the least (30.75%).

Table 4.27: Interaction of N-form of fertilizer, rates and variety on Nitrogen Harvest Index (NHI) atKadawa in 2013.

	2013			Combined		
Treatment	Variety					
N-fertilizer (kg/ha)	FARO 55	FARO 57	FARO 52	FARO 55	FARO 57	FARO 52
Control	44.63a	24.06b	26.58b	42.65a	29.73a	30.69a
USG at 45.1	40.30a	35.82ab	31.31b	37.03a	30.97a	33.63a
USG at 72.2	44.71a	35.07b	37.90a	39.31a	36.24a	35.64a
USG at 117.3	39.54a	47.48a	22.97bc	35.66a	37.13a	28.90ab
GU at 45.1	17.81c	26.92b	29.88b	26.65b	26.27b	31.57a
GU at 72.2	50.68a	17.95c	34.44b	42.18a	21.60b	33.95a
GU at 117.3	41.33a	32.78b	25.86b	38.53a	33.46a	26.93b
GU based on LCC	30.10b	38.37a	36.12a	33.18a	33.31a	36.01a
SE(±)		5.248			5.068	

Means followed by the same letter(s) are statistically the same using DMRT at 5% level of significance

Table 4.28: Effects of N-fertilizers, rates and varieties on Phosphorus harvest index (%) of paddy rice at Talata Mafara andKadawa in 2012, 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	51.23ab	35.34	43.28ab	41.30	24.37c	32.84
USG at 45.1	50.10ab	39.42	44.76ab	35.13	26.38bc	30.75
USG at 72.2	54.83a	29.95	42.39ab	45.17	31.83abc	38.49
USG at 117.3	38.20bc	39.85	39.85ab	44.63	28.40abc	36.51
GU at 45.1	54.76a	38.23	46.49ab	31.76	31.41abc	31.58
GU at 72.2	50.66ab	43.23	46.95ab	34.66	35.26ab	34.96
GU at 117.3	36.46c	36.46	36.46b	41.42	30.54abc	35.98
GU based on LCC	59.67a	43.45	51.56a	44.50	36.17a	40.34
S.E ±	4.175	4.202	3.481	4.906	2.969	3.178
Variety (V)						
FARO 55	45.47b	41.64	43.34	39.77	26.98b	33.37b
FARO 57	49.44ab	35.39	43.79	39.80	25.63b	32.72b
FARO 52	53.55a	37.69	47.36	39.89	39.03a	39.46a
S.E ±	2.952	2.573	2.132	3.004	1.818	1.946
Interaction						
N x V	NS	NS	NS	NS	*	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. *= significant at 5% levels of probability; NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

Varietal response showed that FARO 52 had the highest (47.36 and 39.46%) phosphorus harvest indexes in both sites, while FARO 55 recorded the least 43.34% at Talata Mafara and 32.72% Kadawa respectively. The interaction of N-management and rice varieties on P-harvest index was only significant in 2013 at Kadawa where application of GU at 72.2 kg N/ha to FARO 52 had the highest (55.41%) P-harvestindex. The value obtained was statistically similar to that obtained when GU based on LCC (54.11%) to FARO 52. The lowest (17.01 %) was recorded with the control on FARO 55 as presented in Table 4.30.

4.8.3 Potassium (K)-Harvest Index (%)

Table 4.29 showed the analysed result of N-management and rice varieties on K-harvest index in 2012, 2013 and combined at Talata Mafara and Kadawa. At Talata Mafara, application of GU at 72.2 kg N/ha recorded the highest (30.33%) K-harvest index, while USG at 117.3 kg N/ha had the least (15.71 %). On the other hand, application of USG at 72.2 kg N/ha had the highest (14.28%) K-harvest index at Kadawa, while GU at 72.2 kg N/ha recorded the least (10.03%).

Varietal response showed no significant difference at Talata Mafara, while FARO 55gave the highest. The interaction of N-management and rice varieties on K-harvest index was only significant at Kadawa in 2013, where application of USG at 72.2 kg N/ha to FARO 55 recorded the highest (32.80%) K-harvest index while application of GU at 72.2 kg N/ha on FARO 57 had the least (3.40%) as shown in Table 4.30.

Table 4.29: Effects of N-fertilizers, rates and varietyon Potassium harvest index (%) of paddy rice at Talata Mafara andKadawa in 2012, 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	28.31abc	17.69	23.00ab	15.90	9.84ab	12.87
USG at 45.1	26.11abc	16.22	21.16ab	13.29	8.07ab	10.68
USG at 72.2	33.71ab	14.46	24.08ab	13.60	14.96a	14.28
USG at 117.3	14.87c	15.71	15.71b	12.86	8.38ab	10.62
GU at 45.1	36.60a	15.62	26.11ab	13.60	7.55ab	10.58
GU at 72.2	44.58a	16.08	30.33a	14.97	5.09b	10.03
GU at 117.3	16.19bc	16.19	15.71b	13.45	8.19ab	10.82
GU based on LCC	30.88abc	17.13	24.00ab	15.05	9.21ab	12.13
S.E ±	5.763	2.068	3.578	1.791	2.282	1.562
Variety (V)						
FARO 55	25.01	18.07	22.11	15.41	10.94	13.18a
FARO 57	30.78	15.59	24.19	12.64	6.96	9.80b
FARO 52	36.93	14.75	24.26	14.22	8.83	11.52ab
S.E ±	3.536	1.267	2.191	1.097	1.397	0.957
Interaction						
N x V	NS	NS	NS	NS	*	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. *= significant at 5% levels of probability; NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

Table 4.30: Interaction of N-form of fertilizer, rates and variety on Phosphorus (P) and Potassium (K)Harvest Index at Kadawa in 2013 cropping season.

Treatment	Variety					
	Phosphorus (P)Harvest Index (%)			Potassium (K) Harvest Index (%)		
N-fertilizer (kgha^{-1})	FARO 55	FARO 57	FARO 52	FARO 55	FARO 57	FARO 52
Control	17.01d	23.41c	32.69bc	7.97b	8.69b	12.84b
USG at 45.1	36.89b	17.37d	24.87c	11.79b	5.20b	7.21b
USG at 72.2	33.97b	20.82cd	40.69b	32.80a	4.67b	7.40b
USG at 117.3	27.95c	27.69c	29.56c	9.92b	6.29b	8.94b
GU at 45.1	22.35c	26.08c	45.78ab	6.41b	7.44b	8.81b
GU at 72.2	25.83c	24.52c	55.41a	5.11b	3.40b	6.75b
GU at 117.3	25.35c	37.16b	29.09c	5.26b	12.04b	7.26b
GU based on LCC	26.45c	27.95c	54.11a	8.29b	7.94b	11.40b
SE(±)		5.143			3.952	

Means followed by the same letter(s) are statistically the same using DMRT at 5% level of significance.

4.9 Nutrient Uptake

4.9.1 Nitrogen (N) uptake (kg/ha)

Effect of N-management and rice varieties on total N-uptake in 2012, 2013 and combined is shown in Table 4.31. Application of USG at 72.2 kg N/ha had the highest (83.86 kg/ha) N-uptake and control recorded the least (42.40 kg/ha) at Talata Mafara while at Kadawa, application of USG at 117.3 kg N/ha had the highest (111.77 kg/ha) N-uptake and control had the least (37.09 kg/ha). The varietal response showed that FARO 52 had the highest (92.48 kg/ha) whichis statistically similar to FARO 57, while at Kadawa, there was no significant difference on varietal response.

Also, the interaction of N-management and rice varieties on total N uptake was only significant in 2013 at both locations as presented in Table 4.32. Application of GU based on LCC had the highest (124.45 kg/ha) N-uptake. This was statistically similar to application of GU at 117.3 kg N/ha, GU at 45.1 kg N/ha and USG at 72.2 kg N/ha to FARO 52. FARO 57 under the control treatment recorded the least (20.44 kg/ha) N-uptake at Talata Mafara. Similarly, application of USG at 117.3 kg N/ha to FARO 52 recorded the highest (132.56 kg/ha) N-uptake at Kadawa, while FARO 57 (20.44 kg/ha) under control had the least (27.93 kg/ha) N-uptake. Values obtained with above treatment were at par to that of FARO 57 under control as presented in Table 4.32.

Table 4.31: Effects of N-fertilizers, rates and variety on Nitrogen (N) Uptake (kg/ha) at Talata Mafara and Kadawa in 2012 and 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	53.44c	31.36d	42.40b	38.59d	35.59c	37.09c
USG at 45.1	96.05ab	50.05c	73.05a	100.68bc	87.45a	94.06ab
USG at 72.2	87.94ab	79.79a	83.86a	126.35ab	68.81b	97.58ab
USG at 117.3	72.36bc	62.72abc	62.21ab	135.99a	87.55a	111.77a
GU at 45.1	96.00ab	60.75bc	78.37a	89.57c	84.65a	87.11b
GU at 72.2	113.22a	50.12c	81.67a	103.11bc	73.16ab	88.13b
GU at 117.3	74.21bc	72.21ab	74.21a	97.60bc	72.62ab	85.11b
GU based on LCC	100.32ab	64.60abc	82.46a	87.95c	73.94ab	80.95b
S.E ±	9.35	5.801	7.383	10.973	4.898	7.005
Variety (V)						
FARO 55	54.36c	35.35c	43.50b	107.37	55.76c	81.56
FARO 57	120.06a	54.51b	82.60a	90.08	74.36b	82.22
FARO 52	99.07b	87.54a	92.48a	94.98	88.79a	91.89
S.E ±	6.610	3.550	4.521	6.719	2.999	4.289
Interaction						
N x V	NS	**	NS	NS	*	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. *, ** = significant at 5% & 1% levels of probability; NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

Table 4.32: Interaction of N-form of fertilizers, rates and variety on N uptake (kg/ha) at TalataMafara and Kadawa in 2013 cropping season.

Treatment	Variety					
	2013					
	Talata Mafara			Kadawa		
N-fertilizer ($kgha^{-1}$) Variety	FARO 55	FARO 57	FARO 52	FARO 55	FARO 57	FARO 52
Control	24.89d	20.44d	48.74c	27.93e	32.98e	45.87d
USG at 45.1	35.49d	46.60c	68.05b	64.72c	102.76b	94.87b
USG at 72.2	35.79d	95.87ab	107.70a	55.14d	62.94cd	88.35b
USG at 117.3	44.73c	74.29b	67.61bc	65.94c	64.14c	132.56a
GU at 45.1	40.32cd	43.10c	98.82a	92.11b	75.99c	85.86b
GU at 72.2	29.21d	57.81c	63.33c	45.58d	97.39b	76.49c
GU at 117.3	37.04d	63.96c	121.64a	54.39d	78.38c	85.07b
GU based on LCC	35.34d	34.01d	124.45a	40.23de	80.32bc	101.27b
SE(±)		10.04			8.484	

Means followed by the same letter(s) are statistically the same using DMRT at 5% level of significance.

4.9.2 Phosphorus (P) uptake (kg/ha)

The effect of N-management and three rice varieties on P-uptake in 2012, 2013 and combined at Talata Mafara and Kadawa is presented in Table 4.33. The result showed that that application of GU at 117.3 kg N/ha had the highest (22.62 kg/ha) P-uptake, while the control recorded the least (11.88 kg/ha) at Talata Mafara. On the other hand, USG applied at 117.3 kg N/ha had the highest (35.01 kg/ha) P-uptake, while the control had the least (14.38 kg/ha) at Kadawa. Varietal response showed that at both locations, FARO 52 had the highest (23.79 kg/ha and 26.17 kg/ha) P-uptake, while FARO 55 recorded the least (10.71 kg/ha and 20.54 kg/ha) at Talata Mafara and Kadawa respectively. There were no significant interactions of N- management and rice varieties on P-uptake in all the years and at both locations.

4.9.3 Potassium (K) uptake (kg/ha)

Table 4.34 shows the effect of N-management and rice varieties on total K-uptake in 2012, 2013 and combined at Talata Mafara and Kadawa. Application of USG 117.3 kgN/ha had the highest 197.04 kgN/ha K-uptake, while the control had the least (72.22 kg/ha) at Talata Mafara. However, at Kadawa, application of USG at 117.3 kgN/ha had the highest (338.13 kg/ha) K-uptake, while control had the least (122.15 kg/ha). Varietal response showed that FARO 52 had the highest (187.86 kg/ha) K-uptake, while FARO 55 recorded the least (68.65 kg/ha) at Talata Mafara. On the other hand, FARO 57 had the highest (272.20 kg/ha) K-uptake, while FARO 55 had the least (172.40 kg/ha) at Kadawa. There were no significant interactions of

Table 4.33: Effects of N-fertilizers, rates and variety on Phosphorus (P) Uptake (kg/ha) at Talata Mafara and Kadawa in 2012, 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	11.49c	12.28	11.88b	10.35d	18.41c	14.38d
USG at 45.1	16.42bc	20.38	18.40a	19.42bc	35.08a	27.25b
USG at 72.2	16.18bc	20.62	18.40a	22.21b	28.97b	25.59bc
USG at 117.3	22.98a	21.44	21.44a	30.68a	39.34a	35.01a
GU at 45.1	17.54b	21.77	19.66a	13.25cd	26.86b	20.06cd
GU at 72.2	15.77bc	18.73	17.52a	18.97bc	27.82b	23.39bc
GU at 117.3	22.62a	22.62	22.62a	18.94bc	26.10b	22.52b
GU based on LCC	14.83ab	21.08	17.96a	14.81bcd	26.60b	20.70bcd
S.E $\pm$	1.425	2.178	1.690	2.432	1.984	2.253
Variety (V)						
FARO 55	9.20c	11.84c	10.71c	23.24a	17.84b	20.54b
FARO 57	20.46a	18.45b	19.31b	12.54b	35.73a	24.13ab
FARO 52	16.45b	29.30a	23.79a	19.96a	32.37a	26.17a
S.E $\pm$	1.008	1.334	1.035	1.489	1.215	1.379
Interaction						
N x V	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

Table 4.34: Effects of N-fertilizers, rates andvariety onPotassium (K) Uptake (kg/ha) at Talata Mafara and Kadawain 2012, 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	46.43d	98.01b	72.22c	77.10d	167.19c	122.15c
USG at 45.1	82.60cd	176.83a	129.72b	162.84bc	359.16ab	261.00ab
USG at 72.2	67.53d	198.71a	133.12b	178.07b	321.34ab	249.70ab
USG at 117.3	227.19a	197.04a	197.04a	222.71a	448.54a	338.13a
GU at 45.1	142.44bc	181.04a	161.74ab	131.41c	236.81bc	184.11bc
GU at 72.2	90.84cd	149.71ab	120.27bc	123.71bc	433.02a	278.37ab
GU at 117.3	192.61ab	192.61a	192.61a	155.84bc	249.77bc	202.80bc
GU based on LCC	53.35d	203.76a	128.55b	124.45c	290.04bc	207.25bc
S.E ±	21.53	19.46	17.721	14.291	43.811	31.120
Variety (V)						
FARO 55	34.42b	94.32c	68.65c	176.07a	168.72c	172.40b
FARO 57	105.17a	177.57b	146.54b	114.08b	430.33a	272.20a
FARO 52	102.01a	252.25a	187.86a	152.78a	340.65b	246.71a
S.E ±	15.220	11.914	10.851	8.751	26.829	19.057
Interaction						
N x V	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

N-management and varieties on K-uptake in all the years and locations as presented in Table 4.34.

