MANAGEMENT OF UREA SUPERGRANULE (USG) APPLICATION TO IMPROVE GROWTH AND YIELD OF RICE (*Oryza sativa L*) IN SOME PADDY SOILS OF TOGO AND GHANA

BY

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DECLARATION

I hereby declare that, except for references to works of other researchers which have been duly cited, this work is the result of my own original research undertaken under supervision. It has not been presented either in whole or in part to other University for an award of a degree. All assistances have been duly acknowledged.

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ABSTRACT

Nitrogen (N) is known to be a major limiting crop nutrient which is required in large amounts as compared with other major nutrients. In rice (*Oryza sativa L.*) cropping, urea is the main source of N which is applied to the crop because of its relatively low cost and its high N concentration (46%). However, low N use efficiency is always associated with urea application under paddy fields because of its high N loss, mostly through ammonia (NH_3) volatilization. The split application of prilled urea (PU) has for a very long time being the common strategy for reducing urea-N losses but its efficiency has been of much concern of late. The present study addresses the increase in rice yield and nitrogen use efficiency (NUE) using the urea supergranules (USG) deep placement. The study comprised of (i) a greenhouse experiment carried out in the Sinna Garden, University of Ghana to evaluate the effect of USG application at different depths on ammonia volatilization, rice yield and NUE in some paddy soils, (ii) a field trial conducted in 2017 in the irrigated scheme of Zio valley in Togo to determine the efficiency of USG and its optimum rate to improve rice yield and NUE in three paddy soils and (iii) an open field pot experiment to determine the effect of seedling age and time of application of USG on rice yield and NUE.

The first experiment comprised four paddy soils: Canne and Voudou series that belong to Oxisols (USDA) were sampled in Togo, and Akuse and Bumbi series that belong to Vertisols (USDA) were sampled in Ghana. Six modes of urea application were formulated as treatments: prilled urea (PU, 1.8 g pot^{-1}) applied at soil surface and urea supergranule (USG 1.8 g) applied at soil surface (0 cm) 4, 8, 12 and 16 cm depths and a control without N application. Rice variety IR-841 was planted and a closed chamber device method was used to trap NH_3. The results indicated significant decrease in ammonia loss with deep placement of USG over surface split application of PU in the different paddy soils. Regardless of the depth of USG application, the type of paddy soil significantly affected the cumulative ammonia loss which varied from 8% of N applied in Canne series to 14% in Bumbi series. Ammonia loss decreased drastically with depth of USG application (37% of applied N at the soil surface to 0% at 16 cm depth). The USG deep placement significantly increased rice yield and agronomic use efficiency (AE) over PU in the different paddy soils. The optimum depth of USG application to reduce ammonia loss and to achieve the highest yield and AUE varied according to the soil type: 4 cm in Voudou and Bumbi series, 8-12 cm in Canne and 8 cm in Akuse series.

The field experiment was conducted at three different sites in Togo (Ablotsri, Hahome and Kouto). Three factors were studied: rice variety (IR-841 and TGR-405), the type of urea (PU and USG) and the N rate (0, 52, 78 and 104 kg ha^{-1}). Results indicated that the efficiency of USG deep placement (UDP) varied significantly with the rice cropping and site. USG significantly increased rice growth parameters and yield over PU. Rice yield increased by 17-23% on the clay soil of Ablotsri and sandy-clay-loam soils of Hahome. In the sandy-loam soil of Kouto, USG increased grain yield only by 4% in the first season while in the second, USG and PU gave similar yields. The TGR-405 rice variety increased grain yield over IR-841 by 5-7% but there was no significant interaction effect between the type of urea and rice variety. The USG increased nitrogen uptake by 34-47 kg ha^{-1}, agronomic use efficiency (AE) by 13-16 kg kg^{-1} and recovery efficiency (RE) by 13-16 over PU at Ablotsri and Hahome sites while at Kouto site, no significant increment in the parameters was obtained with USG when compared to PU. Rice yield increased with increasing USG rates. However, application of USG rate of 78 kg ha^{-1} at Ablotsri site, and 104 kg ha^{-1} at Hahome site were more lucrative, while at Kouto site, 104 kg ha^{-1} of PU gave the highest income.

