

**THE EFFECT OF METHOD, RATE AND TIME OF UREA APPLICATION ON
NITROGEN USE EFFICIENCY AND YIELD OF WETLAND RICE IN RWAMAGANA
DISTRICT OF RWANDA**

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April, 2014

DECLARATION**Candidate:**

This thesis is my original work and has not been presented for the award of a degree or any other award in any other University.

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DEDICATION

I lovingly dedicate this thesis

To my late father who nurtured me and who provided an example of hard work and pride in a job well done. The time he spent, the opportunities he provided and the instruction he gave continue to bless my life.

To my mother for her motherly love, care and for shaping me into a person I am today.

To my brothers and sisters, for their undying love and for being my source of motivation and inspiration throughout my studies.

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ABBREVIATIONS AND SYMBOLS

AGRA: Alliance for Green Revolution in Africa

ANOVA: Analysis Of Variance

DNA: Deoxyribo Nucleic Acid

CRD: Completely Randomised Design

EC: Emulsion Constituent

GOR: Government of Rwanda

IFDC: International Fertilizer Development Center

IUSS : International Union of Soil Sciences

ISAR: Institut des Sciences Agronomiques du Rwanda

JMP: Statistical Software for Analysis

LSD: Least significance Difference

MINAGRI: Ministry of Agriculture and Animal Resources

P I: Panicle Initiation

RNA: Ribo Nucleic Acid

USAID: United States Agency for International Development

WARD: World Africa Rice Development Association

WRB: World Reference Base for Soil Resources

ABSTRACT

Rice is the staple food for more than half of the world population and for most low income people especially in Asia. In Africa, over 50 million people depend on rice farming. In Rwanda, the livelihood of nearly half a million individuals is rice-based. Rice is often very responsive to nitrogen fertilization and the high yield potential of modern varieties cannot be realized without adequate nitrogen supply to the plant during the entire growing period. The purpose of this study was to evaluate the effect of mode of application, rates, and timing of urea on rice productivity in Rwamagana marshland, Rwanda. IRR128 variety was used in the experiment. Two separate experiments were conducted. The first one assessed the effect of N fertilizer at different rates and at two modes of application i.e deep and surface placement. The N fertilizer rates were at 4 levels (0, 40, 80 and 120kg N/ha) resulting into a total of 8 treatments. The experiment was factorial and was arranged in a Completely Randomized Design (CRD). The second experiment assessed the effect of time and rates of nitrogen fertilizer applied in splits to the surface only. This second experiment was also arranged in a CRD with 11 treatments. All the treatments were replicated three times. For data analysis, JMP package statistical software was used to analyse data, and for means of separation, Fischer's protected LSD at the 5% significance level was used. Results of Grain yield components and grain rice yields were affected by different application methods but not significantly. Deep placement method appeared to be more effective and superior in rice performance, with grain yield of 5.6t/ha realized when 120kg/ha N was applied compared to 5.3t/ha with surface method, a difference of about 6%. Application of N in splits also influenced the rice yield components and grain yield but not significantly in relation to that of deep placement. In terms of NUE (Nitrogen Use Efficiency), deep placement of N again exhibited higher values than both surface and split methods which ranged between 7.5 and 13.5 kg grain/kg N applied. Nitrogen content in plant tissues and grain was generally low and less than 2% which is the recommended value in plant tissues. Again, deep placement exhibited higher % N content in plant tissues especially in Panicle Initiation where the content was more than 2 % than surface and split modes of application. In overall, deep method of N application appeared more promising in rice productivity than surface and split modes of application in this study at Rwamagana, Rwanda.

CHAPTER ONE: INTRODUCTION

1.1. Background information

Rice is the staple food for more than half of the world population and particularly for most people in Asia. In Africa, over 50 million people depend on rice farming (FAO, 2003). In Rwanda, the livelihood of nearly half a million individuals of growers' families is rice-based, while an additional 2 million people earn their incomes as farm labourers from rice fields (ISAR, 2009).

In Rwanda, rice cultivation has been for at least four decades in exclusively mixed irrigated rain-fed lowlands (ISAR, 2009). The average individual farm size is 0.20-0.25 ha with a yield of 4-5 tons/ha (WARDA, 2009), and / benefit ratio factor of two. However, several cases of yield levels as high as 8-10 tons/ha are frequently reported with model farmers who invest high level of production inputs such as fertilizers (300kg of NPK/ha) and pesticides (ISAR, 2009). Rice is often very responsive to nitrogen fertilization and high yield potential of modern varieties cannot be realized without adequate Nitrogen supply to the plant during the entire growing period. Recovery of applied nitrogen by lowland rice with reliable water supply is invariably low and hardly exceeds 30-50% (Schnier *et al.*, 1988, Mohanty *et al.*, 1999, Song Chen *et al.*, 2012). This low recovery is attributed to several loss processes operating in the rice fields such as volatilization, nitrification, denitrification, leaching and NH_4^+ fixation by clays (Fillery *et al.*, 1984). Many strategies have been developed to increase the Nitrogen use efficiency from fertilizers such as proper timing, rate, placement, modified forms and use of inhibitors on nitrification and urease (Timothy *et al.*, 2007). Split application of fertilizer suggested for increasing Nitrogen use efficiency is often not practical in rain-fed lowland rice due to adverse soil-water situations. Hence, the entire required amount of Nitrogen has to be applied in one dose when the water regime is favourable. A single broadcast application, however, increases nitrogen loss. Deep

placement of urea supergranules (USG) has been proven to improve nitrogen fertilizer efficiency (Mohanty *et al.*, 1999).

In view of above potential and owing to an alarming population growth and subsequent continuing shrinkage of agricultural lands on the hills, the Government of Rwanda, since 2000 has embarked on a marshland development program with a target of 100,000 hectares by 2030 (MINAGRI, 2010) to optimize food production with rice as the key crop. This program, however, identified the limited availability and use of inorganic fertilizers as a major obstacle. In response, a long term initiative-Crop Intensification Program (CIP) launched in 2007, imported and distributed over 30,000 tons of fertilizers for use on Irish potato, maize, wheat and rice in 2009. With the growing challenges of fertilizers supply and availability in Rwanda, there is urgent need to intensify research on fertilizer use efficiency and crop production, and more so to improve rice production which is emerging as a key crop in terms of consumption and trade in Rwanda (ISAR, 2009).

1.2 The Statement of the problem

Rice is the most important food grain in the diets of millions of Rwandans. However, yield on farmers' fields is still very low; ranging from 3 to 5 tons/ha. Nitrogen is globally reported to be the most yield-limiting nutrient in lowland rice production. Thus, proper nitrogen management is needed for improving rice grain yields (Mirza *et al.*, 2009). The method of application, the rate and timing of Nitrogen fertilizers (Timothy *et al.*, 2007) are three of the most important factors affecting rice growth and yield. The knowledge of methods of application, time of application and rates to be used are not known by farmers. Split applications of nitrogen that coincides with plant needs have been suggested as a way of improving nitrogen recovery efficiency. Reports suggest that nitrogen use efficiency is optimized when nitrogen is applied in a single basal application at four-to-five leaf stage. Multiple, or split applications may be employed to fertilize tall, lodging-

prone cultivars or semi dwarf cultivars grown on some clay soils that require high nitrogen rates. Deep placement method has been also reported to protect various nitrogen loss mechanisms at the placement sites in the soil.

Reports also indicate an overall improvement in reversing the falling crop productivity prior to CIP. However, because blanket fertilizer recommendations (84 N, 34 P, 34 K Kg/ Ha), developed three decades ago, are still in use regardless of the crop species, variety, and the array of soil, climatic and cropping conditions existing in Rwanda, this program is likely not to result in optimal efficiency and benefits. There is therefore an urgent need to update and tailor fertilizer needs to the range of production conditions. This study was therefore conducted to compare the effectiveness of surface application (both in single or splits) and the deep placement of nitrogen fertilizers on rice yield and come up with proper fertilizer rates for effective rice production in Rwanda.

1.3 Justification and significance of the study

Rice is increasingly becoming staple cereal crop in Rwanda. Through the promotion of rice intensification by the government, there has been a significant rise in area under rice cultivation. However, the production is still low mainly due to the fact that farmers are still broadcasting NPK as an application method into floodwaters to fertilize paddy plants (ISAR, 2009). This is highly inefficient because the fertilizer nutrients are not taken up by the plant for they are applied at the wrong time or in the wrong place or transformation of nutrients makes them unavailable to plant uptake. About 60% of Nitrogen fertilizer applied is lost as greenhouse gas or becomes a groundwater pollutant (Savant and Stangel, 1990). Urea fertilizer applied at different rates and at deep placement methods are more efficient and environmental friendly in terms of pollution and reduction of nitrogen losses. This study has therefore compared the effectiveness of surface application and the deep placement of urea N fertilizer on rice yield. Ultimately, the findings

from the study will generate information to be used by the government and to advise the farmers on the proper fertilizer management, which will lead to increased rice yields as a part of food security and improvement of farmers' income. The CIP was launched by the GOR in the Cabinet Meeting held on September 14, 2007, as a pilot program with the main goals of increasing agricultural productivity in high-potential food crops and ensuring food security and self-sufficiency

1.4. Overall objective

The overall objective of this study was to increase rice yields through efficient management of nitrogen fertilizers in order to improve livelihoods of many small scale-farmers in Rwamagana district of Rwanda

The specific objectives of the study were:

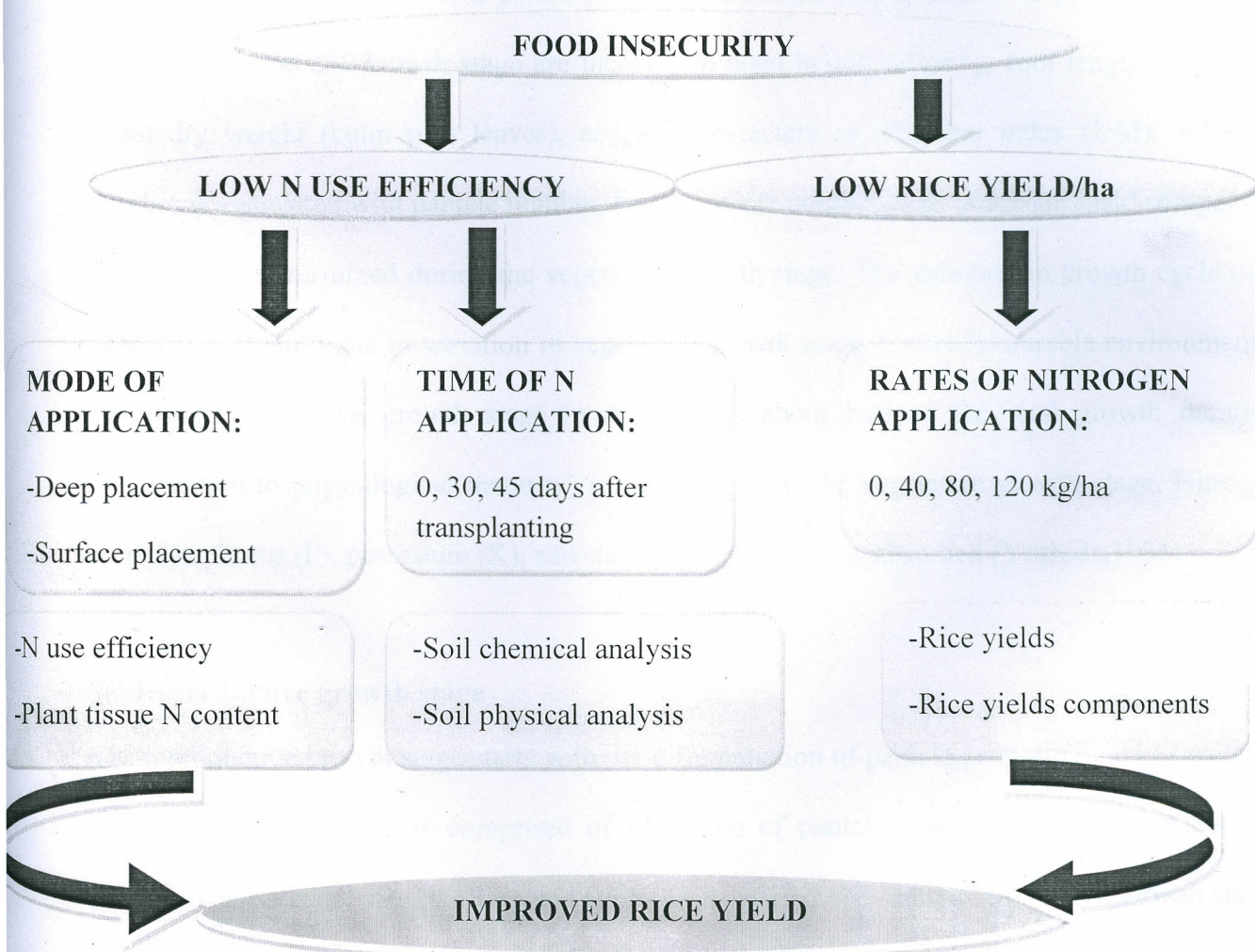
1. To determine the effect of N fertilizer rates on rice grain yield and rice components performance.
2. To evaluate the effective method and rate of nitrogen fertilizer application in terms of nitrogen response and nitrogen use efficiency on grain yield.
3. To determine the effect of method, rate and timing of nitrogen fertilizer application on nitrogen content in rice tissues and grain.

1.5. Research hypothesis

1. Rice grain yield and rice yield components are not affected by different N rates applied to improve performance
2. Nitrogen uptake and nitrogen use efficiency are not affected by modes, rates and timing of Nitrogen application
3. Nitrogen content in plant tissues and grain is not influenced by the method, time and rate of nitrogen fertilizer application

1.6. Conceptual framework

The demand for rice consumption in Rwanda is steadily on the increase as a staple food for many households. However, its production in the country is still very low, estimated at less than 4 tons/ha. A possible leading to low production among others is the poor management of nitrogen which is the most important nutrient in rice production. Proper management of nitrogen to increase its nutrient use efficiency is a first step to boost rice production. To increase N use efficiency, this study considers two modes of N application, the deep and surface placement, and also the rates of N fertilizer and their timing in application, either at once or in splits. The whole concept is centred on proper nitrogen management to increase its use efficiency in order to increase rice per a given unit area.



CHAPTER TWO: LITERATURE REVIEW

2.1 Rice life phases

The rice plant takes 3-6 months from germination to maturity, depending on the variety and the environment under which it is grown. During this period, rice completes two sequential growth stages: vegetative and reproductive. The reproductive stage is subdivided into preheading and post heading periods. Yield capacity, is primarily determined during preheading ultimate yield, which is based on the amount of starch that fills spikelets, is largely determined during post heading. Hence, agronomically, it is convenient to regard the life history of rice in terms of three growth stages: vegetative, reproductive, and ripening (Yoshida, 1981).

2.2 Vegetative growth stage

The vegetative stage refers to a period from germination to the initiation of panicle primordia; Main features of this growth stage are increase in plant height, tillering, root length or weight, shoot dry weight (culm plus leaves), and leaf characters or leaf area index (LAI). Tillering number is associated with panicle number, hence panicle number is an important yield component in rice and is determined during the vegetative growth stage. The variation in growth cycle of a genotype is mainly due to variation in vegetative growth stage. Under favourable environmental conditions, vegetative growth stage in rice covers about half of the total growth duration (germination to physiological maturity) in the tropics. At the vegetative growth stage, Nitrogen (N), phosphorus (P), potassium (K), and sulphur (S) are actively absorbed (Yoshida,1981).

2.3 Reproductive growth stage

The reproductive growth stage starts with the differentiation of panicle primordial and extends up to flowering. This stage is comprised of formation of panicle size or number of spiklet per panicle. The potential size of crop yield is primarily determined in the reproductive growth stage. The reproductive growth stage is characterized by culm elongation, a decrease in tiller number,

emergence of flag leaves (the last leaf), booting, heading, and flowering. Some aspects of panicle formation such as panicle size, compactness and panicle exertion are important traits of this growth stage. Reproductive growth stage is generally completed in 30 days in rice cultivars having 130 to 140 d growth cycle (sowing to physiological maturity) in the tropics. Adverse environmental conditions such as N deficiency, drought, low solar radiation, low or high temperature, and blast disease can reduce panicle size and hence grain yield. (Song Chen *et al.*, 2012, Counce *et al.* 2008).

2.4 Ripening growth stage

Spikelet filling or ripening stage in rice extends from flowering to physiological maturity. It is sometimes also known as maturity growth stage. In this growth stage spikelets filling or weight is determined. The dry weight of the caryopsis increases rapidly up to 15 to 20 d after flowering in the tropics and 25 to 30 days after flowering under temperate conditions. Some adverse environmental factors such as drought, low solar radiation, N deficiency, low or high temperatures, and panicle blast can increase spikelet sterility and consequently grain yield. Spikelet sterility is also genetically controlled. Spikelet filling growth stage like the reproductive growth stage has about 30 days growth duration in cultivars having 130 to 140 days growth cycle from sowing to physiological maturity under Brazilian conditions or tropics. Maximum varietal range is about 25 to 35 days in the tropics. The period from flowering to maturity often ranges from 45 to 60 days in temperate areas where yields are usually high. The spikelet filling duration of japonicas is often slightly longer than that of indicas (Jennings *et al.*, 1979). Spikelet weight and spikelet sterility is main features of this growth stage. During the spikelet filling growth stage, the LAI will decrease due to leaf senescence. This is a normal process in the growth cycle of rice. However, it is important to maintain as many active, green leaves as possible until the linear phase of spikelet growth is completed. The ripening growth stage is subdivided into several stages such as milky, doughy, yellow-ripe, and maturity, on the basis of the size, weight and color of rice

spikelets or grains as indices. During the ripening growth stage, the morphogenesis of the rice plant is already completed and photosynthates are accumulated in the panicles in the form of starch. Mobile carbohydrates, proteins, and mineral nutrients, which are stored in leaves, stems, and roots of the plant, also move to the panicles and the plant gradually becomes senescent. More than 85% of rice grain is composed of carbohydrates, of which the main ingredient is starch (Hayashi, 1995). The starch accumulated in rice grains is originated from carbohydrates assimilated in laminae after flowering or during grain filling growth stage as well as from the carbohydrates stored in the shoot (Hayashi, 1995). Hence, to increase grain yield, it is necessary to increase the carbohydrate production during the ripening growth stage and stored carbohydrates. In most cases, the amount of carbohydrates assimilated during the ripening growth stage is much higher, compared with that of carbohydrates stored in the shoot at the flowering stage (Hayashi, 1995). Therefore, grain yield is mainly affected by the amount of carbohydrates assimilated during the ripening growth stage, especially in the high yielding modern cultivars (Hayashi, 1995). In the high yielding cultivars, Nitrogen absorption generally remains high during the spikelet filling growth stage (Osaki *et al.*, 1991). This means root activity should remain high during maturation, indicating that photosynthates must be translocated to roots. Moreover, when a large amount of Nitrogen is supplied to leaves from roots, photosynthesis should remain high during maturation, to secure the supply of carbohydrates to roots. Hence, growth or activity of roots and shoots was assumed to be mutually regulated by each other (Osaki *et al.*, 1991). Myint *et al.*, 2010 reported that the photosynthetically fixed carbon in leaves of rice is rapidly translocated to harvesting organs during ripening. Hence, a large part of carbon in the harvesting organs was considered to be derived from concurrently assimilated photosynthate.

2.5 Yield component analysis

Rice yield is determined by yield components, which are number of panicles, spikelet per panicle, weight of 1000 spikelet and spikelet sterility or filled spikelet. Therefore, it is very important to understand the management practices that influence yield components and consequently grain yield. Fageria and Baligar (2001) reported that application of N in adequate amount accounted about 91% variation in panicles m^{-2} , about 75% variation in spikelet sterility, and about 73% variation in 1000 grain weight. As discussed earlier that number of panicles are determined during vegetative growth stage, spikelet per panicle during reproductive growth stage and weight and spikelet sterility during spikelet filling or reproductive growth stage. Hence, adequate N supply throughout the growth cycle of rice plant is one of the main strategies to increase grain yield. Rice yield can be expressed in the form of following equation by taking into account the yield components:

$$\text{Grain yield (kg ha}^{-1}\text{)} = \text{Number of panicles m}^{-2} \times \text{Spikelet per panicle} \times \% \text{filled spikelet} \times 1000 \text{ spikelet weight (g)} \times 10^{-5}$$

Among these yield components, panicles or spikelet per unit area is usually the most variable yield component (Fageria *et al.*, 1997).

2.6 Rice growth and nitrogen requirement

Schnier *et al.* (1988) reported that within the first 20 days after transplanting, the root systems of recovering plants have little sink capacity to absorb nitrogen and cannot yet readily take in the basally incorporated nitrogen, subjecting it to high Nitrogen losses.

Nitrogen use efficiency in a drill-seeded cultural system is optimized when nitrogen is applied in a single pre-flood application (PFN) under optimum conditions and intensive management (Bollich *et al.*, 1994; Norman *et al.*, 1999; Song Chen *et al.*, 2012). This single PFN application is made to a dry soil when rice is at the four to five leaf stage and before permanent flood establishment (Bollich *et al.*, 1994; Bollich *et al.*, 1999). Multiple, or split, applications may be employed to fertilize tall, lodging-prone cultivars or semi dwarf cultivars grown on some clay soils requiring high Nitrogen rates (Norman *et al.*, 2003; Chu and Nguyen, 2006). Split applications are also recommended where management is challenging, i.e., permanent flood cannot be established in 5 days, flood could be lost following PFN application and flooding, or rice water weevil (*Lissorhoptrus oryzophilus* Kuschel) infestations are probable. If split applications are used, 50 to 65% of the total Nitrogen requirement is applied immediately prior to permanent flood establishment, and the balance is applied at midseason when rice is at the panicle initiation to panicle differentiation growth stages Nitrogen application rate can influence quality characteristics of rice and rice plants require nitrogen during the tillering stage to ensure a sufficient number of panicles (Islam *et al.* 2009; Ashouri and Amiri, 2011).. The critical time at active tillering for nitrogen application is typically about 14 days after transplanting or 21 days after sowing and panicle initiation.