4.10 Effects of forms of N-fertilizers, rates and variety on nutrient use efficiencies

4.10.1 Agronomic Efficiency (AE)

The effect of N-management and rice varieties on agronomic efficiency in 2012, 2013 and combined at Talata Mafara and Kadawa is presented in Table 4.35. Application of GU at 45.1 kg N/ha had the highest (36.31%) AEat Talata Mafara and this was closely followed by USG at 45.1 kg N/ha, while the least (17.25%) was recorded by GU applied at 117.3 kg N/ha. AtKadawa, application of USG at 45.1 kg N/ha had the significantly highest (38.01%)AE; while the GU applied at 117.3 kg N/ha had the least (11.52%).

Varietiesevaluated also exhibited significant variation in AE at both locations.FARO 52 had significantly the highest (31.81% and 26.72%) AE, while FARO 55 recorded the least (9.67% and 13.67%) at Talata Mafara and Kadawa respectively.

Interaction of N-management and rice varieties on agronomic efficiency had no significant differences across the two locations and the years of study as presented in Table 4.35.

Table 4.35: Influence of N-fertilizers, rates and rice variety on Agronomic Efficiency (AE) at Talata Mafara and Kadawa in 2012, 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	-	-	-	-	-	-
USG at 45.1	30.81ab	37.33a	34.07ab	35.72a	40.29a	38.01a
USG at 72.2	15.47bc	26.17ab	20.82ab	27.27ab	20.27ab	23.77bc
USG at 117.3	20.10b	17.97abc	17.58b	24.05abc	21.61ab	22.83bc
GU at 45.1	43.04a	29.59ab	36.31a	19.03bc	27.04ab	23.03bc
GU at 72.2	24.53b	13.79c	19.16ab	13.08c	21.22ab	17.15bc
GU at 117.3	19.85bc	18.50abc	17.25b	11.74c	11.30bc	11.52c
GU based on LCC	14.10c	35.13a	24.62ab	22.35bc	31.02ab	26.68b
S.E $\pm$	6.077	6.262	5.574	4.184	6.238	6.238
Variety (V)						
FARO 55	13.87b	5.17c	9.52b	17.74b	9.60b	13.67b
FARO 57	20.84ab	25.07b	20.78a	11.26b	30.30a	20.78a
FARO 52	27.33a	36.28a	31.81a	28.51a	24.94a	26.72a
S.E $\pm$	3.721	3.835	3.413	2.562	3.819	2.414
Interaction						
N x V	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

4.10.2 Agro Physiological Efficiency (APE)

The effect of N-management and rice varieties on agro physiological efficiency in 2012, 2013 and combined at both Talata Mafara and Kadawa is presented in Table 4.36. The results indicated that application of USG at 72.2 kg N/ha had the highest (117.21%) APE, while the least (29.14%) was recorded by GU based on LCC at Talata Mafara.

At Kadawa, application of USG at 117.3 kg N/ha had the highest (88.87%) APE and was closely followed by USG applied at 72.2 kg N/ha, while the GU at 45.1 kg N/ha had the least (25.68%).The varietal response and interaction of N-management showed no significant differences across the two locations in the two years of study as presented in Table 4.36.

4.10.3 Nitrogen Utilization Efficiency (NUE)

The effect of N-management on nitrogen utilization efficiency of rice varieties in 2012, 2013 and combined at Talata Mafara and Kadawa is presented in Table 4.37. Results at Talata Mafara showed that application of GU at 45.1 kg N/ha had significantly the highest (72.98%) nitrogen utilization efficiency, while the least (33.16%) was recorded by USG at 117.3 kg N/ha. AtKadawa, results showed that application of USG at 45.1 kg N/ha had significantly increased NUE by above 125.47% above the control, while the GU applied at 117.3 kg N/ha increasedNUE by 38.98% above the control. Generally, USG increased NUE by about 69% over GU at the same rate.

Table 4.36: Influence of N-fertilizers, rates and rice variety onAgro physiological efficiency(APE)at Talata Mafara andKadawa in 2012, 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	-	-	-	-	-	-
USG at 45.1	61.06ab	78.35	69.71ab	32.12a	33.42	32.74ab
USG at 72.2	73.40a	161.03	117.21a	33.82a	51.25	42.53ab
USG at 117.3	33.55ab	32.53	32.53ab	35.60a	34.21	188.87a
GU at 45.1	47.35ab	32.12	39.73ab	27.19ab	24.27	25.68b
GU at 72.2	29.10ab	102.48	65.79ab	15.90b	48.30	32.12ab
GU at 117.3	55.45ab	52.45	55.45ab	26.34ab	46.92	36.64ab
GU based on LCC	17.21ab	41.08	29.14b	33.61a	33.00	33.31ab
S.E ±	20.324	51.40	74.850	8.542	10.44	52.927
Variety (V)						
FARO 55	22.23	94.39	63.47	26.56a	31.66	29.11
FARO 57	43.75	49.03	46.77	11.62b	36.19	80.90
FARO 52	48.14	45.26	46.49	38.58a	35.41	37.00
S.E ±	12.446	31.476	45.837	5.231	6.391	32.412
Interaction						
N x V	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

Table 4.37: Influence of N-fertilizer, rates and rice variety onnitrogen utilization efficiency (NUE) at Talata Mafara andKadawa in 2012 and 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	-	-	-	-	-	-
USG at 45.1	27.78ab	48.20a	37.99ab	72.19a	78.38a	75.28a
USG at 72.2	15.19bc	35.43ab	25.30ab	53.81ab	35.42bc	44.62b
USG at 117.3	22.51bc	19.90bc	19.90c	49.42abc	45.98ab	47.70b
GU at 45.1	51.83a	35.74ab	43.79a	40.16bc	42.25ab	41.20bc
GU at 72.2	25.19b	16.36c	20.78bc	31.34bc	37.26b	34.30bc
GU at 117.3	24.62b	24.62b	24.62ab	23.59c	23.19c	23.38c
GU based on LCC	13.33c	38.53ab	25.93ab	45.26bc	44.56ab	44.91b
S.E $\pm$	7.997	6.940	8.656	8.512	7.649	16.121
Variety (V)						
FARO 55	19.15	8.06b	13.70b	41.53ab	22.90b	31.01b
FARO 57	19.63	33.62a	25.67a	27.33b	52.27a	39.80ab
FARO 52	28.93	40.39a	36.12a	49.58a	42.40a	46.00a
S.E $\pm$	4.898	4.250	4.254	5.212	4.684	3.748
Interaction						
N x V	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

Thevarieties evaluated also exhibited significant differences in NUE at both locations, where FARO 52 had significantly the highest (60.18% and 76.66%) values, while FARO 55 recorded the least (22.84% and 51.68%) at Talata Mafara and Kadawa respectively. There were no significant interactions among the factors observed in all the years at both locations as presented in Table 4.37.

4.11 Influence of N-management and rice variety on soil chemical properties after harvest

Table 4.38 to 4.47 showed the influence of N-management and rice varieties on soil chemical properties after harvest. Combined analysis of the results showed that soil pH in water, organic carbon and exchangeable Na were not significantly influenced by treatments while soil pH in $CaCl_2$, available P, and exchangeable K were significantly affected at Talata Mafara and Kadawa.

For Soil pH in water, there was no significant effect except at Kadawa in 2013. Application of GU at 45.1 kgN/ha gave the lowest (6.59) acidity while control recorded the highest (6.35) as presented in Table 4.38. Similarly at Talata Mafara, soil pH in $CaCl_2$ showed that application of GU at 72.2 kgN/ha recorded the lowest (5.99) acidity while GU applied at 117.3 kgN/ha had the highest (5.66). However, application of GU at 117.3 kgN/ha recorded the highest (6.01) acidity while the control had the lowest (6.22) at Kadawa, as presented in Table 4.39. Furthermore, there is significant interaction of N-management and variety on soil pH in $CaCl_2$. Application of GU at 117.3 kgN/ha to FARO 57 gave the highest (5.54) acidity

Table 4.38: Influence of N-fertilizer, rates and variety on soil pH (water) after harvest at Talata Mafara and Kadawa in 2012 and2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	6.73	6.61	6.67	6.77	6.35ab	6.56
USG at 45.1	6.89	6.73	6.81	6.57	6.52ab	6.55
USG at 72.2	6.92	6.88	6.90	6.56	6.50ab	6.53
USG at 117.3	6.72	6.76	6.76	6.57	6.48ab	6.52
GU at 45.1	6.59	6.87	6.73	6.69	6.59a	6.64
GU at 72.2	6.70	6.75	6.72	6.58	6.44ab	6.51
GU at 117.3	6.71	6.70	6.71	6.50	6.51ab	6.50
GU based on LCC	6.82	6.69	6.75	6.71	6.53ab	6.62
S.E $\pm$	0.113	0.105	0.084	0.107	0.067	4.063
Variety (V)						
FARO 55	6.69b	6.81	6.76	6.59	6.64	6.52
FARO 57	6.72ab	6.69	6.70	6.61	6.49	6.55
FARO 52	6.93a	6.74	6.82	6.65	6.53	6.59
S.E $\pm$	0.080	0.064	0.052	0.065	0.041	0.038
Interaction						
N x V	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

Table 4.39: Influence of N-fertilizer, rates and variety on soil pH ($CaCl_2$) after harvest at Talata Mafara and Kadawa in 2012 and2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	6.06ab	5.73abc	5.80ab	6.55a	5.88	6.22a
USG at 45.1	5.66c	5.81ab	5.73cd	6.24ab	5.78	6.01ab
USG at 72.2	5.99ab	5.66c	5.82bc	6.34ab	5.78	6.06ab
USG at 117.3	5.75c	5.76abc	5.76bcd	6.08b	5.93	6.00ab
GU at 45.1	5.79c	5.75abc	5.77bcd	6.31ab	5.82	6.06ab
GU at 72.2	6.13a	5.85a	5.99a	6.28ab	5.87	6.08ab
GU at 117.3	5.65c	5.66c	5.66d	6.12b	5.89	6.01b
GU based on LCC	5.95b	5.69bc	5.82bc	6.32ab	5.86	6.09ab
S.E $\pm$	0.054	0.045	0.045	0.119	0.049	6.01
Variety (V)						
FARO 55	5.91	5.96b	5.79	6.22	5.83	6.02
FARO 57	5.91	5.73ab	5.81	6.33	5.85	6.09
FARO 52	5.96	5.79a	5.86	6.30	5.88	6.09
S.E $\pm$	0.038	0.028	0.028	0.073	0.029	0.040
Interaction						
N x V	*	*	*	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. * = significant at 5% levels of probability; NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart

whileGU applied at 72.2 kgN/ha recorded the lowest (6.16) as presented in Table 4.40.

For soil organic carbon after harvest, there were no significant effect except in 2012 at Talata Mafara and Kadawa. At Talata Mafara, application of GU at 45.1 kgN/ha gave the highest (10.41 gkg^{-1}) O. C, while GU applied based on LCC recorded the least (5.80 gkg^{-1}). At Kadawa, application of USG at 117.3 kgN/ha recorded the highest (8.07 gkg^{-1}) O. C, while control had the least (4.24 gkg^{-1}) as presented in Table 4.41.

Results of soil total N after harvest showed that there were no significant effects except at Talata Mafara. Application of GU based on LCC recorded the highest (0.39 gkg^{-1}) N, while USG applied at 117.3 kgN/ha had the least (0.18 gkg^{-1}) as presented in Table 4.42.

For soil available P, application of GU at 117.3 kg N/ha had the highest (8.68 $mgkg^{-1}$) A. P, while control had the least (6.81 $mgkg^{-1}$) at Talata Mafara. However, at Kadawa, application of USG at 72.2 kg N/ha had the highest (18.11 $mgkg^{-1}$) A. P, while GU applied at 45.1 kg N/ha recorded the least (9.51 $mgkg^{-1}$) as presented in Table 4.43.

Results of exchangeable K after harvest showed that there were significant effect both locations. At Talata Mafara, control treatment recorded the highest (0.416 $cmolkg^{-1}$) K, while application of USG at 117.3 kg N/ha had the lowest (0.251 $cmolkg^{-1}$). At Kadawa, GU applied at 72.2 kg N/ha gave the highest (0.299 $cmolkg^{-1}$) K which was at par with GU applied at 117.3 kg N/ha,

Table 4.40: Interaction of N-fertilizer, rates and variety on Soil pH ($CaCl_2$) at Talata Mafarain 2012 and 2013 cropping seasons.

Treatment	Variety								
	2012			2013			Combined		
N-fertilizer ($kgha^{-1}$)	FARO 55	FARO 57	FARO 52	FARO 55	FARO 57	FARO 52	FARO 55	FARO 57	FARO 52
Control	6.21a	6.18ab	5.79c	5.78ab	5.70b	5.72b	5.99a	5.94a	5.75a
USG at 45.1	5.79c	5.53d	5.66d	5.75b	5.91a	5.75b	5.77a	5.72a	5.70ab
USG at 72.2	5.88c	5.88c	6.21a	5.60b	5.67b	5.70b	5.74a	5.77a	5.96a
USG at 117.3	5.56d	5.69c	5.99b	5.61b	5.69b	5.99a	5.61b	5.69b	5.99a
GU at 45.1	5.68cd	5.91c	5.80c	5.81a	5.87a	5.58bc	5.74a	5.89a	5.69b
GU at 72.2	5.97b	6.07b	6.34a	5.72b	5.84a	5.99a	5.84a	5.96a	6.16a
GU at 117.3	5.71c	5.54d	5.72c	5.71b	5.54c	5.72b	5.71a	5.54b	5.72a
GU based on LCC	5.94b	5.93bc	5.97b	5.58bc	5.63b	5.89a	5.76a	5.78a	5.93a
SE(±)		0.092			0.078			0.162	

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT

Table 4.41: Influence of N-fertilizer, rates andvariety on soil organic carbon (gkg^{-1}) at Talata Mafara and Kadawa in 2012 and 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	7.70bcd	7.90	7.80	4.24b	5.98	5.11
USG at 45.1	9.56abc	7.00	8.28	4.66ab	6.26	5.46
USG at 72.2	9.32abc	7.03	8.18	5.26ab	6.16	5.71
USG at 117.3	7.20bcd	7.09	7.09	8.07a	6.07	7.07
GU at 45.1	10.41a	6.87	8.64	4.56ab	5.98	5.27
GU at 72.2	9.80ab	7.29	8.54	5.92ab	6.14	6.03
GU at 117.3	6.99cd	6.99	6.99	4.43ab	5.82	5.13
GU based on LCC	5.80d	7.21	6.51	4.48ab	6.22	5.35
S.E $\pm$	0.873	0.816	0.649	1.160	0.667	0.667
Variety (V)						
FARO 55	8.96	6.90	7.78	5.38	5.35	5.37
FARO 57	8.72	7.35	7.94	5.45	6.64	6.04
FARO 52	8.62	7.26	7.84	4.78	6.24	5.51
S.E $\pm$	0.617	0.499	0.398	0.711	0.409	0.409
Interaction N x V	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