The third experiment consisted of four different ages of seedling (10, 14, 21 and 28-days old) and four different USG application times (0, 7, 14, and 21 days after transplanting (DAT). Results indicated that the younger the seedlings, the better were rice performances. The highest rice yield, NU, AE and RE were obtained with 10 and 14-day old seedlings, while the poorest performances were observed for 28-day old seedlings. Application of USG at 7 or 14 DAT gave the highest rice parameters. The interactions between seedling age and time of USG application showed the highest rice performances when USG was applied at 7 or 14 DAT to rice seedlings of 10 to 14-day old.

The overall conclusion from the research was that the USG deep placement significantly reduced ammonia loss in paddy soils over the PU. The optimum depth and rate of USG application to improve rice growth yield and NUE are soil specific. Young seedlings and early USG application (7-14 DAT) should be considered for best rice cropping. .

DEDICATION

To my late Mother Ayabavi, my wife Béatrice and our four childrens:

Espoir, Antoine, Jérémie and Félicia

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AUE:	Agronomy use efficiency
BRRI:	Bangladesh Rice Research Institute
DAT:	Days after transplanting
DCD:	Dicyandiamide
DSID:	Direction des Statistiques, de l'Information et de la Documentation
DSRP:	Document de Stratégie de Réduction de la Pauvreté
EENF:	Enhanced efficiency N-fertilizers
FAO:	Food and Agriculture Organization of the United Nations
FCFA:	Franc des Communautés Francophones d'Afrique
GDP:	Gross domestic product
IFDC:	International Centre for Soil Fertility and Agricultural Development.
IRRI:	International rice Research Institute
ICAT:	Institut de Conseil et d'Appui Technique
ITRA:	Institut Togolais de Recherche Agronomique
MAEP:	Ministère de l'Agriculture, de l´Elevage et de la Pêche
MOP:	Muriate of Potash
NARC:	Nepal Agricultural Research Cuncil
NBPT	N-(n-butyl) thiophosphoric triamide
NGO:	Non-Governmental Organization
NUE:	Nitrogen use efficiency
PADAT:	Projet d'Appui au Développement Agricole du Togo
PARTAM:	Projet D'aménagement et de Réhabilitation des Terres Agricoles dans la Zone de Mission-Tové
PASA:	Projet d'Appui au Secteur Agricole

PBVM:	Projet d'aménagement hydro agricole de la Basse Vallée du fleuve Mono
PDPR-K:	Projet de Développement de la Production Rizicole dans la Kara
PDRD:	Projet de Développement Rural de la Plaine de Djagblé
PDRI-Mô:	Projet de Développement Rural Intégré de la plaine de Mô
PNIASA:	Programme National d'Investissement Agricole et de Sécurité Alimentaire
PPAAO/WAAPP:	Programme de Productivité Agricole en Afrique de l'Ouest/ West Africa Agricultural productivity Program
PPD:	Phenyl phosphorodiamidate
PSCU:	Polymer sulphur coated urea
PU:	Prilled Urea
RE:	Recovery efficiency
SCU:	Sulfur-coated urea
SIREC:	Soil and Irrigation Research Centre
SNDR:	Stratégie Nationale de Développement du Riz
SRI:	System of Rice Intensification
TSP:	Triple Superphosphate
UDP:	Urea deep placement
USDA:	United States Department of Agriculture
USG:	Urea supergranule
VCR:	Value-Cost Ratio