Application of Nitrogen fertilizer during the late reproductive (booting) growth stage may have an effect on rice grain and milling yield, but this response has not been studied extensively. (Buresh, 2008)

2.7 Nitrogen fertilizer and nitrogen content in plant tissues

It has been hypothesized that application of N in splits can enhance the efficiency of fertilizer Nitrogen by synchronizing fertilizer application with plant demands. Fertilizer applied during peak plant nitrogen demand ensures greater nitrogen use efficiency due to limiting losses from the soil-plant system through leaching and denitrification process (Keeney, 1982, Khuang et.al., 2008).

Significant differences for tissue Nitrogen content were observed among various fertilizer application stages (Jung *et al* 1992; Ashouri and Amiri, 2011). Significantly higher tissue Nitrogen content was recorded when nitrogen was applied as full dose at 5 leaves stage as compared with when applied at sowing. Further research has shown that fertilizer Nitrogen is efficiently utilized when available at later stage of plant growth. (Jung *et al.*, 1992; Rozas *et al.*, 2004).

2.8 Timing and rate of nitrogen application

Timing of fertilizer application may be the most critical factor in determining fertilizer uptake efficiency and crop yield. When fertilizer is applied near the time of maximum growth, crops are able to more efficiently use the nutrients. Variables such as crop and soil type, date of planting, and climate affect the optimum timing of nutrient application.

Extra amounts of fertilizer will not ensure better crop yields or more efficient fertilizer uptake.

Excessive application will increase both the cost to the grower and the potential contamination of surface waters and groundwater. Excessive application of nitrogen fertilizer will increase the likelihood of nitrogen to be leached into surface water and groundwater. (Islam *et al*, 2009).

High nitrogen rates at pre flood can increase the risk of cold damage to the developing pollen microspore, if low night temperatures occur during the number of engorged pollen grains per anther, increasing spiklet sterility and reducing yield potential. Grower preference for many years, supported by some research results, was to apply nitrogen fertiliser as a heavy single dose before seeding (pre-flood), 5–10 cm below the soil surface (Ranjith, 2007).

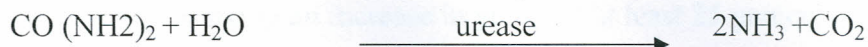
2.9 Urea fertilizer

Urea fertilizer, also known as carbamide, is the most important nitrogenous fertilizer. It is a white crystalline solid organic compound which has the chemical formula of $\text{CO}(\text{NH}_2)_2$, and contains 46 percent nitrogen.

In 1975, IFDC proposed use of supergranules of urea (USG). USG can be prepared by melt-type processes (pan granulation, falling curtain, and fluid bed) and briquetting (a special type of compaction). USG are large, discrete particles of ordinary urea $[(\text{NH}_2)_2\text{CO}]$ containing 46% N as NH_2 (amide form); their weights may vary from 1 to 2 g per particle. USG from melt granulation process are nearly spherical with a relatively smooth surface (Savant and Stangel, 1990). USG is applied as deep placement and increases nitrogen use efficiency because most of the urea nitrogen stays in the soil, close to the plant roots where it is absorbed slowly depending on the plant need.

2.10 Urea hydrolysis and ammonia volatilization

Urea is the dominant Nitrogen fertilizer applied to rice. This Nitrogen form needs to be hydrolyzed to ammonium bicarbonate before the Nitrogen component can undergo other transformations. Urea-Nitrogen is normally taken up by the rice crop after it is hydrolyzed to NH_4^+ . The hydrolysis reaction is:



The enzyme catalyzing the urea hydrolysis reaction is urease. It is naturally present in most submerged soils, and can catalyze urea hydrolysis independently from living organisms.

The amount of urea-N in floodwater following urea application tends to decrease rapidly within 6 days. On the other hand, ammoniacal-Nitrogen ($\text{NH}_4^+ + \text{NH}_3$) tends to increase following urea application. It usually peaks by 1 to 4 days after urea application and then decreases to very low levels in the flood water by 8 days.

Ammonia volatilization is recognized as a major loss mechanism in submerged soils fertilized with urea and ammonium sulfate. Documented losses from rice fields in the Philippines range from 11-54% of the urea-Nitrogen applied by a variety of methods ranging from basal incorporation before transplanting to topdressing at panicle initiation (Dobermann *et al.*, 2001)

2.11 Urea deep placement application method on rice

Urea deep placement is a technology by which urea granular are inserted into the puddled soil to a depth of 7 to 10 cm in tropical and temperate wet land rice, (Mikkelsen *et al.* 1995) in the middle of alternating squares of four hills of rice, within a week after transplanting. Urea granules are termed as Urea Super Granule (USG). This technology improves Nitrogen-use efficiency by keeping most of the urea Nitrogen in the soil close to plant roots and out of the floodwater, where it is more susceptible to loss as ammonia volatilization, nitrification, denitrification, leaching, runoff, seepage, and NH_4^+ fixation by clays (Bowen *et al.*, 2001). Placing the briquettes directly

into the plant root zone reduces nitrogen losses by 40 per cent compared to broadcasting, allowing for a similar reduction in the amount and cost of fertiliser applied. The briquettes are made by compressing prilled or granular urea in small machines with indented pocket rollers that depending on the size of the pocket, produces individual briquettes varying in weight from 1 to 3g. The deep placed urea becomes a 'food store' for the plants, ready to be absorbed when needed, and bringing an increase in yields of at least 25 percent (Mohanty *et al.*, 1999).

Savant *et al.* (1992) reported around 30% Nitrogen savings with deep placement in the irrigated lowlands. Furthermore, in rainfed lowland fields, 30 kg of Nitrogen ha⁻¹ deep placed rather than broadcast resulted in yields which were more than double. At 40-60% less Nitrogen rate, deep placement in a fertile soil could attain comparable yields with split broadcast at high Nitrogen rate (Bautista *et al.*, 2000).

2.12 Urea surface application method on rice

In broadcasting fertilizer is spread over the entire soil area. This may be done before the land is ploughed, immediately before planting or while the crop is growing (Peng *et al.*, 2006).

Nitrogen use efficiency in a delayed-flood, drill-seeded cultural system is optimized when N is applied in a single pre-flood application as broadcasting (Bollich *et al.*, 1994; Norman *et al.*, 1999). This single pre-flood application is made to a dry soil when rice is at the four- to five-leaf stage and before flood establishment (Bollich *et al.*, 1994; Bollich *et al.*, 1999; Wilson *et al.*, 2001). Nitrogen rates for optimum grain yield vary based on cultivar and soil texture (Bond *et al.*, 2006, Norman *et al.*, 2005; Walker, 2006). Rice grown on clay soils typically requires more fertilizer Nitrogen, even though native soil Nitrogen concentrations are greater on clay soils.

1.13 Nitrogen use efficiency (NUE)

Nitrogen use efficiency of crops is examined by taking into account both plant N uptake efficiency, focusing on the recovery of Nitrogen fertilizer, and the utilization efficiency of the absorbed Nitrogen. The latter is further analyzed as the overall effect of the absorbed Nitrogen on crop leaf area, light absorption, photosynthesis, crop growth, biomass partitioning, and yield. The effects of species, cultivar, fertilizer-Nitrogen rate, and form and application method are the main factors affecting Nitrogen use efficiency (Godium and Singh 1998, Metwally et.al.,2011). (Moll et al. 1982) defined nitrogen use efficiency as the ratio of grain weight (Gw) to Nitrogen supply (Ns). That is the Grain weight obtained from N fertilized plots (in Kg) minus grain weight from unfertilized plots (control) divided by Nitrogen inputs (kg). Nitrogen use efficiency describes the efficiency of Nitrogen fertilizer utilization in crop production as well as provides information about the additional Nitrogen applied to an agricultural production system of a region or country.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Site description

The experiment was conducted in Rwamagana marshland in the mid altitude zone over one season (Dry Season 2011). This marshland is at a mean altitude of 1500 m above sea level. The annual mean rainfall is 1000 mm which falls in two seasons (long and short rain seasons). The average annual temperature of the region is 22⁰C and the air relative humidity is 80% (MINAGRI, 2010). The soils of the site are classified under Gleysols according to IUSS Working Group WRB(2006).The soils are acidic(5.6), and have low total nitrogen (0.18%) and medium organic content(2.2%).The soil textural class of the site was clay loam (details are shown in Table 1).

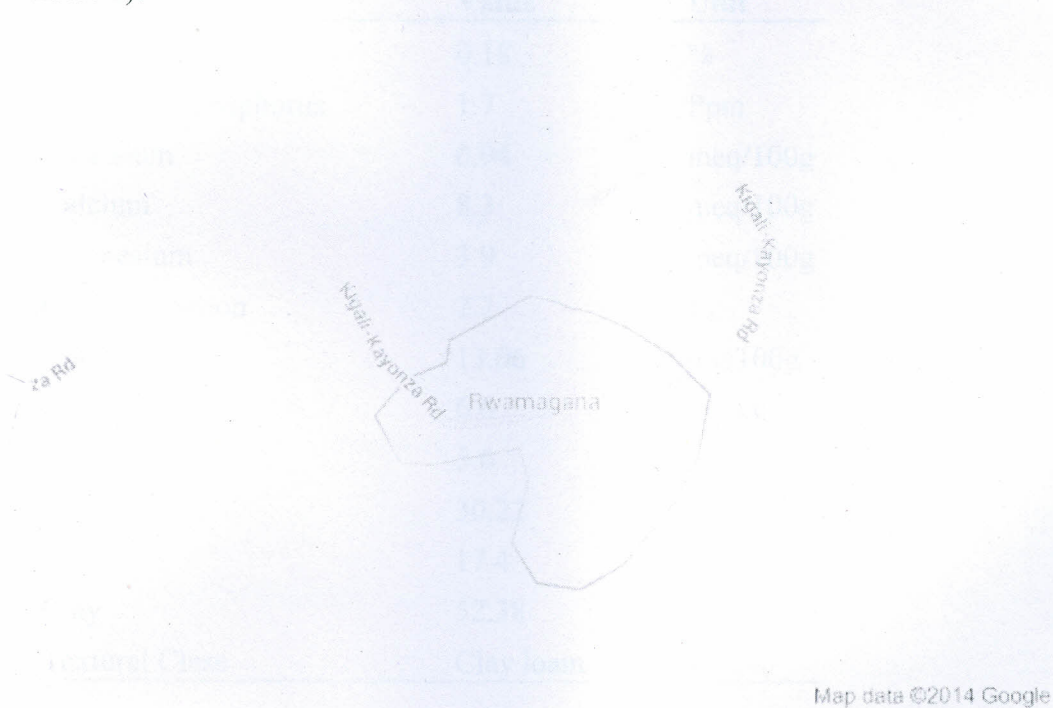


Figure 1: Map of Rwamagana District where the study was conducted.