Table 4.42: Influence of N-fertilizer, rates and variety on soiltotal Nitrogen (g kg^{-1}) after harvest at Talata Mafara andKadawa in 2012 and 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	0.416a	0.320	0.368a	0.304	0.127	0.216
USG at 45.1	0.414a	0.352	0.383a	0.374	0.162	0.268
USG at 72.2	0.490a	0.277	0.383a	0.310	0.197	0.253
USG at 117.3	0.184b	0.184	0.184b	0.260	0.131	0.196
GU at 45.1	0.439a	0.269	0.354a	0.292	0.161	0.227
GU at 72.2	0.539a	0.179	0.359a	0.359	0.128	0.243
GU at 117.3	0.258b	0.258	0.258ab	0.240	0.173	0.207
GU based on LCC	0.509a	0.261	0.385a	0.277	0.131	0.204
S.E $\pm$	0.032	0.083	0.050	0.044	0.022	0.026
Variety (V)						
FARO 55	0.388	0.233	0.329	0.300	0.156	0.228
FARO 57	0.432	0.277	0.362	0.317	0.150	0.234
FARO 52	0.399	0.278	0.361	0.289	0.148	0.219
S.E $\pm$	0.023	0.051	0.031	0.027	0.013	0.016
Interaction						
N x V	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

Table 4.43: Influence of N-fertilizer, rates and variety on SoilAvailable Phosphorus (mg kg^{-1}) after harvest at TalataMafara and Kadawa in 2012 and 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	6.61cd	7.00b	6.81b	20.40ab	8.05	14.23abc
USG at 45.1	6.39d	7.58ab	6.99b	11.14bc	8.13	9.64c
USG at 72.2	7.40bc	7.97ab	7.69b	26.4a	9.81	18.11a
USG at 117.3	8.23ab	7.84ab	7.84ab	9.59c	9.98	9.78c
GU at 45.1	6.33d	8.44ab	7.39b	8.32c	10.70	9.51c
GU at 72.2	6.60cd	7.68ab	7.14b	24.99a	8.49	16.75ab
GU at 117.3	8.68a	8.68a	8.68a	14.20bc	9.04	11.62bc
GU based on LCC	6.15d	8.69a	7.42b	11.78bc	9.74	10.76bc
S.E $\pm$	0.286	0.474	0.319	3.276	1.246	2.042
Variety (V)						
FARO 55	6.65	8.05	7.45	13.55	8.47	11.01
FARO 57	6.54	7.67	7.18	15.41	9.97	12.69
FARO 52	6.55	8.25	7.52	18.60	9.29	13.95
S.E $\pm$	0.202	0.290	0.195	2.006	0.763	1.251
Interaction						
N x V	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

while application of USG at 45.1 kg N/ha recorded the least (0.098 $cmolkg^{-1}$) as presented in Table 4.44.

Varietal response of the rice evaluated on soil properties showed that there were no significant effects on all the parameters observed except for soil pH at Talata Mafara and exchangeable K at Kadawa.

For soil pH in water (2012) and $CaCl_2$ (2013), FARO 52 gave the soil with slight acid (6.93, 5.79); while FARO 55 gave the least (6.69, 5.66) values respectively as presented in Table 4.38 and 4.39.Also for exchangeable K, FARO 55 gave the highest (0.258 cmol kg^{-1}) K, while FARO 57 recorded the least (0.144 cmol kg^{-1}) at Kadawa as presented in Table 4.44.

Results obtained for exchangeable Ca after harvest showed significant effect at Talata Mafara and at Kadawa in 2012 only. At Talata Mafara, application of GU at 117.3 kgN/ha gave the highest (3.956 $cmolkg^{-1}$) Ca, while GU applied at 72.2 kgN/ha recorded the least (3.044 $cmolkg^{-1}$). At Kadawa, USG applied at 45.1 kgN/ha had the highest (2.544 $cmolkg^{-1}$) Ca, while the GU applied at 117.3 kgN/ha recorded the least (1.400 $cmolkg^{-1}$) as presented in Table 4.45.

For exchangeable Mg, there were significant effects at Talata Mafara and at Kadawa in 2012 only. At Talata Mafara, application of GU at 117.3 kgN/ha recorded the highest (1.080 $cmolkg^{-1}$) Mg, while GU applied at 72.2 kgN/ha had the least (0.828 $cmolkg^{-1}$). At Kadawa, application of USG at 45.1 kgN/ha recorded

Table 4.44: Influence of forms of N-fertilizer, rates and variety on exchangeable K (cmol kg^{-1}) after harvest at Talata Mafara and Kadawa in 2012 and 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	0.353	0.478	0.416a	0.177bc	0.140	0.158ab
USG at 45.1	0.362	0.322	0.342ab	0.097c	0.100	0.098b
USG at 72.2	0.314	0.249	0.282ab	0.277abc	0.153	0.215ab
USG at 117.3	0.293	0.251	0.251b	0.126bc	0.100	0.113ab
GU at 45.1	0.327	0.293	0.311ab	0.120bc	0.144	0.132ab
GU at 72.2	0.337	0.300	0.319ab	0.502a	0.097	0.299a
GU at 117.3	0.337	0.338	0.338ab	0.428ab	0.152	0.295a
GU based on LCC	0.287	0.412	0.349ab	0.178bc	0.113	0.146ab
S.E $\pm$	0.019	0.091	0.048	0.101	0.022	0.058
Variety (V)						
FARO 55	0.346	0.296	0.313	0.390a	0.125	0.258a
FARO 57	0.326	0.378	0.355	0.159b	0.128	0.144b
FARO 52	0.308	0.318	0.323	0.168b	0.122	0.145b
S.E $\pm$	0.013	0.048	0.029	0.062	0.013	0.036
Interaction						
N x V	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

Table 4.45: Influence of forms of N-fertilizer, rates and variety on soilexchangeable Ca (cmol kg^{-1}) after harvest at Talata Mafaraand Kadawa in 2012 and 2013 cropping seasons

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	2.674bc	3.800	3.237b	2.289a	2.163	2.226
USG at 45.1	2.719bc	3.666	3.193b	2.544a	2.400	2.472
USG at 72.2	2.637bc	4.022	3.329b	1.756ab	2.333	2.044
USG at 117.3	3.822a	3.844	3.844a	1.933ab	2.378	2.156
GU at 45.1	2.884b	3.600	3.242b	2.322a	2.489	2.406
GU at 72.2	2.467c	3.622	3.044b	2.267a	2.200	2.233
GU at 117.3	3.956a	3.955	3.956a	1.400b	2.689	2.044
GU based on LCC	2.644bc	3.867	3.256b	1.889ab	2.267	2.078
S.E $\pm$	0.113	0.179	0.116	0.262	0.179	0.164
Variety (V)						
FARO 55	2.950	3.725	3.224	1.950	2.253	2.102
FARO 57	2.983	3.900	3.414	2.018	2.400	2.204
FARO 52	2.993	3.767	3.306	2.192	2.442	2.317
S.E $\pm$	0.080	0.109	0.071	0.161	0.109	0.100
Interaction						
N x V	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

the highest (0.684 cmolkg^{-1}) Mg, while GU applied at 117.3 kgN/ha had the least (0.378 cmolkg^{-1}) as presented in Table 4.46.

Results of soil exchangeable Na after harvest showed significant effect only in 2012 at both locations. Application of GU at 72.2 kgN/ha gave the highest (0.268 cmolkg^{-1}) Na, while GU at 117.3 kgN/ha recorded the least (0.169 cmolkg^{-1}) at Talata Mafara. At Kadawa, GU applied at 72.2 kgN/ha had the highest (0.290 cmolkg^{-1}) Na, while application of USG at 117.3 kgN/ha recorded the least (0.097 cmolkg^{-1}) as presented in Table 4.47.

4.12 Correlation Analysis

4.12.1 Correlation analysis at Talata Mafara

The results of correlation analyses in 2012, 2013 and combined among growth, paddy yield, yield components and selected soil parameters at Talata Mafara are presented in Table 4.48, 4.49 and 4.50 respectively. In 2012, paddy yield was found to be significantly and positively correlated with biomass (r = 0.906**), straw yield (r = 0.754**), plant height (r = 0.317**), number of tillers (r = 0.307**), crop dry matter (r = 0.266*), number of panicles (r = 0.275*) and total N uptake (r = 0.869**)**.** Onthe other hand, the paddy yield was strongly and negatively correlated with weight of 1,000-grain (r = - 0.423**). Paddy yield did not significantly correlated with soil pH (r = 0.084) andsoilavailable P (r = 0.007) but was negatively correlated with soiltotal N (r = - 0.084)and soil exchangeable K (r = - 0.116) as presented in Table 4.48.

Table 4.46: Influence of form of N-fertilizer, rates and variety on soilexchangeable Mg (cmol kg^{-1}) after harvest at Talata Mafaraand Kadawa in 2012 and 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	0.721bc	1.008	0.864b	0.612a	0.632	0.622
USG at 45.1	0.738bc	0.957	0.847b	0.684a	0.617	0.651
USG at 72.2	0.728bc	1.076	0.902b	0.472ab	0.620	0.546
USG at 117.3	1.041a	1.046	1.046a	0.519ab	0.626	0.572
GU at 45.1	0.782b	0.974	0.878b	0.623a	0.666	0.644
GU at 72.2	0.668c	0.988	0.828b	0.607a	0.651	0.629
GU at 117.3	1.080a	1.080	1.080	0.378b	0.742	0.560
GU based on LCC	0.709bc	1.047	0.878b	0.508ab	0.607	0.557
S.E $\pm$	0.029	0.049	0.032	0.0703	0.042	0.042
Variety (V)						
FARO 55	0.805	1.007	0.874	0.520	0.630	0.575
FARO 57	0.810	1.053	0.922	0.540	0.632	0.586
FARO 52	0.809	1.005	0.887	0.591	0.673	0.632
S.E $\pm$	0.021	0.029	0.019	0.043	0.026	0.053
Interaction						
N x V	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

Table 4.47: Influence of form of N-fertilizer,rates and variety on soilexchangeable Na (cmol kg^{-1}) after harvest at Talata Mafaraand Kadawa in 2012 and 2013 cropping seasons.

Treatment	Talata Mafara			Kadawa		
	2012	2013	combined	2012	2013	combined
Nitrogen (N) kg/ha						
Control	0.218abc	0.148	0.183	0.132bc	0.087	0.109
USG at 45.1	0.252ab	0.154	0.203	0.246ab	0.114	0.180
USG at 72.2	0.172c	0.214	0.193	0.212abc	0.206	0.209
USG at 117.3	0.180c	0.193	0.193	0.097c	0.214	0.156
GU at 45.1	0.203bc	0.193	0.198	0.183abc	0.128	0.156
GU at 72.2	0.268a	0.157	0.212	0.290a	0.110	0.200
GU at 117.3	0.169c	0.169	0.169	0.204abc	0.101	0.153
GU based on LCC	0.213abc	0.158	0.186	0.108bc	0.157	0.132
S.E $\pm$	0.022	0.023	0.018	0.046	0.056	0.038
Variety (V)						
FARO 55	0.200	0.163	0.183	0.221	0.118	0.169
FARO 57	0.216	0.189	0.207	0.175	0.182	0.179
FARO 52	0.212	0.168	0.192	0.156	0.119	0.137
S.E $\pm$	0.015	0.014	0.011	0.028	0.034	0.023
Interaction						
N x V	NS	NS	NS	NS	NS	NS

Means followed by the same letter(s) within the same column and treatment group are not significantly different at 5% level of probability using DMRT. NS = not significant. USG = Urea Super Granules, GU = Granular Urea; LCC = Leaf Colour Chart.

Table 4.48: Matrix of Pearson correlation coefficients among growth, paddy yield, yield componentsand selected soilparameters at Talata Mafara in 2012.

	13	12	11	10	9	8	7	6	5	4	3	2	1
13	1.000	0.182	-0.094	-0.086	0.087	-0.104	-0.040	-0.051	0.057	0.019	0.013	-0.047	-0.108
12		1.000	-0.514**	0.098	-0.059	0.264*	0.489**	0.407**	0.278*	-0.499**	0.254*	0.089	- 0.126
11			1.000	0.170	0.198*	-0.308**	-0.588**	-0.377**	-0.309**	0.589**	-0.107	-0.003	0.121
10				1.000	0.118	-0.029	-0.202	-0.179	0.181	0.040	-0.071	0.038	0.159
9					1.000	-0.149	-0.052	0.079	0.021	0.286*	0.607**	0.781**	0.823**
8						1.000	0.432**	0.141	-0.078	-0.335**	-0.108	-0.079	- 0.028
7							1.000	0.605**	0.172	-0.608**	0.444**	0.295*	0.056
6								1.000	0.166	-0.373**	0.443**	0.363**	0.191
5									1.000	-0.226	0.108	0.122	0.114
4										1.000	-0.153	-0.013	0.156
3											1.000	0.919**	0.631**
2												1.000	0.885**
1													1.000

Df = n -2 = 70; * and ** = significant @ $p \leq 0.05$ and $p < 0.01$.

1. Grain yield
2 Biomass
3 Straw yield
4 Dry matter yield
5. Plant height
6. Number of tillers plant^{-1}
7. Number of panicles plant^{-1}
8.1,000 grain weight
9. Total N- uptake
10. Soil pH
11. Soil N
12. Soil available P
13. Soil K

Paddy yield significantly and positively correlated with biomass (r = 0.885**), straw yield (r = 0.631**) and total N-uptake (r = 0.823**) at Talata Mafara in 2013 as presented in Table 4.49. In same vein, paddy yield did not correlate significantly with the rest of the parameters, but had a negative correlation with weight of 1,000-grain (r = - 0.028), soil available P (r = - 0.126) and soil exchangeable K (r = - 0.108). For the two years (2012 and 2013) combined at Talata Mafara, it was revealed that paddy yield significantly and positively correlated with biomass (r = 0.885**), straw yield (r = 0.652**), crop dry matter (r = 0.294**), plant height (r= 0.171*) and total N- uptake (r=0.853**), but significantly and negatively correlated with 1,000-grain weight (r = -0.288**). However, all other parameters did not correlate significantly with paddy yield as presented in Table 4.50.

4.12.2 Correlation analysis at Kadawa

The relationship among growth, paddy yield, yield components and selected soil parameters at Kadawa in 2012, 2013 and combined were presented in Tables 4.51 – 4.53. In 2012, there was significant and positive correlation between paddy yield and biomass (r = 0.934**), straw yield (r = 0.851**), crop dry matter (r = 0.349**), plant height (r = 0.556**) and total N-uptake (r = 0.584**). However, number of tillers (r = - 0.022), weight of 1,000-grain (r = - 0.028), soil pH (r = - 0.095), soil total N (r = - 0.118) and soil available P (r = - 0.103) were negatively correlated with paddy yield.The number of panicles (r = 0.157) and soil exchangeable K (r = 0.080) were not significantly correlated with paddy yield as shown in Table 4.51.

Table 4.49: Matrix of Pearson correlation coefficients among growth, paddy yield, yield components and selected soilparameters at Talata Mafara in 2013.

	13	12	11	10	9	8	7	6	5	4	3	2	1
13	1.000	0.071	0.340**	-0.155	-0.044	-0.128	-0.089	0.247	-0.146	-0.121	-0.115	-0.123	-0.116
12		1.000	0.031	-0.251*	0.156	0.042	0.045	-0.048	0.181	0.058	0.115	0.773	0.007
11			1.000	-0.076	-0.088	-0.045	-0.058	0.212*	-0.057	-0.164	-0.071	-0.081	-0.084
10				1.000	0.072	-0.007	-0.025	-0.247*	-0.093	-0.269*	0.072	0.081	0.084
9					1.000	-0.365*	0.178	0.294*	0.283*	0.154	0.786**	0.871**	0.869**
8						1.000	-0.231*	-0.154	-0.247	-0.173	-0.491**	-0.494**	-0.423**
7							1.000	0.309**	0.007	0.412**	0.219*	0.257*	0.275*
6								1.000	0.040	0.085	0.215*	0.267*	0.307**
5									1.000	0.089	0.342**	0.353*	0.317**
4										1.000	0.243*	0.269*	0.266*
3											1.000	0.961**	0.754**
2												1.000	0.906**
1													1.000

Df = n -2 = 70; * and ** = significant @ $p \leq 0.05$ and $p < 0.01$.