CHAPTER ONE

1.0. INTRODUCTION

1.1. Background

Rice (*Oryza sativa L.*) is the second cereal crop after wheat all over the world and it is cultivated in more than 110 countries. It constitutes the a staple food for approximately 50% of the world's population including Asia, Africa and South America (IRRI, 2010). In rice production around the world nitrogen is the most yield-limiting nutrient (Roy *et al*., 2002), especially in tropical soils where almost every farmer has to apply N fertilizer to obtain a sustainable yield of rice (Naher *et al*., 2011). Rice yield increases up to 90% can be observed only by N fertilizer application (Faqir and Malik, 1983). Linquist *et al*. (2013) estimated that, of all nutrients required by crops, N is applied in the greatest quantities. In rice production, efficient nitrogen fertilizer is an important factor, but low N fertilizer use efficiency remains a problem. Vlek and Stumpe (1978) reported that even under good fertilization management nitrogen recovery rarely exceeds 40%.

Urea with its high nitrogen concentration of 46% and low per unit cost is the dominant N-fertilizer use for agricultural production (Glibert *et al*., 2006). In Togo agricultural systems, urea is the only conventional N mineral N fertilizer used. However, its low N recovery efficiency remains a problem because of high loss potential (up to 60% of N applied). The low recovery is attributed to N losses via various pathways such as ammonia (NH_3) volatilization, nitrification, denitrification, leaching and runoff (Fageria and Baligar, 1999; Liu *et al*., 2015). Large amounts of N losses result in various environmental problems, such as atmospheric haze, acid rain, surface water eutrophication, and groundwater contamination (Liu *et al*., 2015). In the atmosphere, even low concentration of NH_3 can induce significant respiratory and cardiovascular diseases in human and animals (Gay and Knowlton, 2009). The NH_3-N loss is generally, the most important form of applied urea losses in rice fields (Zhu, 1997 and Chen *et al*., 2015). Fan *et al.* (2006) recorded ammonia losses from 9% to 40% of the total N applied. Yu *et al*. (2013) reported ammonia losses of 11 to 22 % in sandy soil. Therefore, reducing ammonia losses following urea application can significantly help to improve rice uptake and use efficiency of N and then enhance rice yield.

1.2. Problem statement

To limit N fertilizer losses and improve the N-fertilizer's use efficiency, earlier studies recommended proper choice of N-sources (Dillon *et al*., 2012; Jantalia *et al*., 2012) , rates (Zhao, 2010; Dillon *et al*., 2012; Rochette *et al*., 2013; Yu *et al*., 2013), timing of application to synchronize N-fertilizer application with rice need (Dillon *et al*., 2012), and the use of coated urea and inhibitors (Cantarella *et al*., 2008). Most of the recommendations such as inhibitors and coated urea are not known by small scale rice farmers or are not adopted because of their high cost.

In Togo, split application of urea in a basal and two topdresses at active tillering and panicle initiation stages of rice is the N fertilization practice recommended by researchers (ITRA, 2007). However, the nitrogen use efficiency with the split application of urea is reported to be lower than urea incorporation and urea deep placement which are difficult practices in puddled soils and flooded rice production systems and almost impossible after rice transplanting.

Among the solutions for increasing nitrogen fertilizer efficiency in paddy fields, urea supergranule deep placement (UDP) technology is receiving much attention. The UDP is reported to revolutionize rice production in Asia and therefore, in order to follow the government's rice development policy and contribute to achieve the *objectives one (zero poverty) and two (eradicate extreme hunger) of the Sustainable Development Goals*, the technology merits to be improved and introduced in rice farming systems of Africa.

1.3. Justification

Urea deep placement technology consists of an affordable supply of the Urea Supergranule (USG) and an efficient method for its deep placement. Urea is deeply placed into a reduced soil layer at 7-10 cm depth to avoid its oxidation. To do so, prilled urea is compressed into a bigger size (Supergranules, USG) for slow hydrolysis. The use of USG has several advantages over prilled urea because it requires only one time application after rice transplant. The placement forces urea into the anaerobic soil layer thereby eliminating denitrification, reduce NH_3 volatilization, runoff losses of N, establishing better fertilizer-root contact and reducing weed competition (Singh, 2005; Cai *et al*., 2002). The use of USG is reported to significantly increase rice yield over broadcast prilled urea (Eriksen and Nilsen, 1982a; Mohanty *et al*., 1999; Bony *et al*., 2015). Depending on the agroclimate and N rates used, UDP technology can help save urea fertilizer up to 65% with an average of 33% and also increase grain yields up to 50% over that of the same amount of split-applied N as PU (Savant and Stangel, 1990).