3.2. Soil sampling

Before the experiment was established, the soil samples were taken to characterize the experimental blocks in terms of physical and chemical soil properties. From each block, a representative composite sample was taken for the analysis of total Nitrogen, Phosphorus, Organic C, Zinc, copper, Magnesium, Calcium, Potassium, Soil texture, and pH of the soil as shown in Table 1. The analysis was conducted at the National University of Rwanda Laboratory. Table 1 shows the initial status of the soil chemical and physical properties of the experimental site before land preparation.

Table 1: The initial soil properties of the experimental site

Property	Value	Unit
Total Nitrogen	0.18	%
Available Phosphorus	1.7	Ppm
Potassium	0.04	meq/100g
Calcium	8.3	meq/100g
Magnesium	3.9	meq/100g
Organic Carbon	2.2	%
Iron	13.06	mg/100g
Zinc	6.6	mg/kg
pH (H ₂ O)	5.6	
Sand	30.22	%
Silt	17.4	%
Clay	52.38	%
Textural Class	Clay loam	

3.2. Crop management

A 150 day duration rice popular variety IRRI 28 was used in this experiment. This variety has a potential yield of 8-9 tons /ha (ISAR, 2009). Plant seedlings, were raised in nursery for a period of 28days, after which the seedlings were transplanted to the experimental plots. Each plot measured 3m x 2m, giving an area of 6m² with a spacing of 20 by 20 cm, between and within the rows. After transplanting, water was allowed to flood the experimental plots up to 15 cm height in all the treatment plots. For proper agronomical management to the treatments, major rice weeds were controlled every two weeks and insect pests were controlled using dimethoate 40% EC. Towards the ripening of rice, 3 weeks before grain physiological maturity the fields were drained to field capacity to allow the fields to dry for harvesting.

3.3. Experimental design

The experiment was laid out in two different designs. The first design was a factorial experiment which assessed the effect of application methods and application rates of fertilizers in a Completely Randomized Design arrangement. The two factors included two application methods, that is surface and deep placement of fertilizers, and application rates of urea at 4 levels (0, 40, 80, 120 kg/ ha) which were applied all at once, one week after transplanting. This gave rise to a total of 8 treatments which were replicated three times. The second experiment assessed the effect of application time (0, 30 and 45 days after transplanting) and application rates of 0, 40, 80 and 120 kg/ha which were split as shown in Table 2 (treatments T9-T14). Treatment 15 (T15), which is a blanket fertilizer (200Kg/NPK and 100Kg urea as top dress) by farmers in the area was included in the study for the purposes of comparison with the experimental rates. These treatments were also laid out in a completely randomized design and replicated 3 times.

Table 2: Treatments arrangement

TREATMENT	DAYS AFTER TRANSPLANTING		
	0	30	45
T1	D0	0	0
T2	D40	0	0
T3	D80	0	0
T4	D120	0	0
T5	S0	0	0
T6	S40	0	0
T7	S80	0	0
T8	S120	0	0
T9	S20	S20	0
T10	S40	S40	0
T11	S40	S20	S20
T12	S100	S20	0
T13	S80	S40	0
T14	S80	S20	S20
T15	S 200(NPK)	100(urea)	

T: Treatment, **S:** Surface placement with splits, **D:** Deep placement

T15: Farmers practice

3.4. Data collection

3.4.1 Soil sampling and analysis

Before transplanting the rice seedlings to the experimental site, the site soils were sampled and analysed for soil physical and chemical properties. Composite soil samples were collected from a depth of 0- 20 cm in three different soil profiles from each block. After harvesting, soil samples were again collected from each experimental unit for nutrient analysis to evaluate the dynamic changes that might have taken place during the growing season.

3.4.1.1 Soil pH

Soil pH was measured in a 1:2.5 (soil: water) ratio. A total of 10g of dried soil of each soil sampled were weighed, then 25mL distilled water (for pH water) was added. After the mixture was agitated on the stirrer for 15 minutes, the mixture was allowed to settle for 30 seconds before the calibrated pH meter was used to read the pH by immersing the electrode into the suspension and the pH was recorded for each sample. For each sample analysed, the electrode was removed from the suspension and then rinsed with distilled water before introducing it to the other sample.

3.4.1.2 Soil Organic carbon:

Organic Carbon was determined by Walkway and Black method (Nelson and Sommers, 1982). One g of dried soil, ground to pass 0.5 mm was weighed out and then introduced in an Erlenmeyer flask of 250 ml then 2 ml of water was added. 10 mL of 5% aqueous potassium dichromate $K_2Cr_2O_7$ was added in order to completely wet the soil. Digested standards were also prepared; using a pipette; 2 mL of each working standard were transferred into dry labelled digestion tubes. The digestion tubes had 0, 5, 10, 15, 20 and 25 mg Carbon. These standards were digested along with samples to obtain a standard curve. After 5ml of concentrated sulphuric acid (96%) H_2SO_4 was added, the mixture was digested at 150 °C for 30 minutes and then allowed to cool. After cooling, 100 mL of distilled water was added and mixed thoroughly. The solution was then swirled to mix thoroughly and was brought to 100ml mark by distilled water and allowed to settle overnight so as to leave a clear supernatant solution. Absorbance/concentration of each standard and sample was read at 600 nm on the spectrophotometer. The content of total organic Carbon in air dry soil was calculated and expressed in percentage by using the formula below:

Total soil organic carbon (%) (SCPER):

$$\frac{(\text{SCCONC} - \text{SCBLNK}) * (0.1)}{\text{SCSOLWT}}$$

where

SCCONC = Carbon content of sample (mg C)

SCBLNK = Carbon content of blank (mg C)

SCSOLWT = Dry weight of soil sample (g)

3.4.1.3 Total soil nitrogen

One g of dried soil ground to pass 0.5 mm was weighed and introduced into a Kjeldahl digestion tube and then 1g of selenium powder (catalyst) was added. After 10mL of concentrated H₂SO₄ were added, the mixture was digested at 300°C for two hours until a green colour appeared. The solution was cooled and transversed into a volumetric flask of 100 ml and filled to 100ml mark with distilled water. The blank was also prepared. After which 10mL of aliquot of the digest was taken and put into a distillation tube which also received 10mL of distilled water. To the mixture, a 10mL of NaOH 50% was added and distillation commenced. The distillate was further distilled and collected in an Erlenmeyer flask of 250 ml containing 5ml of boric acid 2% (H₃BO₃). Approximately 100mL of distillate were collected. The solution obtained was titrated with 0.005M H₂SO₄ until a pink colour appeared. Titration continued up to the point when the solution turned into pink. The volume of 0.005M H₂SO₄ used was noted and the percentage of N calculated by the following formula:

$$\%N = (T-b) \times 0.2 \times FC \times FD \times 100 \times 1000$$

Where

FC= Corrective factor

FD= Dilution Factor (=10)

3.4.1.4 Available soil Phosphorus

2.5g of air dried soil (2mm) were weighted into 250 ml plastic bottle and 50 ml of extracting solution (a reagent-grade ammonium fluoride (NH_4F) mixed with distilled water and 250 mL of previously standardized 1M Hcl) was added. After which the solution was shaken for a period of five minutes. Extracts were filtered through Whatman No. 42. Phosphorus was then measured by colorimetry using a blank and standards prepared in the Bray P-1 extracting solution (Bray and Kurtz, 1945).

The calculation was made using the following formula:

$$(a-b) \times v \times f \times 1000$$

$$P \text{ mg kg}^{-1} = \frac{\text{---}}{1000 \times w}$$

Where

a= Concentration of P mg l^{-1} in extract solution,

b= Concentration of P mg l^{-1} in the blank sample,

v= extract volume,

w= weight of the air dried sample and

f= additional dilution factor

3.4.1.5 Exchangeable K, Ca, Mg and Na

Five grams of air dried soil (<2mm) were weighted into a clean plastic flask with a stopper and 100ml of 1M (NH₄OAc) ammonium acetate solution (pH 7) was added. An internal standard and a repeat sample within each batch of test soils were also added. The contents were shaken for 30 minutes and filtered through No. 42 Whatman filter paper. This soil extract was used for K, Ca, Mg and Na determinations using atomic absorption spectrophotometer (Okalebo et al, 2002). The concentration was then calculated using the formula below:

$$\text{Mgkg}^{-1} \text{ K, Ca, Na and Mg in soil} = ((a-b) \times v \times f \times 1000) \div (1000 \times w)$$

Where

a = concentration of K, Na, Ca, and Mg in the sample extract;

b = concentration of the element in the blank extract;

v = volume of the extract solution;

w = weight of the soil sample;

f = dilution factor.

3.4.1.6 Texture (sand, silt and clay) analysis

A sample of 50 g of air dry <2 mm soil was weighed out into a 400 ml beaker and was saturated with distilled water. After which a 10 ml of 10% calgon solution was added. The suspension was transferred to the dispersing cup and added 300 ml of tap water. The suspension was mixed for 2 minutes with an electric high speed stirrer then transferred into a graduated cylinder. The remaining soil in the cylinder was rinsed with distilled water and the hydrometer was inserted into the suspension. About 1130 mL of water was added to the suspension after which the hydrometer was removed. The cylinder was covered with a tight-fitting rubber band and the suspension was

mixed by inverting the cylinder carefully ten times. The time was noted and 2-3 drops of amyl alcohol were quickly added in order to remove froth and after 20 seconds the hydrometer was gently placed into the column. The hydrometer readings and thermometer measurements at 40 seconds intervals were recorded. The cylinder was covered again with a tight-fitting rubber band and the suspension was mixed by inverting the cylinder ten times and then allowed to stand undisturbed for 2 hours after which both hydrometer and temperature readings were taken. The % sand, silt and clay were then calculated (Bouyoucos, 1962).

3.4.2 Plant tissue sampling and analysis

Above ground plant samples (stem, leaves) were sampled in every treatment near panicle initiation (3months after transplantation). At maturity stage, straws, leaves and grain were also sampled and analysed for the total nitrogen content in rice tissues. Plant sampling was done by cutting above ground tissue with a scissor. Then the samples were oven dried at 80° C until a constant dry weight was obtained (about 48 hours). The samples were then cut into small pieces and ground in a mill fitted with a sieve of 1mm screen size. Total nitrogen analysis in plant and grain tissues was analysed using Kjeldhal method and followed the same procedure like that of soil analysis (3.4.1.3).