1. Grain yield
2. Biomass
3. Straw yield
4. Dry matter yield
5. Plant height
6. Number of tillers plant^{-1}
7. Number of panicles plant^{-1}
8. 1,000 grain weight
9. Total N- uptake
10. Soil pH
11. Soil N
12. Soil available P
13. Soil K

Table4.50: Matrix of Pearson correlation coefficients among growth, paddy yield, yield components and selected soil parameters at Talata Mafara for the two years combined.

	13	12	11	10	9	8	7	6	5	4	3	2	1
13	1.000	0.085	0.233**	-0.123	-0.009	-0.083	-0.042	0.135	-0.082	-0.028	-0.079	-0.094	-0.095
12		1.000	-0.246**	-0.098	-0.059	0.268**	0.378**	0.245**	0.238**	-0.397**	0.172*	0.044	-0.132
11			1.000	0.030	0.155*	-0.297**	-0.425**	-0.155*	-0.181*	0.423**	-0.088	-0.007	0.099
10				1.000	0.097	-0.024	-0.121	-0.203*	0.048	-0.010	0.003	0.061	0.124
9					1.000	-0.356**	-0.155*	0.042	0.093	0.393**	0.631**	0.800**	0.853**
8						1.000	0.406**	0.169*	-0.088	-0.498**	-0.234**	-0.283**	-0.288**
7							1.000	0.566**	0.139*	-0.612**	0.306**	0.175*	-0.031
6								1.000	0.133	-0.387**	0.324**	0.265**	0.135
5									1.000	-0.165*	0.227**	0.222**	0.171*
4										1.000	-0.054	0.107	0.294**
3											1.000	0.932**	0.652**
2												1.000	0.885**
1													1.000

Df = n -2 = 70; * and ** = significant @ $p \leq 0.05$ and $p < 0.01$.

1. Grain yield
2. Biomass
3. Straw yield
4. Dry matter yield
5. Plant height
6. Number of tillers plant^{-1}
7. Number of panicles plant^{-1}
8. 1,000 grain weight
9. Total N- uptake
10. Soil pH
11. Soil N
12. Soil available P
13. Soil K

Table 4.51: Matrix of Pearson correlation coefficients among growth, paddy yield, yield components and selected soil parameters at Kadawa in 2012.

	13	12	11	10	9	8	7	6	5	4	3	2	1
13	1.000	0.208*	0.178	-0.185	0.026	-0.106	0.042	0.094	0.216	-0.028	0.035	0.053	0.080
12		1.000	0.119	-0.091	-0.093	-0.059	-0.095	0.199*	-0.091	0.046	-0.146	-0.136	-0.103
11			1.000	-0.156	-0.084	0.165	-0.018	0.091	-0.056	-0.073	-0.022	-0.057	-0.118
10				1.000	-0.229*	-0.212*	-0.123	-0.226*	-0.039	0.175	-0.140	-0.129	-0.095
9					1.000	0.121	0.150	0.058	0.217*	0.159	0.684**	0.673**	0.584**
8						1.000	0.049	-0.009	-0.021	-0.004	0.079	0.018	-0.028
7							1.000	0.065	0.064	0.053	0.181	0.179	0.157
6								1.000	-0.116	-0.001	-0.015	-0.018	-0.022
5									1.000	0.032	0.390**	0.463**	0.556**
4										1.000	0.370**	0.376**	0.349**
3											1.000	0.982**	0.851**
2												1.000	0.934**
1													1.000

Df = n -2 = 70; * and ** = significant @ $p \leq 0.05$ and $p < 0.01$.

1. Grain yield
2. Biomass
3. Straw yield
4. Dry matter yield
5. Plant height
6. Number of tillers plant^{-1}
7. Number of panicles plant^{-1}
8. 1,000 grain weight
9. Total N- uptake
10. Soil pH
11. Soil N
12. Soil available P
13. Soil K

Similarly in 2013, there was significant and positive correlation between paddy yield, and biomass (r = 0.920**), straw yield (r = 0.836**), crop dry matter (r = 0.487**), number of tillers (r = 0.423**), number of panicles (r = 0.212*) and total N-uptake (r = 0.601**) as shown in Table 4.52. On the other hand, paddy yield was negatively correlated with plant height (r = - 0.167), weight of 1,000-grain (r = - 0. 008), soil total N (r = - 0.038) and soil exchangeable K (r = - 0.187), while soil pH (r = 0.078) and soil available P (r = 0.024) were not significantly correlated with paddy yield as seen in Table 4.52.

In the combined for the two years as presented in Table 4.53, significant and positive correlation was obtained between paddy yield and biomass (r = 0.911**), straw yield (r = 0.813**), crop dry matter (r = 0.408**), plant height (r = 0.144*), number of panicles (r = 0.180*) and total N-uptake (r = 0.548**).

However, non- significant relationship was observed between paddy yield and number of tillers (r = 0.063), 1,000-grain weight (r = - 0.055), soil pH (r = - 0.021), soil available P (r = - 0.055) and soil exchangeable K (r = 0.033).

4.13 Principal Component Analysis

4.13.1 Principal component analysis at Talata Mafara

Fivefactors were extracted in the two years combined at Talata Mafara and the results presented in Table 4.54. Factor 1 explained about 28 % of the variance in the original variables, while Factor 2 explained 19%. Factor 3, 4 and 5 explained 10, 8 and 7% respectively of the original variables.

Table 4.52: Matrix of Pearson correlation coefficients among growth, paddy yield, yield components and selected soil parameters at Kadawa in 2013.

	13	12	11	10	9	8	7	6	5	4	3	2	1
13	1.000	0.377**	0.081	-0.293*	-0.106	-0.010	-0.226	0.021	-0.025	-0.176	-0.063	-0.105	-0.187
12		1.000	-0.136	-0.097	0.120	-0.105	-0.148	-0.106	-0.251*	0.042	0.111	0.087	0.024
11			1.000	0.290*	0.081	-0.078	0.090	-0.157	0.150	-0.168	0.009	-0.006	-0.038
10				1.000	0.251*	-0.136	0.182	-0.003	0.031	-0.023	0.163	0.141	0.078
9					1.000	-0.094	0.276	0.107	-0.055	0.473**	0.611**	0.630**	0.601**
8						1.000	0.063	0.114	0.017	-0.168	0.040	0.026	-0.008
7							1.000	0.088	0.176	0.108	0.197*	0.210*	0.212*
6								1.000	0.332**	0.369**	0.385**	0.411**	0.423**
5									1.000	-0.017	-0.207*	-0.202*	-0.167
4										1.000	0.425**	0.461**	0.487**
3											1.000	0.984**	0.836**
2												1.000	0.920**
1													1.000

Df = n -2 = 70; * and ** = significant @ $p \leq 0.05$ and $p < 0.01$.

1. Grain yield
2. Biomass
3. Straw yield
4. Dry matter yield
5. Plant height
6. Number of tillers plant^{-1}
7. Number of panicles plant^{-1}
8. 1,000 grain weight
9. Total N- uptake
10. Soil pH
11. Soil N
12. Soil available P
13. Soil K

Table 4.53: Matrix of Pearson correlation coefficients among growth, paddy yield, yield components and selected soil parameters at Kadawa for the two years combined.

	13	12	11	10	9	8	7	6	5	4	3	2	1
13	1.000	0.270**	0.251**	-0.124	0.079	-0.085	-0.012	0.225**	0.120	-0.053	-0.037	-0.015	0.033
12		1.000	0.255**	-0.003	0.059	-0.076	-0.118	0.371**	-0.111	0.019	-0.140	-0.117	-0.055
11			1.000	0.087	0.145*	0.038	-0.036	0.500**	0.002	-0.114	-0.137	-0.118	-0.062
10				1.000	-0.007	-0.188*	-0.035	0.111	-0.014	0.090	-0.062	-0.050	-0.021
9					1.000	0.017	0.155*	0.312**	0.076	0.232*	0.496**	0.535**	0.548**
8						1.000	0.060	-0.038	0.001	-0.072	0.069	0.031	-0.055
7							1.000	-0.039	0.122	0.080	0.200*	0.202*	0.180*
6								1.000	-0.009	-0.008	-0.153*	-0.087	0.063
5									1.000	0.025	0.035	0.073	0.144*
4										1.000	0.392**	0.415**	0.408**
3											1.000	0.981**	0.813**
2												1.000	0.911**
1													1.000

Df = n -2 = 70; * and ** = significant @ $p \leq 0.05$ and $p < 0.01$.

1. Grain yield
2. Biomass
3. Straw yield
4. Dry matter yield
5. Plant height
6. Number of tillers plant^{-1}
7. Number of panicles plant^{-1}
8. 1,000 grain weight
9. Total N- uptake
10. Soil pH
11. Soil N
12. Soil available P
13. Soil K

Therefore, the factor components (FCs) with Eigen values > 1 were retained and this showed that the first five FCs accounted for 71% of the variance of soil and plant attributes standardized data.

The FC1 which explained about 28% of the variance included exchangeable Mg (0.882), Ca (0.879) and K-uptake (0.592) as the major contributing variables is presented in Table 4.54. FC2 accounted for 19% which included total N-uptake (0.899), P-uptake (0.816) and K-uptake (0.658) as the major contributing variables. The FC3, FC4 and FC5 explained for 25% of the total variance which included exchangeable K (0.572), pH in water (- 0.579) and pH in $CaCl_2$ (- 0.516) in FC3, while FC4 composed of pH (0.474) and FC5 included exchangeable K (0.472), soil N (0.451) and organic carbon (- 0.627) as the major contributing variable as seen in Table 4.55

4.13.2 Principal component analysis at Kadawa

The results presented in Table 4.56 showed that for the two years (2012 and 2013) combined, five factors were extracted. Factor component 1 explained about 24% of the total variance, while FC2 accounted for 11% and FC3, 4 and 5 explained 12, 9 and 9 % respectively of the total variance. The FC1 which explained 24% included K – uptake (0.838) and was closely followed by the P –uptake (0.823) in addition to a moderate negative loading pH (- 0.598). On the other hand, FC2 composed of total N – uptake (0.733) in conjunction with exchangeable potentials of

moderatenegative loading of Ca (- 0.576) and Mg (- 0.626). Similarly, FC3 was dominated

Table4.54: Eigenvalue, proportion and cumulative variance explained by factor analysis using correlation matrix (standardized data) for grain yield and measured soil parametersat Talata Mafara in 2012 and 2013.

Factors	2012			2013			Combined		
	Eigenvalue	Proportion ←(%)→	Cumulative	Eigenvalue	Proportion ← (%)→	Cumulative	Eigenvalue	Proportion ← (%)→	Cumulative
1	4.899	30.62	30.62	3.797	23.73	23.73	4.432	27.70	27.70
2	2.854	17.84	48.46	2.917	18.23	41.96	3.011	18.82	46.52
3	1.389	8.64	57.13	1.925	12.03	53.99	1.587	9.92	56.44
4	1.322	8.27	65.40	1.249	7.81	61.80	1.257	7.85	64.30
5	1.065	6.66	72.05	1.189	7.43	69.24	1.072	6.71	71.00
6				1.083	6.77	76.01			

Table 4.55: Proportion of variance using varimax rotation and communality estimates for soil attributes and grain yield for each of the retained factors for the field experiments at Talata Mafara in 2012 and 2013.

	FC1			FC2			FC 3		
Attribute	2012	2013	combined	2012	2013	combined	2012	2013	combined
Nupt.	-0.053	**0.916**	-0.265	**0.939**	0.046	**0.899**	0.219	-0.311	0.243
GUpt.	0.586	**0.917**	0.419	**0.686**	0.002	**0.816**	0.032	-0.017	-0.013
Kupt.	**0.717**	**0.909**	**0.592**	0.482	-0.044	**0.658**	-0.114	-0.141	-0.023
pH (water)	-0.057	0.224	-0.080	0.185	-0.419	0.208	-0.338	**0.592**	**-0.579**
pH ($CaCl_2$)	-0.383	0.285	-0.408	0.143	-0.489	0.226	-0.297	**0.577**	**-0.516**
Organic Carbon	-0.251	-0.074	-0.283	0.089	0.302	0.018	0.441	0.045	0.405
Soil Nitrogen	**-0.737**	-0.227	-0.555	0.226	0.242	-0.029	-0.175	-0.296	0.342
Available P	0.693	0.149	0.619	-0.110	**0.637**	0.005	0.274	-0.096	0.307
K	0.068	-0.138	0.083	-0.005	0.435	-0.124	**0.687**	-0.124	**0.572**
Ca	**0.893**	0.099	**0.879**	-0.146	**0.877**	-0.081	-0.025	0.292	0.167
Mg	**0.893**	0.094	**0.882**	-0.166	**0.886**	-0.092	-0.032	0.280	0.179

Factor scores of variables in bold letters indicate the major contributors in the group. FC = factor component

Table 4.55 contd.

Attribute	FC4			FC5			FC6		
	2012	2013	combined	2012	2013	combined	2012	2013	combined
Nupt.	0.069	0.015	0.031	-0.015	-0.095	0.025		0.060	
GUpt.	-0.107	0.102	-0.085	0.132	0.117	-0.067		-0.183	
Kupt.	-0.185	0.121	-0.199	-0.184	0.092	0.083		0.002	
pH (water)	**0.786**	0.267	**0.474**	-0.021	-0.230	0.393		0.310	
pH ($CaCl_2$)	0.051	0.239	0.239	**0.443**	-0.135	-0.062		-0.049	
Organic Carbon	**-0.425**	0.076	0.121	**0.512**	0.118	**-0.627**		**-0.619**	
Soil Nitrogen	0.049	**0.599**	0.122	-0.134	-0.072	**0.451**		0.399	
Available P	0.311	-0.321	0.224	0.064	-0.066	-0.036		0.077	
K	0.178	**0.506**	0.133	-0.329	**-0.448**	**0.472**		0.232	
Ca	0.147	0.143	0.274	0.107	-0.118	0.023		-0.075	
Mg	0.152	0.109	0.275	0.106	-0.088	0.039		-0.052	

Factor scores of variables in bold letters indicate the major contributors in the group. FC = factor component

Table 4.56: Eigenvalue, proportion and cumulative variance explained by factor analysis using correlation matrix (standardized data) for grain yield and measured soil attributes at Kadawa in 2012 and 2013.

	2012			2013			Combined		
Factors	Eigenvalue ←(%)→	Proportion	Cumulative	Eigenvalue ← (%)→	Proportion	Cumulative	Eigenvalue ← (%)→	Proportion	Cumulative
1	3.792	23.70	23.30	3.544	22.15	22.15	3.856	24.10	24.10
2	2.252	14.08	37.77	2.754	17.22	39.37	2.279	14.25	38.35
3	1.975	12.35	50.12	1.946	12.16	51.53	1.908	11.93	50.28
4	1.533	9.58	59.70	1.404	8.78	60.31	1.438	8.99	59.27
5	1.416	8.85	68.55	1.183	7.40	67.70	1.429	8.93	68.20
6	1.224	7.65	76.20						
7	1.079	6.75	82.95						

by exchangeable Ca (- 0.576) and Mg (0.671) with high positive loading. FC4 included pH in water (- 0.639) and pH in $CaCl_2$ (- 0.506) as moderate negative loading. Lastly, FC5 has exchangeable K (0.664) as the only major contributing variable as seen in Table 4.57.