With regards to the advantages of UDP, the technology merits to be introduced in paddy fields of Sub-Saharan-Africa. However, local scientific knowledge needs to be established for best practices of the technology. Savant and Stangel (1990) suggested that practical questions merit answers for effective transfer of the technology into specific regions that vary with agroclimatic socioeconomic, and education. Urea Supergranule efficiency depends on several factors including soil, climate, ecology type and rice variety.

In general, it is noted that deep application of urea considerably reduces ammonia loss over broadcasting of prilled urea (PU) in paddy soils. However, few studies have assessed the effect of USG on NH_3 loss but none reported the influence of USG application depth on NH_3 loss in different soils. Although some studies have considered the USG application time on its efficiency, knowledge on the effect of combined factors such as application time and rice seedling age on USG efficiency is limiting. In Sub-Saharan Africa (SSA), even though some studies have been carried out on USG, data on its efficiency over PU is not yet well established, especially in Togo where no data is available on the effect of different N-rates application with USG on rice performance. The above situation justifies the need to carry out the present research on the efficiency of USG deep placement over prilled urea in rice production with the general objective of *managing urea supergranule to improve growth and yield of rice in some paddy soils of Togo and Ghana.*

The specific objectives are to:

1. Evaluate ammonia losses, rice yield and nitrogen use efficiency at varying depths of USG application in different paddy soils;
2. Determine the application rates of USG that optimise rice yield and improve nitrogen use efficiency in some irrigated paddy soils and;
3. Determine the seedling age for transplanting and USG application time that improves rice N use efficiency and yield.

Hypotheses

H0: The deep placement of USG will not reduce ammonia loss as compared with the split application of PU

H1: The deep placement of USG will reduce ammonia loss as compared with the split application of PU.

H0: Ammonia loss amounts will neither vary with the depth of USG application nor with the type of paddy soils.

H1: Ammonia loss amounts will vary with the depth of USG application and the type of paddy soils.

H0: The optimum USG application rate will not vary with rice variety or with the type of paddy soils.

H1: The optimum USG application rate will vary with rice variety and the type of paddy soils.

H0: The time of USG application for the best rice nitrogen use efficiency and yield will not depend on the age of transplanted seedlings.

H1: The time of USG application for the best rice nitrogen use efficiency and yield will depend on the age of transplanted seedlings.

CHAPTER TWO

2.0. LITERATURE REVIEW

2.1. Rice morphology, agronomy and ecology

Rice (*Oriza sativa L.*) is of the gramineae family and is a famous plant for its seeds. Over the world, rice is the second food after wheat (Carney, 2001). Depending on the variety, rice can grow up to 1.8 meters in height. It presents inside, a stem in the form of cane. The leaves are lanceolate, long and flattened with tapered endings and parallel venation. The panicles or inflorescence is made up of spikelets bearing flowers that produce the grain. Grains are caryopsis with a very high content of starch in the endosperm surrounded by hard clear brown cover called rice bran is externally protected by a clear and papyraceous cover (Botanical on line, 2019).

The average world rice yield is below 4 t ha^{-1}. However, in experiments sites, grain yield commonly reaches 6-7 4 t ha^{-1} (Fageria and Baligar, 2001; Fageria and Prabhu, 2004). This indicates that there is large gap between on-farm yields and those obtained at experimental sites. This gap can be reduced significantly if appropriate technology is adopted and the socio-economic conditions of the rice farmers are improved.