3.4.3 Grain yield and its components measurement

Rice yield and its components (1000 grain weight, number of panicle per unit area, number of filled spikelet per panicle, tillers/plant and grains) were determined at physiological maturity of rice by harvesting 1m² from the middle of each plot leaving border rows. The grains were oven dried at 65⁰c for a period of two days until constant weight was attained and then adjusted to 14% grain moisture content. 1000 grain were counted using a grain counter and then measured with a precision scale. Filled spikelets were separated from empty spikelets using water and then dried and counted.

3.5. Statistical analysis

The analysis of variance (ANOVA) was performed with an appropriate statistical package (JMP version Pro 9) to determine the statistical significance of individual treatments and Fischer's protected LSD at the 5% significance level was used for means separation. Correlation and regression tools were also used on the data to determine any relationship between relevant variables.

CHAPTER FOUR: RESULTS AND DISCUSSION

This chapter presents the findings of the study. The results of the effects of different treatments on grain yield and rice yield components are presented in section 4.1; nitrogen fertilizer response on grain yield and nitrogen use efficiency in relation to mode of application (deep, surface and nitrogen split) in section 4.2; and in section 4.3; effect of application methods (deep and surface) and timing on nitrogen content in grain yield and plant tissues.

4.1 Effect of the different treatments on rice yield components and grain yield

Table 3 shows the results of rice yield components (panicles, tillers, grain filling and 1000 grain weight) and grain yields as affected by various experimental treatments.

Table 3: Effect of treatments on rice yield components and grain yield

Treatment	Panicle/m ²	Tillers/m ²	Grain filling (%)	1000 grain weight (g)	Grain yield (t/ha)
T1	367 ^{efg}	384 ^{cd}	48	21	4.3
T2	434 ^{abcd}	442 ^{abcd}	48	21	4.6
T3	469 ^{ab}	475 ^{ab}	37	20	5.4
T4	492 ^a	513 ^a	42	20	5.6
T5	351 ^g	405 ^{bcd}	46	21	4.3
T6	357 ^{fg}	370 ^d	49	21	4.5
T7	421 ^{bcdef}	458 ^{ab}	49	21	4.9
T8	423 ^{bcde}	438 ^{bcd}	48	21	5.3
T9	385 ^{cdefg}	420 ^{bcd}	45	21	4.8
T10	392 ^{cdefg}	409 ^{bcd}	46	21	5.0
T11	412 ^{bcdefg}	428 ^{bcd}	48	21	5.2
T12	371 ^{defg}	409 ^{bcd}	49	21	4.7
T13	366 ^{efg}	382 ^{cd}	47	21	4.6
T14	446 ^{abc}	474 ^{ab}	42	21	5.0
T15	421 ^{bcdef}	454 ^{abc}	45	21	4.6
P-value	0.0019*	0.0213*	0.2646NS	0.2860 NS	0.4738NS

Means in the column with letter superscripts are not significantly different at $\alpha = 0.05$

The treatments (Table 3) exhibited highly significant effects for panicle per m² and tillers per m². However, they did not show any significant effects on 1000grain weight, grain filling and grain yield. The highest grain yields (5.6 ton/ha) were obtained in treatment T4, where 120 kg/ha N was

applied all at once in a deep placement method. The same treatment (T4) had also the highest number of both panicle per m^2 (492) and tillers per m^2 (513). The lowest grain yield of the experiment was 4.3ton/ha and was obtained in the control (T1). This was about 23% lower than the highest yields (5.6 ton/ha) of the experiment. Compared to treatment T15, which is the common practice of farmers in the area, where they use 200kg/ha NPK and 100 kg/ha urea as topdress, 4.6 tons/ha grain yield was realized which is 300kg or 7% higher than the control but 16% less than the highest grain yield of the experiment (5.6tons/ha). Grain filling percentage was similar in all treatments, and it attained only 49% of filled spikelets which shows that grain filling was extremely poor for all treatments. Similarly, the 1000 grain weight showed no weight differences among the various treatments. This behavior could be due to the low content of phosphorous in soil which is a reproductive element, the rice variety and the general environmental conditions such as the weather of the area.

According to Yoshinda (1983), the 1000-grain weight is a more stable yield component across cultivars and production conditions because of the existence of a strong genetic control which restricts the hull size and thus the potential rice grain size. The filled spikelets ratio of at least 85 % is considered normal (Yoshida, 1981). This means that the above mentioned filled spikelet ratio percent range was considerably poor. This is common under specific weather conditions such as the extreme low air temperature (Yoshida, 1983, COUNCA *et al*, 2008) prevailing in inland valleys of the highlands (1400-1600 masl) of Rwanda. Monthly mean air temperatures in Rwanda range from 21oC and 19oC (USAID, 2008). In particular, night time air temperatures can fall below 15oC in the bottom valley rice production areas. (Metwally *et al*, 2010) reported that application of nitrogen decreases the 1000 grain weight. The highest 1000 grain weight appeared when nitrogen was not applied this mainly due to the higher number of spikelets per panicle in plants received nitrogen at any of rates than those did not receive any nitrogen. So the sink

capacity is high and the source is limited, therefore the filling of grain will be more consequently the weight of grains will be high.

In a correlation test to find out whether the number of tillers and panicles had influence or effect on grain yields, as shown in Figs.2 and 3, the correlation effect was positive and substantial but low ($R^2=0.5016$ for tillers and $R^2=0.4765$ for panicles). This means that both tillers and panicles did not have a pronounced effect or influence on rice grain yield. Fageria *et al.* (1997a) reported that panicles and spikelets per unit area are usually the most variable yield components and therefore can influence grain yield differently.

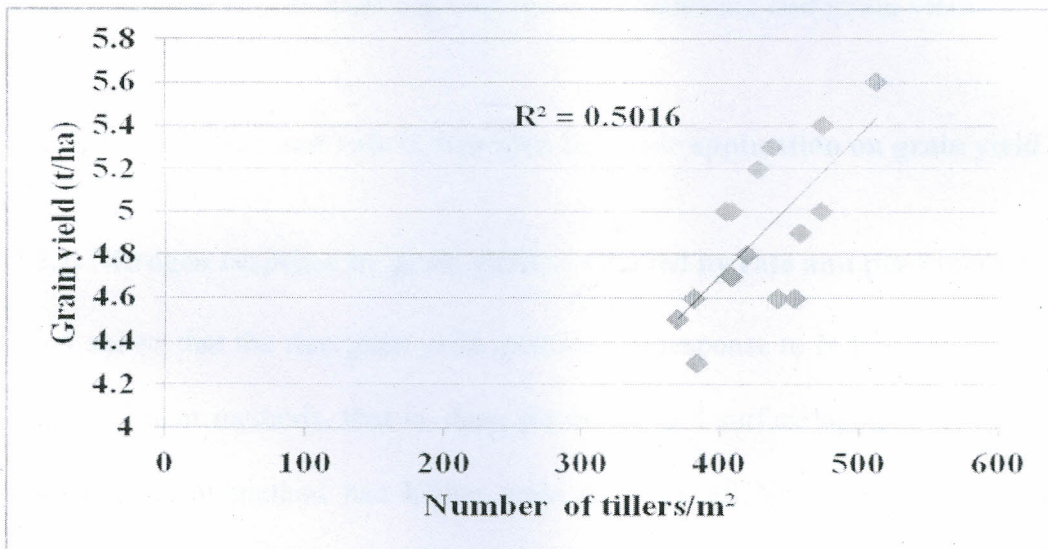


Figure 2: Relationship between number of tillers/m² and grain yield

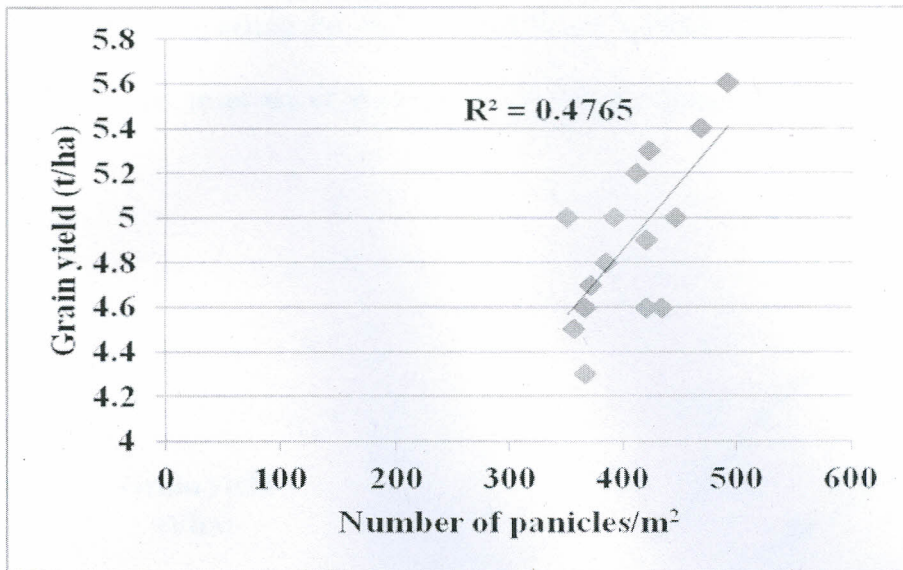


Figure 3: Relationship between number of panicles/m² and grain yield

4.2. Effect of mode and rate of Nitrogen fertilizer application on grain yield and nitrogen use efficiency.

4.2.1. Nitrogen response by grain yield as affected by rate and placement method

Fig.4 shows that the rice grain yield increased in response to N fertilizer application rates and to two placement methods, that is, deep placement and surface application. The N fertilization by deep placement method had higher grain yields at all Nitrogen rates as compared to surface application. The yields increased from 4.3 to 5.6tons/ha by deep placement while those by surface application increased from 4.3 to 5.3tons/ha at 120 kg N/ha dose, a difference of 300kg (Table 3). But with 80kg N dose, the yield difference was 500kg. This shows that though there were steady increase of grain yields by the two methods and that deep method appeared better than surface application, the differences, however, were not significant. Similar trends of rice grain yield responses have been reported by Saito *et al.*, (2006); Kanyika *et al.*,(2007) and Fageria (2001). Fageria (2001) reported a significant increase of rice grain by N fertilization of up to 120 kg N/ha

The yield comparison by the two modes of N fertilizer application are made clearer in Fig.5 which shows response of rice grain yield to N fertilization in bar graph.