4.14 Application of QUEFTS as Decision Support Tools

4.14.1 Estimating Indigenous soil nutrient supply

For both 2012 and 2013 at Talata Mafara, observed mean grain yields of 2.69 t/ha (0N), 3.11 t/ha (0P) and 2.93 t/ha (0K) in the N, P, and K omission plots were presented in Table 4.58. Similarly, mean paddy yields in the N, P, and K omission plots at Kadawa were 2.96 t/ha (0N), 3.45 t/ha (0P) and 3.36 t/ha (0K) respectively. It was observed that N and K were limiting yields and P was considerable i.e. application of P did not cause a significant yield increase at both locations.

Moreover, indigenous soil nutrient supply was estimated based on the N, P, and K omission plots as presented in Table 4.59. The INS was 25 – 92 kg N/ha, an IPS of 6 – 19 kg P/ha and an IKS of 47 – 95 kg K/ha at Talata Mafara, while at Kadawa, INS was 54 – 94 kg N/ha, an IPS was 12 – 29 kg P/ha and an IKS of 91 – 156 kg K/ha as seen in Table 4.59. Results showed that indigenous soil nutrient supplies were higher at Kadawa than at Talata Mafara.The sequence of limiting nutrients at both Talata Mafara andKadawa was in the order N > K > P and the most limiting nutrients at both sites was nitrogen (N) as shown in Table 4.59.

Table 4.57: Proportion of variance using varimax rotation and communality estimates for soil attributes and grain yield for each of the retained factors for the field experiments at Kadawa in 2012 and 2013.

	FC1			FC2			FC3		
Attribute	2012	2013	combined	2012	2013	combined	2012	2013	combined
Nupt.	**0.712**	**0.588**	0.019	0.079	0.297	**0.733**	0.018	**0.518**	0.299
GUpt.	**0.802**	**0.893**	**0.823**	0.354	0.259	0.352	-0.196	0.133	0.236
Kupt.	**0.881**	**0.849**	**0.838**	0.191	0.025	0.223	-0.198	-0.138	0.069
pH (water)	-0.363	0.232	-0.248	0.118	-0.269	-0.035	-0.502	**0.560**	0.225
pH ($CaCl_2$)	-0.445	0.268	**-0.598**	0.078	-0.363	0.177	-0.282	-0.369	0.269
Organic Carbon	0.360	0.167	0.287	-0.055	0.397	0.156	0.049	-0.367	-0.080
Soil Nitrogen	-0.046	-0.081	-0.468	0.480	0.043	0.179	0.452	**0.509**	0.400
Available P	-0.216	0.068	-0.348	0.351	**0.530**	0.069	0.331	-0.191	0.442
K	0.162	-0.312	-0.216	0.061	**0.723**	0.353	**0.712**	-0.178	0.161
Ca	-0.383	-0.055	0.191	**0.818**	**0.803**	**-0.576**	-0.139	-0.027	**0.723**
Mg	-0.385	-0.166	0.214	**0.817**	**0.783**	**-0.626**	-0.142	0.075	**0.671**

Factor scores of variables in bold letters indicate the major contributors in the group. FC = factor component

Table 4.57 contd.,

Attribute	FC4			FC5			FC6			FC7		
	2012	2013	combined	2012	2013	combined	2012	2013	combined	2012	2013	combined
Nupt.	0.498	0.050	0.207	0.355	0.180	-0.489	0.252			0.017		
GUpt.	-0.254	0.097	-0.065	-0.149	-0.109	-0.038	0.173			0.104		
Kupt.	-0.093	-0.415	-0.242	0.233	-0.049	0.119	-0.129			-0.054		
pH (water)	-0.192	0.327	**-0.639**	0.307	0.009	-0.254	0.010			**).531**		
pH ($CaCl_2$)	-0.091	0.464	**-0.506**	0.473	0.017	-0.109	0.275			0.429		
Organic Carbon	0.237	0.188	0.428	-0.398	0.373	-0.183	-0.181			**).567**		
Soil Nitrogen	0.022	0.206	0.216	-0.246	-0.424	0.093	-0.323			0.219		
Available P	-0.155	0.208	0.149	-0.099	**0.511**	0.306	**0.527**			-0.138		
K	-0.432	-0.132	0.241	0.278	-0.011	**0.664**	-0.017			0.037		
Ca	0.292	0.205	0.129	0.070	-0.173	-0.124	-0.163			-0.143		
Mg	0.298	-0.072	0.149	0.061	-0.188	-0.122	-0.161			-0.139		

Factor scores of variables in bold letters indicate the major contributors in the group. FC = factor component

Table 4.58: Mean Grain Yield (t/ha) of Nutrient Omission Trials (NOT) on rice variety at Talata Mafara and Kadawa.

Rice variety	Talata Mafara			Kadawa		
	PK (0 N)	NK (0 P)	NP (0 K)	PK (0 N)	NK (0 P)	NP (0 K)
FARO 55	0.47	0.89	1.02	2.17	3.01	2.91
FARO 57	3.66	3.76	3.76	2.71	3.12	2.91
FARO 52	3.93	4.69	4.69	4.00	4.23	4.26
Mean	2.69	3.11	3.70	2.96	3.45	3.36

Table 4.59: Indigenous soil nutrient supply (N, P and K) of rice variety at Talata Mafara and Kadawa.

		2012			2013			Mean		
Rice Variety	Location	INS ←	IPS (kg/kg)	IKS →	INS ←	IPS (kg/kg)	IKS →	INS ←	IPS (kg/kg)	IKS →
FARO 55	Talata Mafara	35.73	6.07	41.97	14.78	5.49	52.99	25.26	5.78	47.48
FARO 55	Kadawa	78.09	10.94	113.12	30.59	13.37	67.93	54.34	12.16	90.53
FARO 57	Talata Mafara	118.74	12.33	50.43	71.79	16.01	45.23	92.27	14.17	47.83
FARO 57	Kadawa	52.68	9.33	90.56	58.11	24.77	183.58	55.40	17.05	137.07
FARO 52	Talata Mafara	68.26	9.46	59.71	54.44	29.30	129.91	61.35	19.38	94.81
FARO 52	Kadawa	106.40	23.62	122.88	82.60	34.08	189.72	94.50	28.84	156.30

INS = Indigenous N supply, IPS = Indigenous P supply, IKS = Indigenous K supply.

4.14.2 Internal efficiency of N, P, K and fertilizer recovery fraction

The internal efficiency represents maximum accumulation and maximum dilution of the nutrients. The maximum accumulation of N, P, and K at Talata Mafara ranged between 16 – 44 kg N/ha, 104 – 274 kg P/ha and 15 – 53 kg K/ha as presented in Table 4.60; while maximum dilution ranged between 38 – 70 kg N/ha, 175 – 349 kg P/ha and 29 – 101 kg K/ha as shown in Table 4.61.

Similarly, maximum accumulation of N, P, and K were 28 – 36 kg N/ha, 114 – 160 kg P/ha and 19 – 30 kg K/ha as presented in Table 4.60; and maximum dilution of 52 – 197 kg N/ha, 190 – 267 kg P/ha and 32 – 39 kg K/ha were recorded at Kadawa and presented in Table 4.61. Observed internal efficiencies were generally higher at Talata Mafara than at Kadawa.

On the other hand, the fertilizer recovery fractions were presented in Table 4.62. Fertilizer recovery fractions obtained for N, P, and K at Talata Mafara (Table 4.62) ranged from 0.25 – 0.55 (NRF), 0.09 – 0.12 (PRF) and 0.27 – 0.44 (KRF); while at Kadawa, it was 0.35 – 0.50 (NRF), 0.21 – 0.48 (PRF) and 0.35 – 0.64 (KRF) respectively as shown in Table 4.62. Results also revealed higher fertilizer recovery fractions at Kadawa than Talata Mafara.

Table 4.60: Internal efficiency (maximum accumulation) of N, P and K for rice variety at Talata Mafara and Kadawa.

		2012			2013			Mean		
Rice Variety	Location	YNA ←	YPA (kg/kg)	YKA →	YNA ←	YPA (kg/kg)	YKA →	YNA ←	YPA (kg/kg)	YKA →
FARO 55	Talata Mafara	13.99	114.94	18.12	18.27	92.72	11.52	16.13	103.83	14.82
FARO 55	Kadawa	29.77	225.17	31.28	36.25	94.88	28.54	33.01	160.03	29.91
FARO 57	Talata Mafara	34.82	310.14	52.62	52.34	205.47	53.05	43.58	257.81	52.84
FARO 57	Kadawa	17.03	128.69	16.32	39.65	188.98	22.00	28.34	158.84	19.16
FARO 52	Talata Mafara	48.36	467.39	66.94	33.23	80.66	20.16	40.80	274.03	43.55
FARO 52	Kadawa	27.87	109.86	32.10	43.21	117.65	22.68	35.54	113.76	27.39

YNA = accumulation N, YPA = accumulation P and YKA = accumulation K

Table 4.61: Internal efficiency (maximum dilution) of N, P and K for rice variety at Talata Mafaraand Kadawa.

		2012			2013			Mean		
Rice Variety	Location	YND ←	YPD (kg/kg)	YKD →	YND ←	YPD (kg/kg)	YKD →	YND ←	YPD (kg/kg)	YKD →
FARO 55	Talata Mafara	31.24	210.43	42.10	45.08	140.55	15.10	38.16	175.49	28.60
FARO 55	Kadawa	49.10	385.80	44.90	57.68	147.61	32.44	53.39	266.71	38.67
FARO 57	Talata Mafara	54.07	361.33	101.82	80.87	277.50	99.52	67.47	319.42	100.67
FARO 57	Kadawa	28.30	220.87	21.94	365.81	222.48	42.72	197.06	221.68	32.33
FARO 52	Talata Mafara	61.85	528.48	127.33	78.62	169.60	38.78	70.24	349.04	83.06
FARO 52	Kadawa	41.41	222.36	42.29	63.00	158.19	35.12	52.21	190.28	38.71

YND = dilution N, YPD = dilution P, and YKD = dilution K

Table 4.62: Apparent fertilizer recovery fraction of NPK for rice variety at Talata Mafara and Kadawa.

Rice Variety		2012			2013			Mean		
	Location	NRF	PRF	KRF	NRF	PRF	KRF	NRF	PRF	KRF
FARO 55	Talata Mafara	0.44	0.15	0.42	0.06	0.03	0.11	0.25	0.09	0.27
FARO 55	Kadawa	0.45	0.38	0.57	0.24	0.19	0.36	0.35	0.29	0.47
FARO 57	Talata Mafara	0.50	0.08	0.67	0.37	0.15	0.69	0.55	0.12	0.69
FARO 57	Kadawa	0.22	0.02	0.53	0.69	0.40	0.69	0.61	0.21	0.64
FARO 52	Talata Mafara	0.45	0.09	0.49	0.17	0.08	0.17	0.31	0.09	0.44
FARO 52	Kadawa	0.55	0.59	0.57	0.65	0.11	0.13	0.50	0.48	0.35

RFN = recovery fraction N, RFP = recovery fraction P and RFK = recovery fraction K

4.14.3 Fertilizer recommendation by QUEFTS model

Based on the application of Quantitative Evaluation of Fertility of the Tropical Soils (QUEFTS) model, the fertilizer recommendation was generated using indigenous soil nutrient supplies at both locations as presented in Table 4.63. The fertilizer recommended varied greatly depending on the soil conditions and crop cultivars.

It was revealed that FARO 55 plot required more of N- fertilizer at both locations, while FARO 57 and FARO 52 required low K- fertilizer as seen in Table 4.63. There is also a great variability in fertilizer requirements even within the same location but different varieties.

4.14.4 Statistical evaluation and validation of QUEFTS model

The QUEFTS model calibration was conducted using data obtained from the omission plots in 2012 at the Irrigation Research Stations, Talata Mafara and Kadawa. The model was then validated using the data collected in the field experiment during 2013. In this study, the paddy yields at maturity were calibrated by comparing the observed data from the field experiment with simulated results with respect to grain yield (Figure 4.2 – 4.7). Combinations of graphical and statistical tools were employed to evaluate the model performance.

Table 4.63: Fertilizer Recommendation (kg/ha) modeled by QUEFTS.

Rice variety	Talata Mafara			Kadawa		
	N	P	K	N	P	K
FARO 55	140	94	46	130	34	10
FARO 57	120	81	28	92	56	19
FARO 52	104	69	23	120	50	12

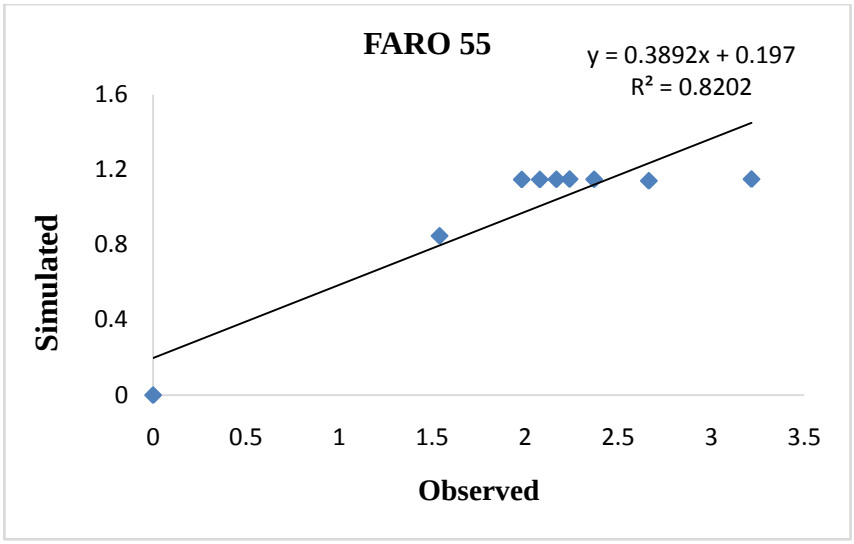


Figure 4.2: Comparison of observed and simulated mean grain yields of FARO 55 for different nitrogen regimes at Talata Mafara.