Rice cultivation comprises two mains ecosystems: Irrigated (or flooded) rice that is defined as rice cultivated on relatively flat lands wherein water is accumulated (Fageria, *et al*., 2003) and rainfed growing rice in naturally well-drained soils, without surface water accumulation or phreatic water supply (Fageria, 2001).

Rice can be cultivated on different types of soil: saline, alkaline and acid sulfur soils (Ahn *et al*., 1992). Temperature below 18°C at night during pollen formation results in sterile pollen in all rice cultivars (Mc Donald, 1994). In paddy rice, maximum yields are obtained in the dry season, when cloud cover is less and photosynthetic active radiation is greater than during the wet season (Mc Donald, 1994).

2.2. Status of rice cultivation in Togo

In Togo, rice constitutes a major part of the population's diet. It is rated as the third cultivated cereal after maize and sorghum, and contributes about 3% of the country's Gross Domestic Product (MAEP, 2010). Domestic production of paddy rice in Togo varied from 110,109 tons in 2010 to 147,930 tons in 2014 (DSID, 2017). In 2014, the production was able to meet 50% of the national demand which was estimated to be 200,000 tons of milled rice (USDA, 2016). The country's production-consumption deficit is annually met by imports, valued at over 20 billion FCA (35 millions of dollars) annually.

Depending on water availability, three types of rice cultivation systems are practised in Togo. These are upland rainfed, lowland rainfed, and lowland irrigated rice systems. Lowland rainfed system is the most practised and it occupies 65% of rice cultivation areas, upland rainfed rice occupies 10% and the lowland irrigated rice farming occupies 25% of the total area of rice production (ITRA, 2007). Although lowland irrigated rice occupies lower proportion of rice cultivated areas as compared with the rainfed lowland, it contributes more than 50% of the total rice domestic rice production because it is characterized by intensive production system with high yield (3-5 tons ha^{-1}) and two to three cultivation seasons per year.

Rice yield in Togo varies greatly in general and the average on farmer's field hardly reaches 2 tons ha^{-1} which is very low as compared with the potential yield of 4-5 tons ha^{-1} (ITRA, 2007). The low rice yield is due to several factors, but it is more attributed to the poor standard of production technologies and the dominance of local rainfed rice varies with low productivity (Africa Rice, 2015).

More than 40 rice varieties are grown in Togo (Aboa *et al*., 2007). Kluvi (2013) indicated that 50% of rice farmers grow improved varieties, while 34% still use local varieties and

16% of them use both improved and local varieties on different field. Among the improved varieties, IR-841 is the most cultivated (41% of rice farmers) because of its natural perfume. According to ITRA (2007), the local varieties most cultivated are Lobolobo, Dapaong Kambiaka and Agoana. Recently introduced, NERICA variety occupies 5% of the rice cropping areas and it is especially grown in the southern areas by women (MAEP, 2010).

In terms of fertilization, there are blanket recommendations across the country. These are 46 kg N ha^{-1}, 23 kg P_2O_5 ha^{-1} and 23 kg K_2O ha^{-1} for upland rice and 76 kg N ha^{-1} , 30 kg P_2O_5 ha^{-1} and 30 kg K_2O ha^{-1} for the lowland rice (Aboa *et al*., 2007). However, mineral fertilizers used by farmers vary greatly from no fertilizer application in rainfed systems to 300 kg ha^{-1} in intensive rice production of irrigated lowland system. Average fertilizer use in Togo is generally low (5 kg ha^{-1}). Most small scale farmers in rainfed system do not apply any fertilizer to rice whereas in the irrigated system, fertilizers are applied but the rates are far below the recommendations, leading to low yields.