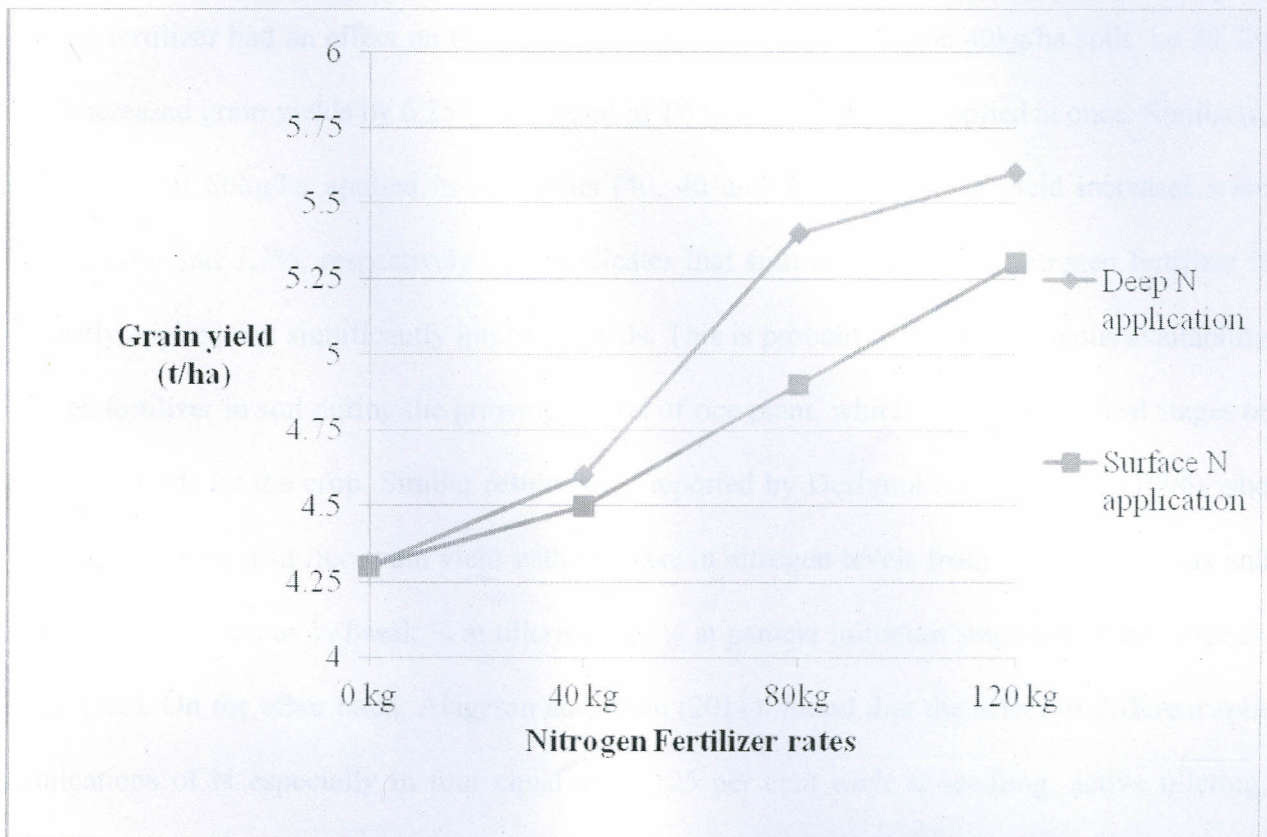


Figure 4: Response curve of nitrogen fertilizer on rice grain yield

4.2.2. Effect of nitrogen fertilizer split on rice grain yield

Figure 6 shows the effect of split of N fertilizer application on grain yields. The split application of urea fertilizer had an effect on the grain yield but not significant. The 40kg/ha split, i.e. 20, 20 (T9) increased grain yields by 6.25% compared to T6 where 40kg were applied at once. Similarly, in the case of 80kg/ha applied in two splits (40, 40 and 40, 20, 20) the yield increases were between 4.0 and 7.7%, respectively. This indicates that split application of Nitrogen fertilizer if correctly applied can significantly improve yields. This is probably due to continuous availability of urea fertilizer in soil during the growing period of rice plant, which covers the critical stages of nutrients needs by the crop. Similar results were reported by Deshmukh and Tiwari, (1996) who found improvement in rice grain yield with increase in nitrogen levels from 40 to 120 kg /ha and nitrogen application as $\frac{1}{2}$ basal, $\frac{1}{4}$ at tillering and $\frac{1}{4}$ at panicle initiation stage which had highest grain yield. On the other hand, Alagesan and Babu (2011), found that the effect of different split applications of N especially in four equal splits (25 per cent each at seedling, active tillering, panicle initiation and flowering stages) was the best timing of application for obtaining higher yields in wet seeded rice. They also observed that the grain yield was lowest when the quantity of Nitrogen supply was restricted in the early stages and increased after panicle initiation.

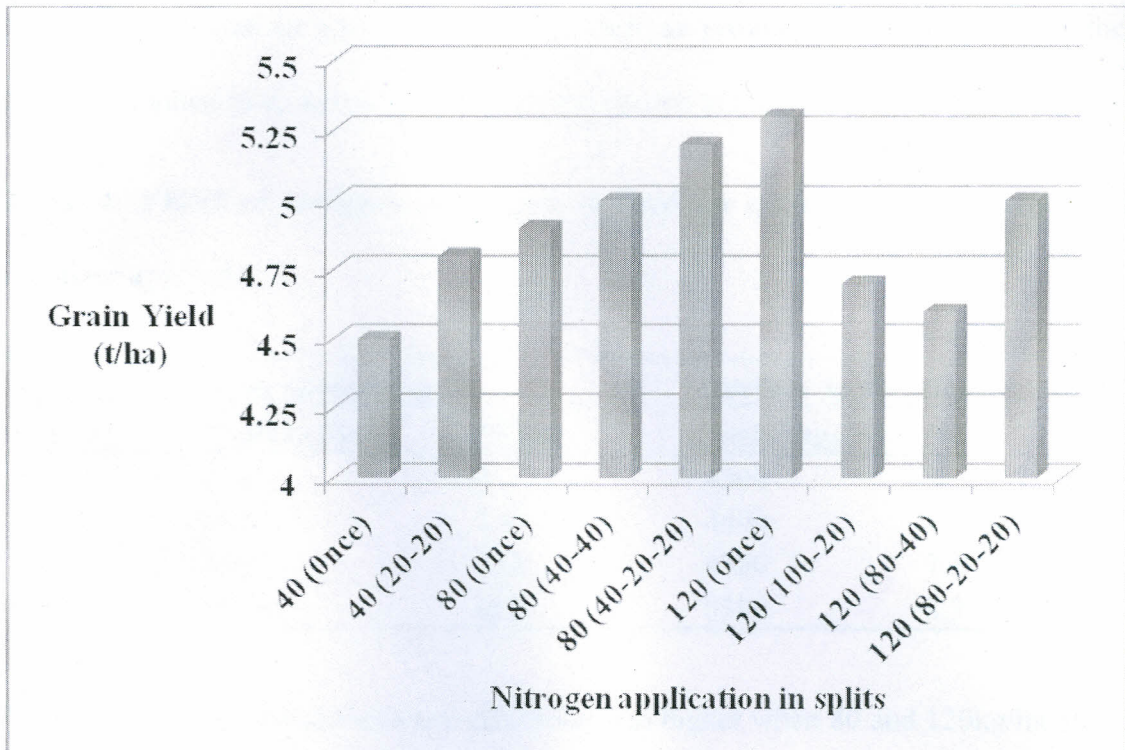


Figure 5: Nitrogen fertilizer split application effect on grain yield

This indicates, therefore, that nitrogen requirement of the crop is heavy between shoot formation and tillering stage of the crop. Similar findings have been reported by many researchers (Wada *et al.* 1986, Singh and Singh; 1998 and Singh *et al.* 2006) who reported that Splits application when maintained continuous supply nutrients to the crop during its growing period and hence the good yield.

4.2.3. Nitrogen use efficiency as affected by placement method, rate and nitrogen split.

Nitrogen use efficiency (NUE) is defined as the ratio between the amount of fertilizer N removed from the field by the crop and the amount of fertilizer N applied. However, in this study only the amount of fertilizer Nitrogen removed by the rice grain was considered. According to Moll *et al.* (1982), NUE is determined by calculating the Nitrogen crop uptake fertilized Nitrogen crop uptake unfertilized divided by Nitrogen fertilizer input. This approach is called “Difference Method (Johnson and Poulton, 2009). Nitrogen use efficiency describes the efficiency of Nitrogen

fertilizer utilization in crop production as well as provides information about the additional Nitrogen applied to an agricultural production system of a region or country.

Table 4: Effect of nitrogen placement method on nitrogen use efficiency (kg grain/kg fertilizer applied)

Treatments (kg/ha)	Deep application		Surface application	
	Yield (kg/ha)	NUE	Yield (kg/ha)	NUE
0	4300	0	4300	0
40	4600	7.50	4500	5.0
80	5400	13.8	4900	7.5
120	5600	10.8	5300	8.3

Table 4 shows that the nitrogen use efficiency was higher when 80 and 120kg/ha of nitrogen were deep applied with 13.8 and 10.8kg grain/kg N fertilizer applied, respectively. The Table also indicates that urea surface application of 120kg/ha gave higher Nitrogen use efficiency (8.3kg) than other surface levels. These results show that as levels of nitrogen fertilizer increased, NUE also increased, except for 120kg in deep placement where NUE decreased. In general, however, deep placement method exhibited slightly higher NUEs than surface method. The same results had been reported by Zhang (2007) who found that the nitrogen use efficiency increased with nitrogen deep placement and N increasing rates to a certain maximum before it started to decline. Schnier *et al.*, (1988), however, attributed this yield increase to band or point placement of fertilizer than to surface application, whereas other researchers (Mandana *et al.*, 2011 and Fageria *et al.*, 2010) found that NUE varied significantly with Nitrogen rate increments and rice genotypes. Senthil *et al.*, (2008) concluded that this variation could be due to excess application of N, which is not effectively utilized by the crop and that the rate of production becomes lesser per unit of Nitrogen applied.

Table 5: Effect of nitrogen fertilizer split on nitrogen use efficiency (NUE)

Treatments (Kg/ha)/split level	Grain yield (Kg/ha)	NUE
0	4300	0.0
40 (Once)	4500	5.0
80 (Once)	4900	7.5
120 (Once)	5300	8.3
40 (20-20)	4800	12.5
80 (40-40)	5000	8.8
80 (40-20-20)	5200	11.3
120 (100-20)	4700	3.3
120 (80-40)	4600	2.5
120 (80-20-20)	5000	5.8

In case of split nitrogen application as shown in Table 5, NUE increased with the number of splits at each fertilizer level, with the highest at the second split of 40kg/ha (12.5kg grain/kg N fertilizer) and lowest at first splits of each level (eg 2.5). In comparison to surface full dose N fertilizer application (Table 4), application by split had relatively higher NUEs than surface application. This could be associated to the little loss of nitrogen from the soil and slowly releasing process which resulted in slightly high nitrogen recovery. These results are in accordance with (Mirza *et al*, 2009) findings where he reported the nitrogen use efficiency increase when different splits application were applied.