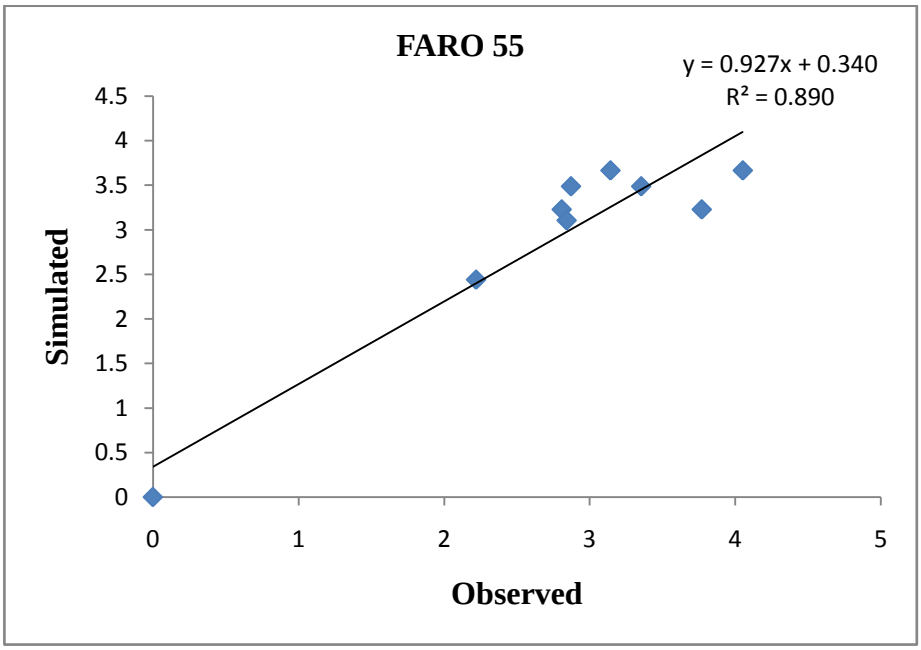


Figure 4.3: Comparison of observed and simulated mean grain yields of FARO 55 for differentnitrogen regimes at Kadawa.

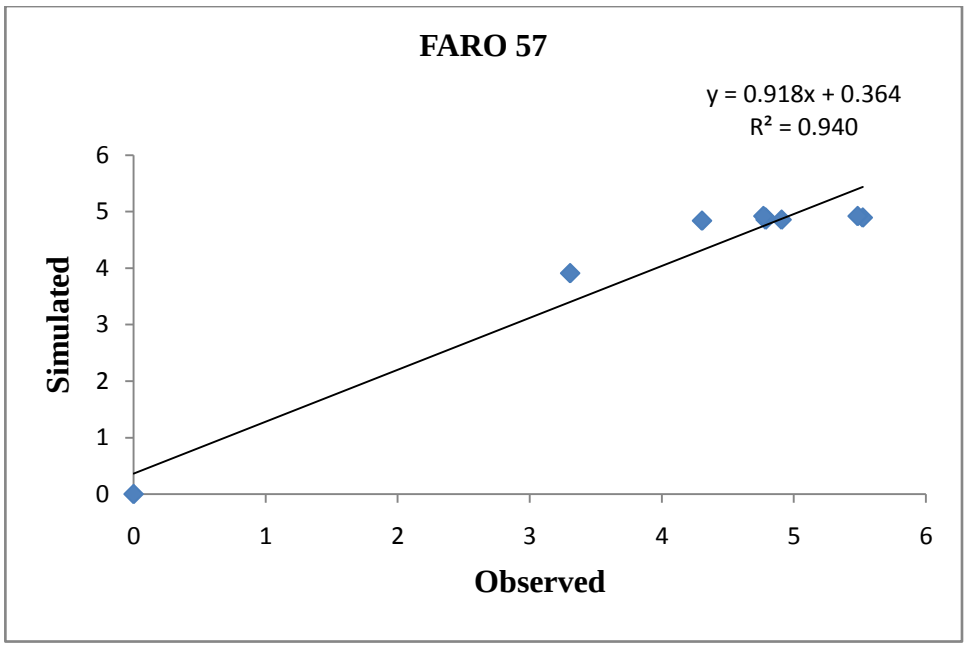


Figure 4.4: Comparison of observed and simulated mean grain yields of FARO 57 for differentnitrogen regimes at Talata Mafara.

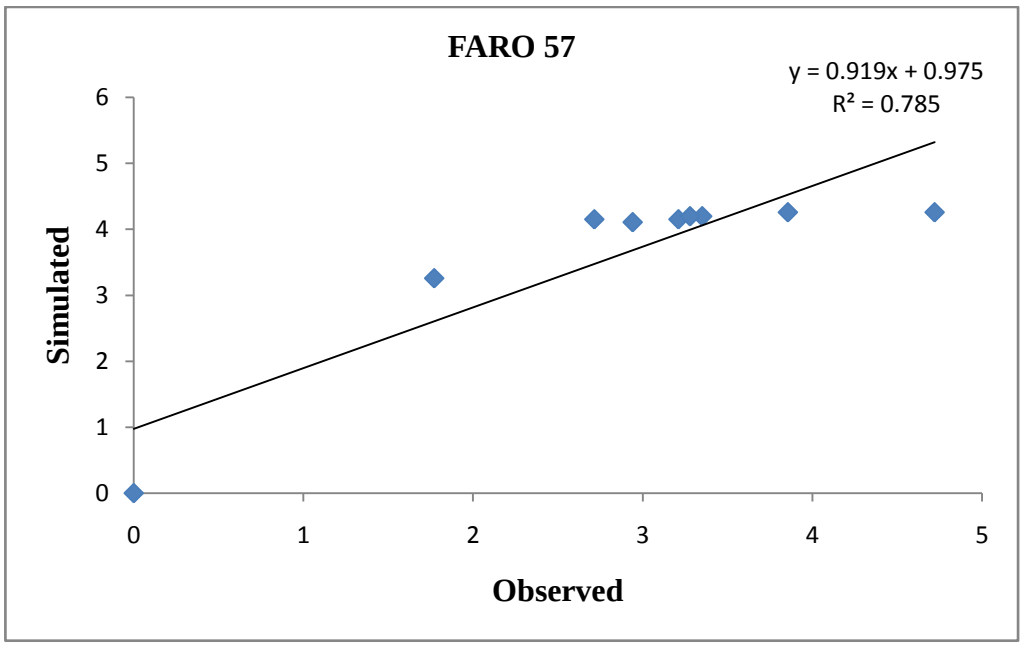


Figure 4.5: Comparison of observed and simulated mean grain yields of FARO 57 for differentnitrogen regimes at Kadawa.

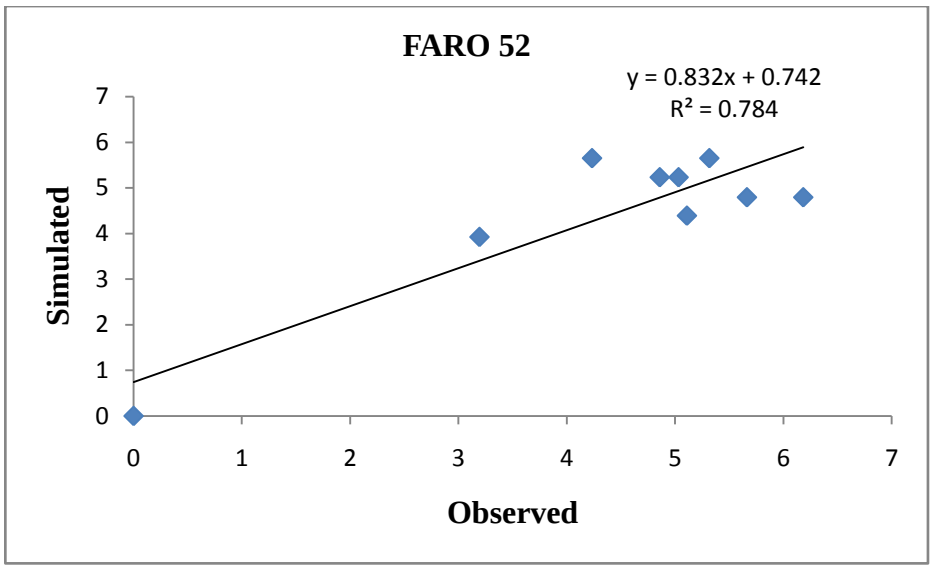


Figure 4.6: Comparison of observed and simulated mean grain yields of FARO 52 for differentnitrogen regimes at Talata Mafara.

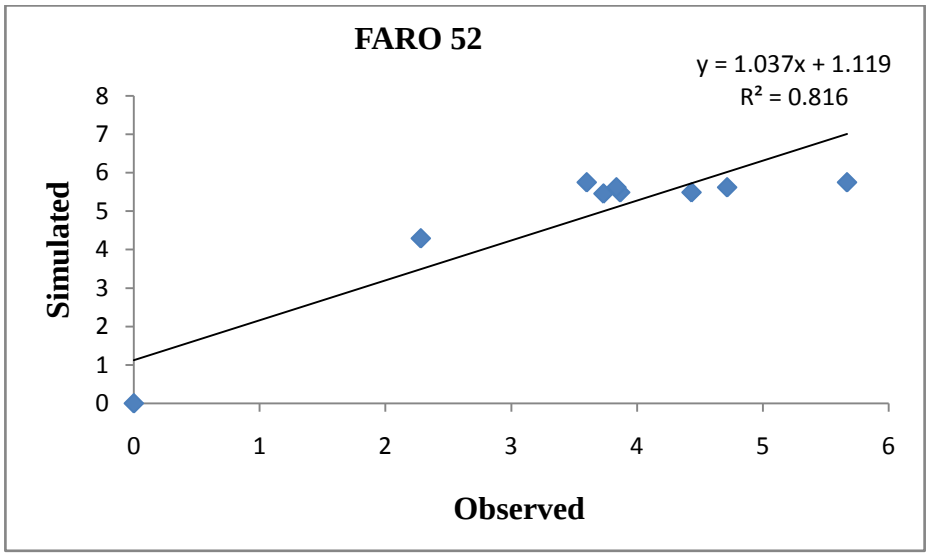


Figure 4.7: Comparison of observed and simulated mean grain yields of FARO 52 for different nitrogen regimes at Kadawa .

The coefficient of determination (R^2) values ranged from 0.784 – 0.940 at Talata Mafara while at Kadawa, it ranged from 0.785 – 0.890. Again, the Root Mean Square Error (RMSE) of 0.419 – 1.243 and 0.496 – 1.550 were also computed for both Talata Mafara and Kadawa respectively. Similarly, normalized Root Mean Square Error (RMSE-n) was also determined as 8.84 – 54.45 % at Talata Mafara and 15.84 – 38.63 % at Kadawa. Lastly, the index of agreement (d) ranging from 0.51 – 0.87 at Talata Mafara and 0.65 – 0.80 at Kadawa, was used to test the goodness of fit of the QUEFTS model as presented in Table 4.64.

4.15 Cost Benefit Analysis of the various treatments Evaluated

4.15.1 Partial economic analysis of paddy yield at Talata Mafara

The gross margin (₦/ha) and return per naira invested (₦) on investment of growing three rice varieties using USG and GU in 2012, 2013 and combined at Talata Mafara is presented in Table 4.65. The results showed that non application of N- fertilizers to either of the rice varieties (FARO 55, FARO 57 or FARO 52) brought gross margins of ₦7,960.41k/ha, ₦117,561.26k/ha and ₦121,723.26k/ha with profit of ₦0.10k, ₦1.47k and ₦1.53k respectively.

Production of paddy rice using GU at 45.1 kg N/ha on FARO 52 gave the highest gross margin of ₦282,197.15k/ha with profit of ₦3.11k per naira invested; and was closely followed by application of the USG at 45.1 kg N/ha on FARO 52 with a gross margin of ₦251,533.48k/ha and profit of ₦2.85k per naira invested. The rice

Table 4.64: Statistical summary comparing observed data with simulated values for rice variety using QUEFTS model in Talata Mafara and Kadawa.

Rice Variety	Location	Observed Mean	Simulated Mean	R^2	RMSEn ($Mgha^{-1}$)	RMSEn (%)	d
FARO 55	Talata Mafara	2.283	1.110	0.820	1.243	54.45	0.87
FARO 55	Kadawa	3.133	6.419	0.890	0.496	15.84	0.80
FARO 57	Talata Mafara	4.735	4.760	0.940	0.419	8.84	0.51
FARO 57	Kadawa	3.231	4.069	0.785	1.026	31.74	0.65
FARO 52	Talata Mafara	4.948	4.954	0.784	0.869	17.56	0.65
FARO 52	Kadawa	4.017	5.427	0.816	1.55	38.63	0.77

R^2, Pearson's correlation coefficient; RMSE, Root mean square error; RMSEn, normalized RMSE and d, index of agreement.

Table 4.65: Profitability analysis on investment of growing three rice varieties using Urea Super Granules (USG) and Granular Urea (GU) at Talata Mafara.

Treatments						
Fertilizer (N) Management	Rice Variety	Yield (t/ha)	Gross Revenue (₦/ha)	Total Variable Cost (₦/ha)	Gross Margin (₦/ha)	Return per naira invested (₦)
Control	FARO 55	1.46	87,710.41	79,750.00	7,960.41	0.10
USG at 45.1	FARO 55	2.05	123,070.09	88,285.00	34,785.09	0.39
USG at 72.2	FARO 55	2.29	137,407.72	90,950.00	46,457.72	0.51
USG at 117.3	FARO 55	3.47	209,122.33	100,285.00	108,837.33	1.09
GU at 45.1	FARO 55	2.23	133,600.26	90,650.00	42,950.26	0.47
GU at 72.2	FARO 55	2.64	158,359.04	94,050.00	64,309.04	0.68
GU at 117.3	FARO 55	3.05	184,157.65	105,250.00	78,907.65	0.75
GU based on LCC	FARO 55	2.99	180,641.48	82,000.00	98,641.58	1.21
Control	FARO 57	3.23	197,311.26	79,750.00	117,561.26	1.47
USG at 45.1	FARO 57	4.91	297,204.81	88,285.00	208,919.81	2.37
USG at 72.2	FARO 57	5.42	327,206.96	90,950.00	236,256.96	2.60
USG at 117.3	FARO 57	5.89	354,552.15	100,285.00	254,267.15	2.54
GU at 45.1	FARO 57	4.68	284,189.26	90,650.00	193,539.26	2.14
GU at 72.2	FARO 57	4.79	289,861.00	94,050.00	195,811.00	2.08
GU at 117.3	FARO 57	5.45	329,028.30	105,250.00	223,778.30	2.13
GU based on LCC	FARO 57	4.44	270,539.52	82,000.00	188,539.52	2.34
Control	FARO 52	3.35	201,473.26	79,750.00	121,723.26	1.53
USG at 45.1	FARO 52	5.66	339,818.48	88,285.00	251,533.48	2.85
USG at 72.2	FARO 52	4.86	290,454.89	90,950.00	199,504.89	2.19
USG at 117.3	FARO 52	4.78	287,446.67	100,285.00	187,161.67	1.87
GU at 45.1	FARO 52	6.18	372,847.15	90,650.00	282,197.15	3.11
GU at 72.2	FARO 52	5.03	304,500.37	94,050.00	210,450.37	2.24
GU at 117.3	FARO 52	5.73	344,339.44	105,250.00	239,089.44	2.27
GU based on LCC	FARO 52	5.11	304,664.15	82,750.00	221,914.15	2.68

Calculation of total revenue is based on ₦ 6,000 per bag (75 kg) of paddy rice at the farm gate price.

production with least gross margin of ₦7,960.41k/ha and profit of ₦0.10k per naira invested wasFARO 55 with no N-fertilizer as seen in Table 4.65.

4.15.2 Partial economic analysis of paddy yield at Kadawa

The result of gross margin (₦/ha) and return per naira invested (₦) on investment of growing three rice varieties using USG and GU in 2012, 2013 and combined at Kadawa is presented in Table 4.66. Results showed that non application of N-fertilizer to either of the rice varieties (FARO 55, FARO 57 or FARO 52) brought gross margins of ₦61,638.52k/ha, ₦37,251.11k/ha and ₦66,114.81k/ha with profit of ₦0.96k, ₦0.58k and ₦1.03k respectively.