With regards to low rice yield of rice in Togo, efforts are being made by the government to increase domestic rice production in order to reduce the large dependence on imports. Through many agricultural projects the country invests in rice production that got an important place in the strategic food security policy. Thus, in the context of the "Complete Strategic Document of Poverty Reduction (DSRPC)" adopted in 2008 in which agricultural development was identified as the first pillar, a "National Strategy for Rice Development (SNDR)" was designed and adopted for eight years (2010-2018). The goals were to (i) increase the cultivation areas from 36,492 to 66,500 ha, (ii) improve yields from 2 to 3.5 tons ha^{-1}; (iii) increase annual paddy rice production from 85,540 to 232,750 tons or 139,650 tons of milled rice in 2018 (MAEP, 2010). The SNDR is being implemented under the umbrella of the National Program for Agricultural Investment and Food Security (PNIASA) since 2011 with several projects as Agriculture Sector Development Project (PASA), Enhancing Agricultural Development in Togo (PADAT), West African Agricultural Productivity Project (PPAAO/WAAPP).

All these projects aim to improve crop including rice and animal production. To achieve SNDR goals, besides the above mentioned projects, specific projects of irrigated lowland development for rice production were designed and being implemented in the PNIASSA across the country. They are (i) Agricultural Land Development Project of Mission-Tové (PARTAM), (ii) Water and Agricultural Land Development Project of The Valley of Mono River (PBVM), (iii) Rice Development Project of Kara Zone (*PDPR-K*), (iv) the Integrated Rural Development Project of the Mô Plain (PDRI-Mô) and (v) the Rural Development Project of Djagble Plain (PDRD). These projects were designed and being implemented to expand rice cultivation areas in order to improve production.

Earlier on, a regional project for developing lowland for rice-production systems in sub-saharan Africa was implanted in Togo between 2010 and 2015. This project (SMART IV) was guided by the Smart-Valley approache that is based on a participatory, sustainable and low-cost approach. Smart-valleys approach was developed by Africa Rice Center (AfricaRice) and its national research and development partners in Benin and Togo.

The government of Togo has aimed at expansion of cultivated areas, however adoption of proper production skills of which adequate mineral fertilization technology should be considered. The government, through its various agricultural projects makes fertilizers available to farmers at subsided prices. In this way, more and more fertilizer use is being promoted by the government of Togo but the expected yield increase is not attained, particularly when it comes to the use of urea which supplies N, the most limiting yield nutrient in paddy fields. In fact, the use of urea in paddy soil is associated with serious N losses leading to its low efficiency, money wastage and environmental hazards. Therefore, the effort of the government to improve rice production should be followed by proper urea application practices.

2.3. Nitrogen for Rice plant

2.3.1. Importance of nitrogen fertilization in rice production

Over the world, nitrogen (N) is used to sustain and increase crop production. In rice cropping, nitrogen constitutes one of the major nutrients and is considered as an important element in the economic viability of agriculture systems (Fixen and West, 2002). Cassman *et al.* (2002) indicated that increase in nitrogen fertilizer use had worldwide contributed to crop yields improvement. FAO (2015) projected the world demand for nitrogen in 2018 at 119,418 thousand tonnes while the demand for phosphate (P_2O_5) and potash (K_2O) were respectively estimated to be 46,648 and 34,456 thousand tonnes, suggesting that, over the world, nitrogen fertilizers are used in highest amount compared with other fertilizers.

Watkins *et al.* (2008) estimated N fertilization for rice in the southern United States to account for 25% of the variable costs associated with commercial production suggesting that rice cropping requires high management and large amounts of nitrogen. Fageria (2013) suggested that the amount required makes nitrogen to be the single most important rice nutrient. In addition, the large amount of N required by modern crop cultivars and the limited ability of soils to supply available N cause it to be the most yield-limiting nutrient for crop production on a global basis. Nitrogen's fundamental importance as a primary nutrient element is augmented by the fact that many improved rice varieties cultivated around the world have been bred to show a marked response to the application of nitrogenous fertilizers (Fageria, 2013). Rice's uptake of N is generally greater than its uptake of any other essential nutrient. However, in some newly developed cultivars, N is absorbed in equal or slightly lower amounts than is potassium (Fageria *et al*., 2010).