4.3. Effect of placement method, rate and timing on nitrogen content in rice *plant tissues and grain*.

4.3.1 Nitrogen content in plant tissues and grain as affected by deep placement

Table 6: Effect of deep placement on nitrogen content in plant tissues and grain

N dose level (kg/ha)	% N plant at PI	% N straw	% N grain
0	2.14 ^b	0.5 ^b	1.5
40	2.52 ^{ab}	0.68 ^b	1.5
80	2.64 ^a	0.69 ^b	1.6
120	2.7 ^a	0.91 ^a	1.6
P-value	0.02 [*]	0.026 [*]	0.18 ^{NS}

Table 6 shows the effect of nitrogen doses and deep placement method on nitrogen content in plant tissues and grains. Nitrogen uptake at panicle initiation and in straw had a significant response to different nitrogen fertilization rates. Nitrogen uptake at panicle initiation increased significantly with increase of nitrogen rates. The highest content was 2.7% obtained at 120kgN/ha rate. Nitrogen uptake in the straw differed significantly between 0.5 and 0.91% in an upward trend, with respect to N inputs. Fageria *et al* (2009) reported that this could be associated with maximum shoot yield.

In a correlation analysis, as shown in Fig.7, there was a high and positive relationship ($R^2=0.7443$) between nitrogen content at panicle initiation and that in the grain. This means that nitrogen content at panicle stage had an influence on nitrogen content in grains. However, nitrogen content in straw (Fig.8), did not have much influence on nitrogen content in grain as its correlation coefficient was low ($R^2=0.3787$) but positive. This suggests that as the plant matures, nitrogen in the straw is translocated and accumulated in the grain.

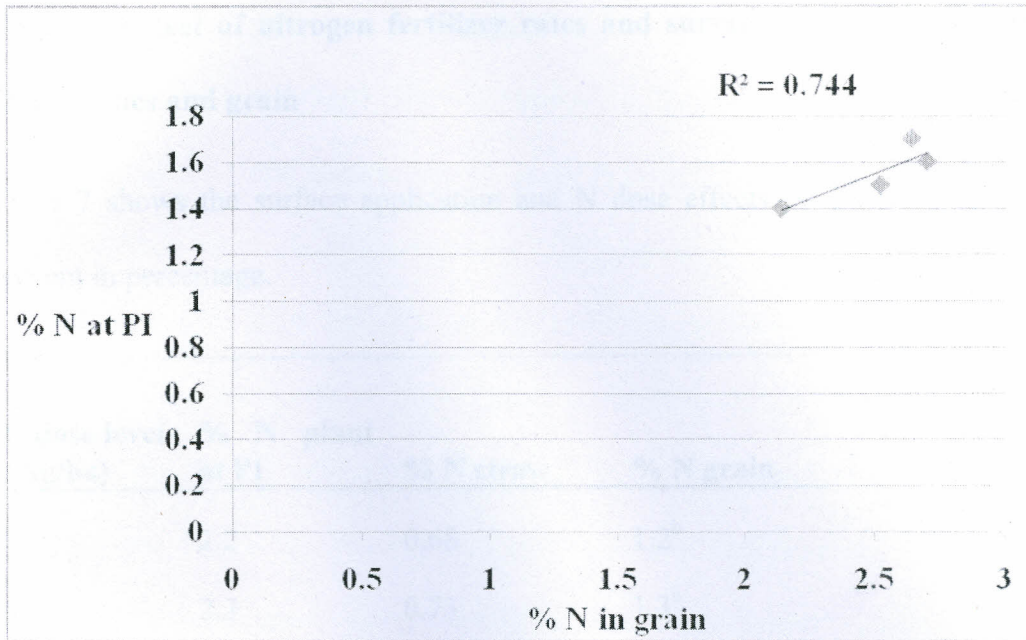


Figure 6: Relationship between nitrogen content at panicle initiation and nitrogen content in grain

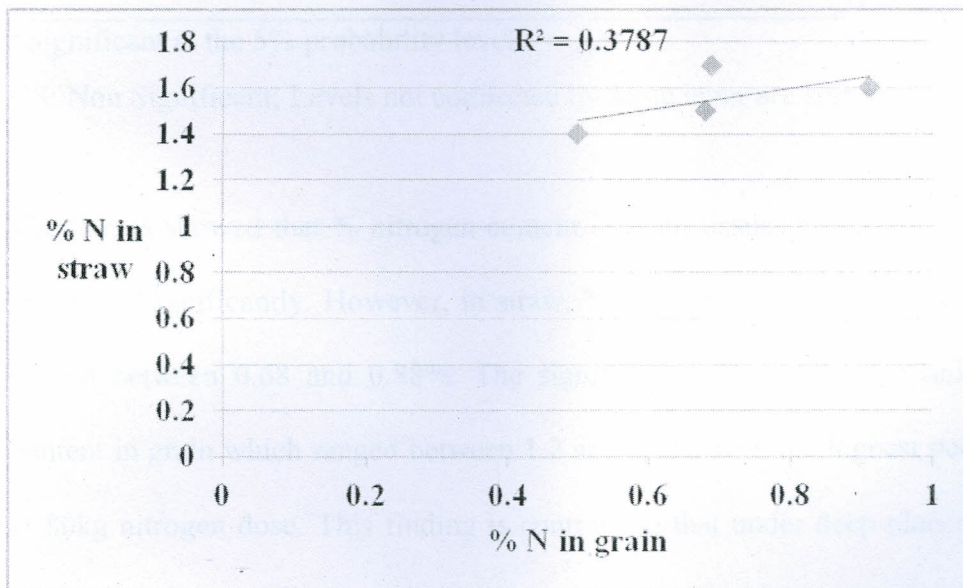


Figure 7: Relationship between nitrogen content in straw and nitrogen content in grain

Table 7: Effect of nitrogen fertilizer rates and surface placement on nitrogen content in plant tissues and grain

Table 7 shows the surface application and N dose effects on plant tissues and grain nitrogen content in percentage.

N dose level (kg/ha)	% N plant at PI	% N straw	% N grain
0	2.2	0.68	1.2 ^b
40	2.3	0.73	1.3 ^b
80	2.3	0.83	1.5 ^a
120	2.3	0.88	1.4 ^a
P-value	0.2 ^{NS}	1.3 ^{NS}	0.02*

*Significant at the 5% probability level

NS: Non Significant; Levels not connected by same letter are significantly different.

The results showed that % nitrogen content in plant tissues at panicle initiation and in straw did not differ significantly. However, in straw, % nitrogen increased with nitrogen level inputs, and ranged between 0.68 and 0.88%. The significant differences were only observed in nitrogen content in grain which ranged between 1.2 and 1.5%, with the highest percentage of 1.5 obtained at 80kg nitrogen dose. This finding is contrary to that under deep placement method in Table 6 where significant differences in nitrogen content were observed at Panicle Initiation and straw stages whereas for surface method, significant differences were with grain only. In general, deep placement exhibited higher % nitrogen values at Panicle Initiation and grain stages than surface method, which had higher % nitrogen content with straw than deep placement and increased with nitrogen level inputs. For example with 120 kg, the content of nitrogen in grain was 1.6% with deep placement while it was 1.4% with surface placement.

In correlation analysis as shown in Figs.10 and 11, both correlation coefficients for PI and straw to grain were high and positive ($R^2=0.6$ and $R^2=0.72$). That means that both N content at panicle initiation and straw had great influence on the N content in the grain.

Findings from other various researchers (Das Gupta, 1972, Jung et al.1992, Rozas et al, 2004, Indira Chaturvedi, 2005 and Wei et al., 2008) reported that in cereals including rice, nitrogen accumulation is associated with dry matter production and yield of shoot and grain. Wei et al., (2008) found that N utilization efficiency was positive and significantly correlated with N accumulation during the heading and mature stages. Fageria *et al*, (2003) and Shinano *et al*, (1995) reported that grain nitrogen uptake increased significantly with nitrogen fertilizer.

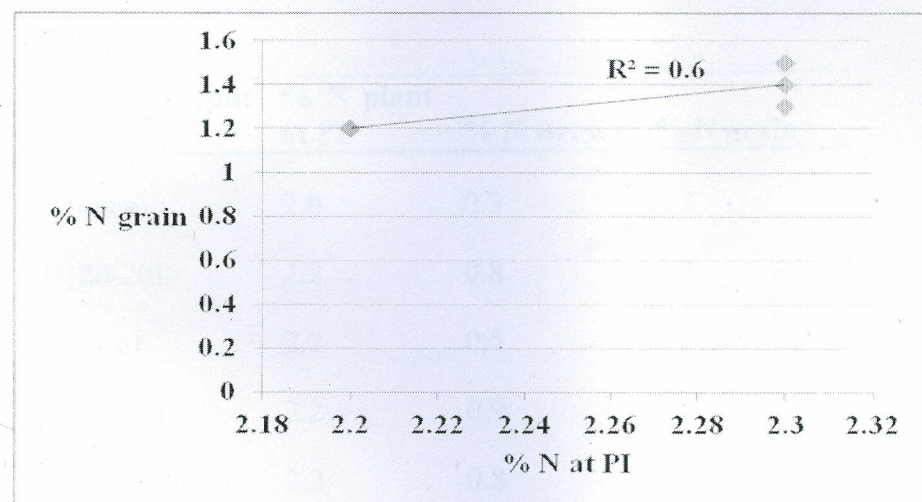


Fig.8 Relationship between nitrogen content at panicle initiation and nitrogen content in grain

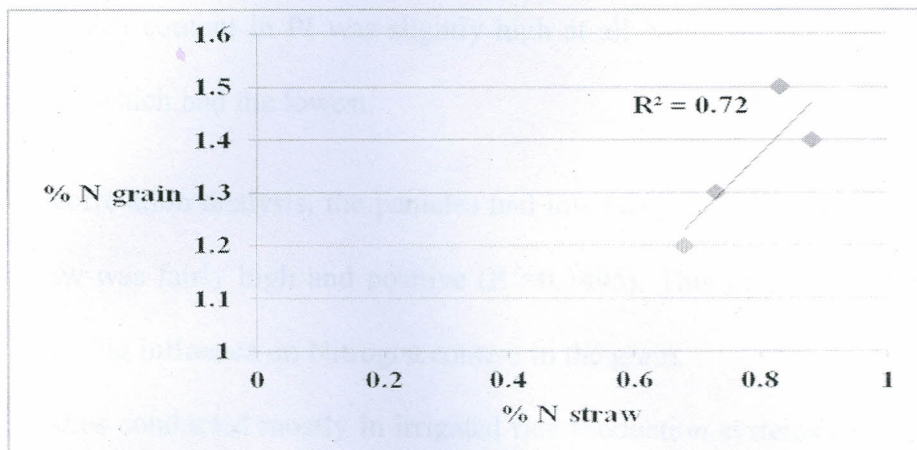


Figure 9: Relationship between nitrogen content in straw and nitrogen content in grain

Table 8: Effect of nitrogen fertilizer rates and split on nitrogen content in plant tissues and grain

N level	dose/Split	% N plant at PI	% N straw	% N grain
40 (once)		2.0	0.3	1.3
40 (20-20)		2.2	0.8	1.4
80(once)		2.2	0.5	1.5
80 (40-40)		2.2	0.9	1.6
80(40-20-20)		2.2	0.8	1.5
120 (once)		2.1	0.7	1.5
120 (100-20)		2.2	0.9	1.5
120 (80-40)		2.1	0.9	1.6
120 (80-20-20)		2.2	0.9	1.6
P=value		0.6983 ^{NS}	0.6847 ^{NS}	0.6715 ^{NS}

*Significant at the 5% probability level

NS: Non Significant; Levels not connected by same letter are significantly different

PI: Panicle Initiation

Table 8 shows the effects of nitrogen rates and splits on the % Nitrogen content in plant tissues and grain. Overall, there were no significant differences observed within the parameters. The %

Nitrogen content in PI was slightly high at all Nitrogen splits as compared to that in grain and straw which had the lowest.