Production of paddy rice using USG at 117.3 kg N/ha on FARO 52 was the most profitable with highest gross margin of ₦237,907.22k/ha and a profit of ₦2.81k per naira invested. This was closely followed by the application of USG at 72.2 kg N/ha on FARO 52 with a gross margin of ₦193,197.41k/ha and return per naira invested of ₦2.57k. Again, the rice production with least gross margin of ₦61,638.52k/ha and a profit of ₦0.96k per naira invested was FARO 55 with no N-fertilizer as presented in Table 4.66.

Table 4.66: Profitability analysis on investment of growing three rice varieties using Urea Super Granules (USG) and Granular Urea (GU) at Kadawa.

Treatments						
Fertilizer (N) Management	Rice Variety	Yield (t/ha)	Gross Revenue (₦/ha)	Total Variable Cost (₦/ha)	Gross Margin (₦/ha)	Return per naira invested (₦)
Control	FARO 55	2.22	125,738.52	64,100.00	61,638.52	0.96
USG at 45.1	FARO 55	3.77	213,760.37	72,635.00	141,125.37	1.94
USG at 72.2	FARO 55	3.35	189,837.41	75,300.00	114,537.41	1.52
USG at 117.3	FARO 55	4.05	229,743.33	84,635.00	145,108.33	1.72
GU at 45.1	FARO 55	2.81	159,047.04	75,000.00	84,047.04	1.12
GU at 72.2	FARO 55	2.87	162,852.96	78,400.00	84,452.96	1.08
GU at 117.3	FARO 55	3.14	178,080.37	89,600.00	88,480.37	0.99
GU based on LCC	FARO 55	2.84	160,975.56	68,600.00	92,375.56	1.33
Control	FARO 57	1.77	101,351.11	64,100.00	37,251.11	0.58
USG at 45.1	FARO 57	3.21	184,133.33	72,635.00	111,498.33	1.53
USG at 72.2	FARO 57	3.35	191,687.04	75,300.00	116,387.04	1.54
USG at 117.3	FARO 57	4.72	270,512.59	84,635.00	185,877.59	2.20
GU at 45.1	FARO 57	2.71	155,681.48	75,000.00	80,681.48	1.07
GU at 72.2	FARO 57	3.28	188,434.81	78,400.00	110,034.81	1.40
GU at 117.3	FARO 57	3.86	220,214.81	89,600.00	130,614.81	1.46
GU based on LCC	FARO 57	2.94	168,724.81	67,100.00	101,624.81	1.52
Control	FARO 52	2.28	130,214.81	64,100.00	66,114.81	1.03
USG at 45.1	FARO 52	4.43	252,837.04	72,635.00	180,202.04	2.48
USG at 72.2	FARO 52	4.72	268,497.41	75,300.00	193,197.41	2.57
USG at 117.3	FARO 52	5.67	322,542.22	84,635.00	237,907.22	2.81
GU at 45.1	FARO 52	3.87	220,757.78	75,000.00	145,757.78	1.94
GU at 72.2	FARO 52	3.84	218,610.37	78,400.00	140,210.37	1.79
GU at 117.3	FARO 52	2.60	205,826.30	89,600.00	116,226.30	1.30
GU based on LCC	FARO 52	3.73	212,660.00	69,350.00	143,310.00	2.07

Calculation of total revenue is based on ₦ 5,700 per bag (75 kg) of paddy rice at the farm gate price.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Characteristics of the Study Sites

The results of soil analysis in Table 1 indicated that the sites had soils that were Sandy Loam at both Talata Mafara and Kadawa. The sandy loams ensure adequate production especially with regular supply of water as reported by Agbato (2003). The soil reaction (pH) was moderate to slightly acidic in all the years and for the two locations; and these were within the pH limit (5.5 to 6.5) set for optimum crop production in the tropics (Esu, 2010). The soils of the study sites were characteristically low in organic carbon content (< 3 g kg^{-1}), total nitrogen (< 1 g kg^{-1}) and CEC (< 6 c mol kg^{-1}) due to low clay content and low organic matter content of the studied soils; but exchangeable bases were relatively moderate. These values were in accordance of the report by FMARD (2012).

The low level of organic carbon is associated with sandy nature of the soil as presented in Table 2which would enhance rapid leaching of basic cations; this is in line with Enwezor *et al.* (1989) and this could account for low value of CEC. The soil pH value in water was above 5.0 (i.e. > 5.8) indicating that exchangeable Al toxicity may not be a problem in the studied soil. Furthermore, the low content of the soil nutrients indicate possibility of a good response to applied nutrients. In the same vein, the conducive environmental factors such as total amount of rainfall per year (72 – 120 cm), its distribution (over a period of 6 months), adequate moisture (relative humidity of 57 – 69 %) with temperature maximum (32 – 34^0C) and minimum (20 – 24^0C) as shown in Figure 2 which fall within the optimum range for rice production in Nigeria similar to that reported by Agbato (2003) may have contributed to the good performance of the crop during the years under investigation.

5.2 Effect of N- fertilizer Management on Growth Characters of Rice varieties

Generally, significant increases in growth characters as well as delayed days to heading with increase in N- fertilizer applications rates were observed irrespective of the forms of the fertilizer. The increment could be attributed to the fact that nitrogen (N)-fertilizer enhances dark green colour of the leaves, the formation of photosynthetic activities and vigorous vegetative growth of rice as Kamara et al., (2011) argued. Similarly, plant height increased with increasing N levels which is consistent with the submissions of Singh and Singh (1986) who reported that plant height increased with increase of nitrogen level, and that deep placement of USG resulted in the highest plant height than GU. The number of tillers increased with increasing levels of USG and GU, with the highest number of tillers obtained when USG was applied at 117.3 kg N/ha. This finding corroborates the observation made by Hasan (2007); Bayan and Kandasamy (2002) who reported that number of tillers increased with the application of nitrogen fertilizer while Mamum *et al.* (2013) also reported that the deep placement of USG produced higher number of tillers than GU application at harvest.

The crop dry matter, number of panicles and length of panicles followed the same trend as was with number of tillers where application of USG at 117.3 kg N/ha produced more than others except at Talata Mafara where GU toproduced more than USG.This is observed to be due to inconsistent management practices of supplementing irrigation withrain water observed at Talata Mafara while at Kadawa, it was GUrely rain-fed. The progressive improvement in the formation of tillers was due to the efficiency and availability of nitrogen, which promoted tillering ability. This is seen as a result of crop management such as earlier transplanting of the seedling with spacing of 20 cm x 20 cm and at one seedling per stand.

Moreover, adequate N fertilizer was applied and this encourage maximum tillering apart from proper timing of N application targeted at tillering which is one critical stage for rice production. Adequacyof nitrogen as USGwas observed to have favoured the cellular activities during panicle initiation and development which in turn led to increase number of productive tillers. Increase in number of panicles and length of panicle resulting from higher N-fertilizer application especially USG, also led to higher dry matter production and consequently higher yields than others. These results indicates that the deep placement of urea (USG) increased the efficiency of nitrogen fertilizers for both vegetative and reproductive growth of rice plants as Eriksen and Nilsen (1982) posited and this explained the fact that nitrogen supply by the USG was synchronized with crop demand and hence created better utilization.

It also showed that continuous availability and slow release of N from USG played significant role in cell division due to higher photosynthetic activities for the availability of N that helped to sustain vegetative and reproductive stages. The observed delay in heading due to higher N- application in form of USG was observed to be due to availability of nutrients which prolonged vegetative growth and development. Crops are usually induced to enter reproductive phase when under nutrient deficiency stress.

5.3 Effect of N- fertilizer Management on Yield and Yield components of Rice

Significant increase obtained on grain yield and yield attributes such as number of panicles, panicle length,biological and straw yields after application of USG was an indication of improved soil fertility (nutrient supply) which could be due to slow release of nutrient and

reduced loss of N from soil as compared to GU (Bandaogo *et al.,* 2016). This finding is in line with the work of Islam *et al.*(2013) and Liu *et al.*(2007) who reported that the absorbed N used for leaf growth at tillering stage was later transported to the panicles and at advanced developmental stage to form rice straw. Result on biological, straw and grain yield at Talata Mafara indicated no significant differences from the GU, the USG and management by the use of leaf colour chart (LCC). This does not agree with the submissions of Dongarwar *et al.* (2003) that there was a significant increase in grain yield with successive increase in fertilizer rate, and those of Kumar and Singh (1983) and Raja *et al.,* (1987) who reported that N fertilizer in the form of USG gave 14.4% higher yields compared to split application of urea.

On the other hand, results from Kadawa, where USG gave 13.26% more rice grains than the GU is in consonance with these findings; and that of Tarfa and Kiger, 2013 who stated that Urea Deep Placement (UDP) of USG in irrigated rice had a yield increase of 20 – 30 % over farmer's practice in Gombe, Kebbi and Niger states of Nigeria.. Again, the submissions of Ali (1985) that deep point placement of USG was superior to 2 or 3 applications of GU and USG was superior at all N rate which also supports this study. We found also that USG gave additional 810 kg/ha rice grain over Granular urea (GU) in this study, which agrees with Mohanty *et al.* (1999) who reported that USG deep placement resulted in additional grain yield of 1080, 510 and 350 kg/ha over Granular urea in alternate wetting and drying, shallow lowland and intermediate low land rice respectively.

Moreover, yield components were improved with N fertilizer application than without and this was what Mishra *et al.* (1999) observed that application of nitrogen increases the number of panicle, panicle length, number of tillers, N uptake and consequently the grain and

straw yield of lowland rice. Formof fertilizers (USG and GU) significantly influenced total biological yield in the rain-fed rice experiment in this study, with USG giving a higher biological yield than the Granular urea, implying that USG is a better management options for improving the total biomass in rice. This finding agrees with Ahmed *et al.* (2002) who areof the opinion that USG was most efficient form of nitrogen in producing all yield components and in turn, grain and straw yields.

Singh *et al.* (2005) also toe the same line where they reported that each increment dose of N significantly increased grain and straw yields over its preceding dose. However, the results obtained from the irrigation experiment at Talata Mafara, where forms of urea application had no significant effect on the total biomass of rice remained an exception. Hence, the disparity between results obtained in Talata Mafara and Kadawa was attributed to inconsistent water management practices of complementing irrigation and rain wateras well as harvesting the crop during wet season at Talata Mafara.

5.4 Effects of N-management on Harvest Indices

Grain harvest index (GHI) was slightly influenced by forms of urea, but significantly by leaf colour chart (LCC). In the irrigation experiment for instance, the highest (49.57 %) GHI was obtained by the LCC, whereas the lowest(42.10 %) was obtained with application of GU at 117.3 kg N/ha. With the urea forms, USG was better than GU by 4.08%. A similar result was obtained by Miah *et al.,* (2012) who reported that grain harvest index was found to be higher in USG than GU. The work of Hassanuzzaman *et al.* (2012) also confirmed that USG at 160 kg N/ha gave higher grain harvest than other treatments. The higher grain harvest index

obtained also enhances efficient distribution of photosynthetic product between shoot and grain and hence improved grain yield (Fageria *et al.*, 2011).

As for the N- harvest index, effect of N- fertilizer was not significant, but N-harvest index decreases with increasing N application and this could have led to excessive N uptake as reported by Mandana *et al.* (2011). Effect of N- management on P- and K- harvest indices were not consistent and varied greatly between USG and GU even with GU based on LCC having higher value than others.

5.5 Effect of N-management on Nutrient (N, P and K) Uptake

Generally, the amount of total N, P and K uptake in this study increased with increasing rate of N- fertilizer for both USG and GU. However, USG recorded higher nutrient uptake than GU. The work of Bowen *et al.* (2004) confirmed this finding, who stated that the use of urea super granule enhances the crop uptake of applied N fertilizers in irrigated rice. This result is attributed to the fact that USG provide adequate N in a single application to satisfy crop requirements, while maintaining mineral N in the soil throughout the growing period apart from reduced loss of N associated with USG deep placement. Moreover, subsequent increase in P and K uptake under USG may be due to interdependence between N, P and K (Rabat, 2003). Again, the fact that N is a limiting nutrient in rice systems and its availability with USG increases the P and K uptake (Segda, 2006). Although, there are other assertions that the application of 120 kg N ha^{-1}(close to highest N rate of 117.3 kg N/ha applied in this study) recorded significantly higher N, P, and K uptake in rice compared to the rest of the N levels.

5.6 Effect of N management on nutrient use efficiency

Generally, results obtained from this research work showed that Agronomic Efficiency (AE), Agro physiological Efficiency (APE) and Nitrogen Utilization Efficiency (NUE) increased with decreasing N levels for both USG and GU and this agrees with the findings of Haefele *et al*. (2008) that AE reduce with increasing N levels. On the average, USG at 45.1 kg Nha^{-1} gave the highest AE, APE and NUE which were significantly higher than the other N rates including GU at 45.1 kg Nha^{-1}. This could be attributed to reduced N losses in the USG owing to deep placement which eliminates NH_3 volatilization and significant reduction in de-nitrification (Savant and Stangel, 1998).

Similarly, the decreasing use efficiency of nitrogen with increasing N levels as observed in both locations is attributed to loss of N to the environment which usually takes place when high concentrations of soluble N forms are present in the soil solution in excess compared to the amount that plants can take up (Fageria and Baligar, 2005). Again, this research finding agree with work of Jena *et al.* (2003) who reported that deep placement of USG significantly improved nitrogen use efficiency of rice and reduced volatilization loss of ammonia relative to the application of GU. Furthermore, Ali (1985) also discovered that NUE was significantly higher with USG than split broadcast of urea, while Mohapatra (1988) reported only 1% and 2% volatilization loss of NH_3 from USG in both wet and dry seasons whereas the losses were 4 and 6% respectively for GU. This reduced volatilization loss of NH_3 in USG may be responsible for the improved NUE. The above findings support the assertion that placement of USG in the root zone is the most effective method for increasing the nitrogen use efficiency and rice yield (Prasad *et al.,* 1982; Sharma, 1985).

5.7 Response of Varieties to N management

Generally, crops differ in their ability to assimilate photosynthesis, and thereby vary in their growth and yield components. The varieties used in this study exhibited consistent significant differences in both growth and yield characters. The growth attributes includes plant height, number of tillers, crop dry matter and days to 50 % heading, while yield components observed were number of panicles, panicle length, biological yield (biomass), straw and grain yield; and 1000-grain weight. In all the above mentioned growth characters, FARO 52 had robust growth in both locations and years under study than the other two varieties, except in plant height where FARO 55 produced the tallest plant, while the shortest plant was obtained from FARO 57.

Similarly, in terms of yield and yield attributes, FARO 52 was superior to both FARO 57 and FARO 55 in that order, except in 1,000-grain weight and grain harvest index where FARO 57 produced heavier grains than other varieties. The probable reason of these varietal differences in both growth and yield characters is the genetic make-up of the variety which is primarily influenced by heredity. These results corroborates the findings of BINA (1998), Om *et al.*(1998) and Bhowmick and Nayak (2000) who stated that effective tillers varied due to variety and also agree with the submissions of Shamsuddin *et al*,(1988) and Chowdhury *et al.* (1993) who reported differences in 1000-grain weight among rice varieties. In addition, varietals differences regarding grain yield was also reported by Patel (2000).