2.3.2. Role of nitrogen element in rice plant

Mainly, nitrogen is absorbed in form of NH_4^+ and NO_3^- by plants. But in submerged soils, rice absorbs nitrogen mostly in NH_4^+ form. The key role played by nitrogen is observed in various physiological processes (Bloom, 2015). Judicious supply of nitrogen imparts dark-green colour in plants indicating high photosynthetic process (Hemerly, 2016).

Nitrogen is an integral component of many essential plant compounds. It is essential for carbohydrate use within the plant. Being the major plant food, nitrogen is a major constituent of all the building blocks (amino acids) of enzymes (proteins), nucleic acids and chlorophyll (Swan, 1971; Brady and Weil, 1996). The dry matter of the protoplasm is constituted of 40% to 50% of Nitrogen compounds. Adequate supply of nitrogen induces increasing protein content and quality of grain stimulates the uptake and utilization of other nutrients (Hemerly, 2016).

2.3.3. N deficiency symptoms of rice

Nitrogen is recognized to constitute the major limiting soil nutrients under the tropics. Thus lack of application of N-fertilizer results in deficiency symptoms observed on cropping plants. Nitrogen deficiency is generally reported in lowland as well as upland rice cropping systems (Fageria *et al*., 2010).

Nitrogen deficiency symptom of rice, first, appears on older leaves as cholorosis observable by the changing of the green color to light green and yellow (Bianco *et al*., 2015). This is explained by the migration of nitrogen from the older leaves to the younger ones when the nutrient lacks. In prolonged deficiency conditions, the entire plant shows yellow coloration and when the deficiency becomes severe, leaves become dry at the tips and margins. Later on, nitrogen deficient rice plant shows a general purple appearance due to the accumulation of anthocyanin pigments (Hopkins and Huner, 2009). Morphologically, reduced plant height and tillering are observed when nitrogen is deficient, leading to a severe plant stunting.

Observable rice nitrogen deficiency symptom is reported to have good advantage for direct field application in term of N-fertilizers management. N need of growing rice is directly detectable and solved by N supply without any specific laboratory analysis of plant or soil. (Fageria and Baligar, 2005)

Excessive rate of N has also adverse effects on plant development. It promotes deep dark-green color of the leaves and makes the entire plant succulent and predisposes it to insect attack (Cu *et al.*, 1996). As result, low yields, less grain quality and increasing susceptibility to lodging are recorded (Duy *et al.*, 2004). In general, plant N toxicity is rare, however, imbalance in plant nutrition can result from excess N rates. Rahman *et al.* (2005) obtained decreasing rice yield while increasing amounts of nitrogen above 150 kg ha^{-1}. They recorded 6% improvement of rice yield with 150 kg ha^{-1} treatment over the one treated with 200 kg ha^{-1}.

2.3.4. Role of nitrogen fertilizers in rice productivity

The direct role of applied nitrogen on crops desired by rice is the improvement of plant growth and yield increases. Nitrogen is a predominant nutrient in agriculture. The importance of nitrogen fertilization in rice production had been largely discussed by researchers.

Yoshida (1981) stated that nitrogen is a key nutrient required for crop yield and its lack or absence, leads to drastic reducing of rice yield. Hemerly (2016) indicated that, adequate supply of nitrogen dramatically stimulates the vigor, promotes vegetative growth, rapid leaf and stem of the rice plant. Moreover, it increases protein content and quality of grains and stimulates the uptake and utilization of other nutrients (Brady and Weil, 1996). Chopra and Chopra (2000) found consistent enhancement of rice yield components with 80 and 120 kg n ha^{-1} when compared with the control. Cong *et al*. (2015) collected data from 1844 sites per year of rice in China and reported that over 96% of the sites showed yield increase with N fertilization, and the highest increase rate reached 79 % compared with the no N application.