In correlation analysis, the panicles had low but positive correlation ($R^2=0.2273$) while that for straw was fairly high and positive ($R^2=0.5495$). This indicates that neither the PI nor the straw had a big influence on Nitrogen content in the grain.

Studies conducted mostly in irrigated rice production systems have pointed to the importance of maintaining a critical Nitrogen concentration greater or equal to 2% in above-ground vegetative biomass at all time during plant development to achieve optimal growth and grain yield (Sheehy *et al.*, 1998) of up to 8t/ha or more. This Nitrogen concentration appears to remain unchanged across environments in the tropics, subtropics and the temperate regions.

In this study plant nitrogen concentration greater or equal to 2% could only be achieved in the plant at the panicle initiation stage (PI) but not in the straw and the grain at physiological maturity, suggesting perhaps why the grain yield levels were as low as half of the high attainable yield of 8 t/ha or more with modern rice varieties.

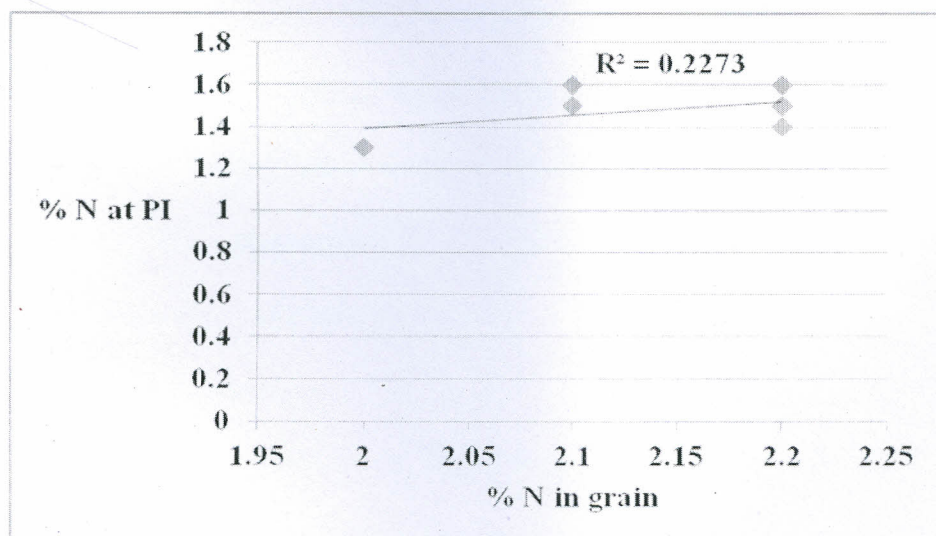


Figure 10: Correlation between nitrogen content at panicle initiation and nitrogen content in grain

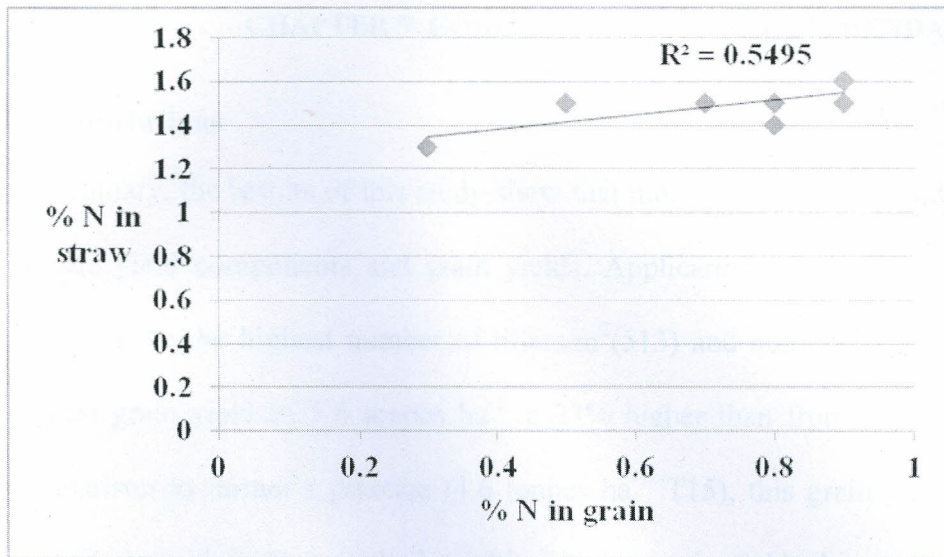


Figure 11: Relationship between nitrogen content in straw and nitrogen content in grain

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In summary, the results of this study show that mode of application and N rates had an influence on rice yield components and grain yields. Application of 120 kg N ha⁻¹ by deep placement method gave the highest number of tillers/m²(513) and number of panicles/m² (429),as well as highest grain yield of 5.6 tonnes ha⁻¹, a 23% higher than from the control (4.3 tonnes ha⁻¹).In comparison to farmer's practice (4.6 tonnes ha⁻¹ T15), this grain yield was higher by 16%. In general, deep placement method exhibited higher grain yields than surface with a yield difference of between 300 and 500kg /ha which is 6-8% high. Split of nitrogen fertilizers also improved grain yields above the control but not of significant importance.

In terms of Nutrient Use Efficiency, deep placement method had slightly higher NUEs (7.0-13.8 Kg grain/kg N) as compared to surface (5.0-8.3) and even to split mode of N application (2.5-12.5).

Nitrogen content in plant tissues was generally low and in most cases less than 2 % except at panicle initiation stage. Nitrogen uptake at panicle initiation increased significantly with increase of nitrogen rates. Application of 120kg/ha gave the highest content of 2.7% at the panicle initiation. Nitrogen content in the straw was overall low (below 1%) followed by that of grain. Generally, deep placement method exhibited higher % Nitrogen content in all plant tissues and grain than surface and split methods.

5.2. Recommendations

From the results of this study, where deep placement method exhibited better grain yields in all aspects than surface and split treatments , it is recommended that farmers should be encouraged to adopt deep placement mode of N application and at rates above 100Kg N ha⁻¹.

Nevertheless, considering that the findings of this study were obtained from one season and that the yield target of 8tonnes ha⁻¹ was not attained, more research is therefore needed. Future research endeavours should consider the following options:

1. The proper timing of Nitrogen splits to match the crop needs according to crop growing phases.
2. Inclusion of other plant nutrients such as phosphorus, potassium and micronutrients which are deficient in most soils in Rwanda.
3. Improvement in deep placement mode of N application to include Nitrogen splits and placement depths.
4. To try other improved rice varieties or genotypes. This calls for Rwanda Government to quickly evolve into a variety development program in order to find better adapted varieties to low temperatures in the highland rice productions ecologies of Rwanda.

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APPENDIX

Appendix 1 Experiment lay out

Blocks	Randomized treatments				
Block 1	T6	T7	T12	T10	T14
	T13	T4	T15	T11	T8
	T1	T5	T2	T9	T3
Block 2	T10	T6	T3	T15	T1
	T13	T8	T7	T4	T12
	T9	T2	T5	T14	T11
Block 3	T1	T12	T7	T5	T9
	T8	T4	T10	T6	T14
	T13	T2	T15	T3	T11

Appendix 2 Effect of nitrogen doses and application method on rice yield components and grain yield

N dose/ Appl mode	Panicle/m ²	Tillers/m ²	Grain filling (%)	1000 grain weight (g)	Grain yield (t/ha)
40/ Deep	434 ^{abcd}	442 ^{abcd}	48	21	4.6
40/ Surface	357 ^{fg}	370 ^d	49	21	4.5
80/ Deep	469 ^{ab}	475 ^{ab}	37	20	5.4
80/ Surface	421 ^{bcdef}	458 ^{ab}	49	21	4.9
120/ Deep	492 ^a	513 ^a	42	20	5.6
120/ Surface	423 ^{bcde}	438 ^{bcd}	48	21	5.3
P-value	0.001*	0.02*	0.26NS	0.28NS	0.4NS

Appendix 3: Nitrogen Split application effect on rice yield components and grain yield

Treatments (Kg/ha)/split level	Panicle/m²	Tillers/m²	Grain filling (%)	1000 grain weight (g)	Grain yield (t/ha)
40 (once)	357 ^{fg}	370 ^d	49	21	4.5
80 (once)	421 ^{bcdef}	458 ^{ab}	49	21	4.8
120 (once)	423 ^{bcde}	438 ^{bcd}	48	21	4.9
40 (20-20)	385 ^{cdefg}	420 ^{bcd}	45	21	5
80 (40-40)	392 ^{cdefg}	409 ^{bcd}	46	21	5.2
80 (40-20-20)	412 ^{bcdefg}	428 ^{bcd}	48	21	5.3
120 (100-20)	371 ^{defg}	409 ^{bcd}	49	21	5.1
120 (80-40)	366 ^{efg}	382 ^{cd}	47	21	4.8
120 (80-20-20)	446 ^{abc}	474 ^{ab}	42	21	5.4
P (Value)	0.001 *	0.021 *	0.264*	0.280 NS	0.473 NS

Appendix 4. Interpretation of soil properties values

Interpreted values	Mean values of the analysis	Soil classes and/ or qualification
pH water	>8,5	Very high
	7,0 - 8,5	High
	5,5-7,0	Medium
	<5,5	Low and very low
CEC (meq/100g)	>40	Very high
	25-40	High
	15-25	Medium
	5-15	Low
	<5	Very low
Exchangeable Bases (en meq/100g)		
Calcium	>10	High
	4-10	Medium
	<4	Low
Magnesium	>4	High
	4-0.5	Medium
	<0,5	Low
Potassium	>0,6	High
	0.6-0.2	Medium
	<0,2	Low
Sodium	>1	High
	0-1	Medium
	0	Low
Organic carbon in %	>10	High
	4-10	Medium
	<4	Low
Total Nitrogen (Kjeldahl) in %	>0,5	High
	0,2-0,5	Medium
	<0,2	Low
Available Phosphorus in ppm (Bray 1, advised for acid soils)	>50	High
	50-15	Medium
	<15	Low