Moreover, the high nutrients (N, P and K) uptake and its use efficiencies (AE and NUE) recorded by FARO 52 throughout the study might have been as result of its ability to absorb higher amount of N than FARO 57 and FARO 55 in that order (i.e. to enhance the conversion

of applied N fertilizers to yield better than other varieties); thereby leading to greater yield performance and hence high NUE. This agrees with the report that rice genotypes differ significantly in N uptake and utilization efficiency (Fageria, 2007) and it is known that the response of crops to N varies due to their genetic makeup. Again, the differential performance observed among the three varieties could be attributed to genotypic difference in the rooting system, nutrient uptake and grain filling capacity as reported by many authors on the influence of genotypic traits such as plant type and growth duration on the nutrient use efficiency (Duan *et al.*, 2005; Fageria *et al.*, 2010).

This difference among rice genotypes in terms of nutrient uptake can also be linked to their differences in rhizosphere effects on the extent and pattern of soil N mineralization (Kundu and Ladha, 1997). Specifically, differences in rooting characteristics such as root surface area, root mass, root depth, root number and root length density (Kirk and Bouldin, 1991) can also be implicated.

5.8 Effects of N management and variety on soil chemical properties

Generally, the effect of N management and varieties for both USG and GU resulted in no significant differences on most of the observed soil chemical properties with some levels of inconsistencies across the two locations within the period under investigation.

5.9 Interactions

Generally, the interaction of N management (USG and GU) and variety were not significant and inconsistent in most of the observed parameters. However, combination of USG at 45.1 kg N/ha and FARO 52 or FARO 57 resulted in significant increase in growth parameters

while combination of USG at 117.3 kg N/ha and FARO 52 resulted in significant increase in both grain and biological yields. The high performance recorded by USG at 117.3 kg N/ha in combination with FARO 52 or FARO 57 which might be due to the nitrogen (N) use efficiency of varieties from different sources and the fact that N took part in grain formation especially with USG at adequate level of 117.3 kg/ha where maximum N was taken up by rice plant and later converted into dry matter for producing grains. The persistent least growth and yield recorded by the control (0 kg N/ha) on FARO 55 could be attributed to the presence of little or no N and the fact that FARO 55 showed lower N uptake under USG.

These findings could be explained by the genotypic differences of the rice varieties used in this study and their relationship with the root environment. Similar research findings were also reported by Qurashi *et al.*(2013) and Jisan *et al.*(2014) where the highest grain and straw yields were recorded from higher rates of N (75 – 120 kg/ha) as USG and the lowest from 0 kg N/ha.

There were no significant interactions of N management and variety on straw yield, 1,000-grain weight, grain harvest index, nutrient use efficiencies (AE, APE and NUE) and soil chemical properties observed in all the sampling periods.However, application of USG at 117.3 kg N/ha toFARO 52 gave significant N uptake than other treatment combinations.

5.10 Correlation and Principal Components Analyses

5.10.1 Correlation analysis

The significant and positive correlations observed among paddyyield, biological yield, straw yield, dry matter, plant height and N uptake indicated their relevance as yield determining

factors. This implies that improving these traits may mean high yield in rice genotypes under study. Similar results had been observed by Ukaoma *et al.* (2015) and Abdus Salam *et al.* (2009) in which plant height, shoot dry matter and number of tillers exhibited significant correlation with the yield of hybrid rice. Sahrawat, (1983) also observed significant positive correlation between dry-matter yield of rice and N uptake.

On the other hand, non-significant relationship occurred between paddy yield, soil pH, soil P and K. However, a strong and positive relationship existed between number of tillers, soil N, available P and K indicating the importance of number of tillers and these nutrients for rice production and this is in line with the findings of Linca *et al.* (2016) who reported positive interrelationship of soil variables, plant growth and yield parameters. The persistent negative relationship between the soil pH and soil available P suggests careful management of available P for continuous and sustainable rice production in the study areas as observed by Abiodun (2015) in his report on soil properties for sustainable rice production in Nigeria.

5.10.2 Principal component analysis

Factor analysis grouped 16 measured attributes into five factor components (FC 1 – 5) in the combined years (2012 and 2013) at both locations. All the five factors related to one or more soil functions ranging from soil exchange capacity, potential nutrients, acidifying properties and soil organic properties. Measured attributes constituting these factors influenced soil nutrient uptake and capacity properties which resulted in yield turnover. These five factor components (FCs) identified constitute the minimum dataset required to group rice soils in the study areas.

The FC 1 was directly related to 'plant nutrients uptake' with a high positive loading of P- and K- uptake which constituted the most dominant factor that influences biomass yield. FC 2, called 'additional plant nutrient uptake factor' with a high positive loading composed of N uptake as the major contributing variable and this explained the significance of 'plant nutrients uptake' on paddy yield production.

FC 3, named 'soil base status factor' because it had a high positive loading on cation exchange capacity i.e. calcium (Ca) and magnesium (Mg) as the major variables of the exchange capacity of the treatment. This factor significantly influenced the acidifying capacity and nutrient availability as evident by their high positive loading which leads to the production of free organic acids that make the environment alkaline.

FC 4 was the 'soil acidifying properties' as the most dominant contributing variables, with moderate negative loading from pH water and $CaCl_2$. The negative loading from pH water would have contributed to the gain of pH- dependent charges and hence increase in pH from the treatments resulted in more positively charged ions in the soil system i.e. high positive loading of Ca, Mg with a moderate loading of K. The submissions in FC 3 and FC 4 also agrees with the findings of Tabi *et al.* (2012) and Salami *et al.* (2011) who identified available P, organic matter, acidity and sand-silt as factors responsible for soil fertility variation in Logone/Chari flood plain, Cameroon and northern guinea savanna zone of Nigeria respectively.

FC 5, identified as 'soil additional potential nutrients' with a moderate positive loading from exchangeable potassium (K), nitrogen and moderate negative loading from organic carbon.

Positive loading from soil organic matter and nitrogen indicated their essentiality in rice production and suggesting organic matter accumulation. This finding was similar to the work of Linca *et al.*(2016) who reported that rice soils were characterized by pH, organic carbon, and nitrogen; exchangeable Ca, Mg and available Si as the major contributing variables for soil evaluation method in the fields. Again, the fifth components (FC 5) also confirms the report of Mengel and Kirkby, (2001) who stated that nitrogen is one of the most important factors controlling potentially mineralizable N in wetland rice soils.

5.11 Application of QUEFTS model

5.11.1 Estimating indigenous soil nutrient supply, internal nutrient efficiency and fertilizerrecoveryfraction

The nutrient uptake of rice significantly influenced yields which in turn increased indigenous nutrient supply and this implied significant nutrient use efficiencies by rice crops in the study areas. This finding is also similar to that of Wanyama *et al.*(2015) and Das *et al.* (2015) who reported that nutrient uptake especially P and K increased lowland rice yield. The mean indigenous soil nutrient supplies (INS and IPS) obtained in this study was slightly high, but the low IKS obtained is common to tropical rice soils. This is in line with the research ofDobermann *et al.* (1996). Thevariability observed in INS, IPS and IKS is similar to the findings of Haefele *et al.* (2003b) who reported that variability observed for all indigenous soil nutrient supply is due to soil and plant characteristics, cropping systems; crop management, fertilizer dosage, source and application timing used.

Theaverage internal nutrient efficiencies (IEs) across all observations were generally low and this is attributed to the N lost through leaching, de-nitrification, ammonia volatilization and

surface run-off. Theoverall N recovery efficiency recorded in this study is similar to the value obtained by Wanyama *et al.*(2015) and Wopereis *et al.* (1999) in their researcher-managed trials but slightly higher than other authors (Haefele *et al.,* 2003a and Dobermann *et al.,* 2002). Again, the values obtained at Talata Mafara (25 – 50 % NRF, 9 – 12 % PRF and 27 – 44 % KRF) under irrigation are lower than those obtained at Kadawa (35 – 72 % NRF, 21 – 48 % PRF and 35 – 91 % KRF). This is similar to the report of BCI (2002) who stated that recovery efficiency is influenced by splitting and timing of fertilizer applications; and this implies that it is a function of crop and soil management

5.11.2 Fertilizer recommendation by QUEFTS model

The recommended fertilizer dosage modeled by QUEFTS varied depending on the locations and cultivars and was also higher than the conventional 'blanket fertilizer' rate recommended over the years. The higher N and lower K recommended for FARO 55 and FARO 57 or FARO 52 respectively suggest different fertilizer combinations for different soil conditions, thereby emphasizing site specific nutrient management (SSNM) techniques. This result also corroborates the findings of Yagus and Edy, (2011) who reported different fertilizer recommendations by QUEFTS model for maize in Indonesia based on varying soil conditions and management practices in farmers' fields.

In addition, results from field validation of the QUEFTS model at both locations with higher value of d-stat (0.71), desirable coefficient of prediction R^2 (0.85), RSME of 0.93 and RSMEn of < 30% showed a good agreement between observed and simulated yields; and thus confirmed the better performance of QUEFTS model in the rice ecosystem under

different nitrogen regimes. Hence, the QUEFTS model can performwell and could be usedas a decision support tool for improved fertilizer recommendations for rice in the study areas.

5.12 Partial Economic Analysis of Paddy Yield

Results obtained in this study showed that regardless of variety used, application of N-fertilizers (USG and GU) up to 117.3 kg N/ha increased the biological yield. The economic analysis of rice production showed that the applications of GU at 45.1 kg N/ha and USG at 117.3 kg N/ha on FARO 52 gave the highest gross margin of ₦282,197.15k with a profit of ₦3.11k per naira invested at Talata Mafara and ₦237,907.22k with a profit of ₦2.81k per naira invested at Kadawa respectively. The higher profitability observed in the application of USG to all varieties of rice at both Talata Mafara and Kadawa resulted from higher yield and low total variable cost especially, the labour on fertilizer application and fertilizer cost incurred on the USG fertilizer options. Thereby, reduces the cost of fertilization. In addition, there was a substantial difference between the yields of paddy rice under different N-fertilizer regimes which can be attributed to differences in absorption of nutrients by the rice varieties differently and availability of the nutrients which differs for each treatment. On the other hand, the cost of fertilization of GU was relatively higher due cost incurred on fertilizer application (2 splits).

Result also showed that production of rice under irrigation had higher gross margin (₦282, 197.15 with a profit of ₦3.11 per naira invested) at Talata Mafara; while at Kadawa under rain-fed had lower gross margin (₦237,907.22 with a profit of ₦2.81 per naira invested). This finding corroborates the report of Daudu *et al.* (2014) who observed higher profitability of

lowland rice (₦264, 420.00 with a profit of ₦3.24k) over the upland rice (₦93, 780.00 with a profit of ₦1.15k) in the northern Nigeria.

CHAPTER SIX

6.0 SUMMARY, CONCLUSIONAND RECOMMENDATIONS

6.1 Summary

The focus of this study was to evaluate nitrogen management in rice systems through the use of urea super granule (USG), Granular urea (GU) and application of GU based on LCC on three rice cultivars (FARO 55, FARO 57 and FARO 52) in the Sudan savanna ecological zone of Nigeria. The treatments consisted of four rates of USG (0, 45.1, 72.2 and 117.3 kg N/ha), four rates of GU [(0, 45.1, 72.2, 117.3 kg N/ha and a rate based on leaf colour chart (LCC)]. The first experiment involved field experiment in which all the treatments were laid in a randomized complete block design (RCBD) in a factorial arrangement and replicated three times. The second experiment of the study involved the use of the QUEFTS model to determine alternative fertilizer recommendation (AFR) for irrigated and rain-fed rice in Sudan savanna, Nigeria.

Resultsfrom the study revealed that the soil of the study sites were moderate to slightly acidic with low organic carbon, total nitrogen, cation exchange capacity and moderate exchangeable bases. Growth parameters generally increased with increase N application for both USG and GU, but with delay in days to heading especially with USG. Application of USG at 117.3 kg N/ha significantly increased yield and yield attributes except for grain harvest, phosphorus harvest and potassium harvest indices where application of GU based on LCC gave the highest values. USG technology also gave higher N, P and K uptakes and nutrient use efficiencies (AE, APE and NUE) even at lower rates. Among the rice varieties evaluated,

FARO 52 was superior to both FARO 57 and FARO 55 in that order in most of the parameters observed. Interactionbetween N management and varieties indicated that the combined application of USG at 117.3 kg N/ha and FARO 52 resulted in significantly higher rice yields.

Paddy yield was positively and significantly correlated with biological yield, straw yield, dry matter, plant height and N uptake; but negative relationship existed between soil pH and available P. In addition, principal component analysis (PCA) indicated the relevance of N, P, K, Ca, Mg, organic matter accumulation and soil pH as the major contributing variables on paddy yield.

The indigenous soil nutrient supplies (INS, IPS and IKS) varied greatly with low internal nutrient efficiencies and nutrient recovery efficiencies at both locations. The recommended fertilizer dosage modeled by QUEFTS varies depending on soil conditions and rice cultivars. It was higher than the conventional 'blanket fertilizer' rate recommended over the years. The model also recommends higher N with lower K for FARO 55 but lower K for FARO 57 and FARO 52; thereby advocating for site specific nutrient management (SSNM) through the use of different fertilizer combinations for different soil conditions. Field validation of the QUEFTS model showed a good agreement between observed and simulated yields, hence confirming better performance of QUEFTS in the rice ecosystem under different nitrogen regimes.Partial economic analysis of paddy rice production at Talata Mafara and Kadawa revealed that application of USG at 45.1 and 117.3 kg N/ha onFARO 52 gave the highest gross margin as well as profit per naira (₦) invested.

6.2 Conclusion

From the results of this study, it can be concluded that application of USG at 117.3 kg N/ha, gave the highest paddy yield as well as most growth attributes. Nutrients (N, P and K) uptake were better enhanced with the application of USG at 117.3 kg N/ha. However, nutrient use efficiencies (AE, APE and NUE) were higher at lower rate of USG (45.1 kg N/ha). Paddy yields were better and the nitrogen utilization efficiency (NUE) more efficient with FARO 52 using USG as compared to FARO 57 and FARO 55. The growth and yield characters such as plant height, number of tillers, number of panicles, dry matter, straw yield as well as soil attributes like N uptake, pH, organic matter accumulation considered in this work made significant contribution to paddy yield and thus constitute important characters when breeding for high yielding varieties.

Observed indigenous soil nutrient supplies (INS, IPS and IKS) vary with low nutrient recovery efficiencies in the study areas. Recommended fertilizer dosages modeled by QUEFTS varies and were higher than the conventional 'blanket fertilizer' rate recommended over the years, thereby advocating for site specific nutrient management (SSNM) techniques. QUEFTS model validation showed good agreement with predicted values; hence application of QUEFTS model could be used as a decision support tool for improved fertilizer recommendation for rice in the study areas. The combinations of USG at 117.3 kg N/ha and FARO 52 gave the highest gross margin as well as profit per naira invested.

6.3 Recommendations

- Application of USG at 117.3 kgN/ha is recommended for transplantedrice in the studyareas.
- Promotion of USG through urea deep placement as a new technology for rice production ishighly desirable and should be introduced and promoted in the study areas.
- The use of leaf colour chart (LCC) is a novel, more economically sound and promising technology. It should be deployed and promoted by researchers and extension organizations to farmers.
- FARO 52 and FARO 57 varieties were recommended for rice production in the studyareas.
- Further studies at the on-farm level should be conducted to validate the use of QUEFTSmodel especially for smallholder rice farmers in the study areas.

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