Long-term experiments conducted on rice N requirements in Philippines and India revealed that significant yield responses to applied N were observed in almost all types of soils (Nambiar and Ghosh, 1984; De Datta *et al*., 1988). Singh *et al*. (2000) observed in a field experiment that each increment dose of N significantly increased grain and straw yields of rice over its preceding dose. Similarly, Duhan and Singh (2002) reported that rice yield and uptake of nutrients increased significantly with increasing levels of N. Dongarwar *et al*. (2003) also recorded significant increases in grain yield with successive increase in fertilizer rate during a field experiment conducted in India. Similar results of improved responses of rice yield to increasing N-fertilizer rates were obtained in Cuba by Obiol *et al*. (2003).

Mazumder *et al*. (2005) reported the influence of various rates of nitrogen on rice yield. They obtained a decreasing yield of rice while reducing the amount of the recommended rate of N and recorded the lowest yield with the no nitrogen fertilizer application treatment. Rahman *et al*. (2005), observed increased rice yield with increasing N application rates. They obtained the highest grain yield (4.19 t ha^{-1}) with at 150 kg N ha^{-1}. Fageria and Baligar (1996) reported that lowland rice yields in central Brazil on Varzea soil were higher at 200 kg N ha^{-1} than at 100 kg N ha^{-1}.

2.3.5. Nitrogen requirement for rice

Earlier studies revealed that appropriate application of nitrogen fertilizers rate can substantially increase the yield and improve the quality of rice (Place *et al.*, 1970). Insufficient or inappropriate N-fertilizer management can directly be detrimental to crops and the environment, while excess of N also causes negative effects on plant such as excess vegetative growth particularly in tropical areas (Miah and Panaullah, 1999). The potential for increased rice production strongly depends on the ability to integrate a better crop management into an existing cultivation system. Among many other factors, rice N requirement depends upon the locations, seasons and varieties. Globally, Fageria (2013) stated that, production of every ton of crop yield needs 20-25 kg of nitrogen. However, for the production of one ton of rice, Dobermann and Fairhurst (2000) estimated the amount of N removal to be 16 to 17 kg. For tropical zones of Africa, Nwilene *et al.*, (2008) recommended 40-120 kg ha^{-1} of N. Depending on rice varieties in USA, recommendations range from 120 to 150 kg ha^{-1} (Roberts and Hardke, 2016).

In India, field trial indicated N requirement of 120 kg ha^{-1} but for the maximum yield, N requirement depends upon various factors as variety and location (Kadiyala, 2012). For grain production, rice varieties of short to medium duration maximize N consumption during vegetative growth stage and the absorbed N is stored to be used in the subsequent stages. Kadiyala (2012) concluded from a review of results of many experiments on N fertilization that, split application of nitrogen, at planting, tillering and at flowering is the best management strategy for rice yield improvement.

2.4. The fate of urea N in paddy soils

In agricultural systems over the world, urea is usually the conventional N mineral fertilizer used because of its high N content (46%) and relatively low cost. However, urea-N is associated with losses and N loss amount mostly depend on the soil conditions.

2.4.1. Characteristics of flooded paddy soil

Most of the world's rice is produced on flooded soils, either under irrigated or rainfed lowland condition. Rice can grow under these circumstances because of its ability to oxidize its rhizosphere through the intake of atmospheric oxygen that diffuses from the leaves through intercellular channels (Alberda, 1953). Flooding however, brings about a series of physical, chemical and biological changes in the soil, quite different from those under upland conditions and that affects differently the fate of the applied urea (van Keulen, 1977).

Physically, flooding of an originally dry soil results in saturation of the structural aggregates of the soil matrix, while the pressure built up by air entrapped within the soil, causes disintegration of many of the aggregates (Ponnamperuma, 1965).

From the biological point of view, aerobic microorganisms present in the soil consume oxygen in their respiratory processes. After flooding, oxygen in the soil is quickly depleted as the rate of diffusion of oxygen through water is slower than in the absence of water. Under this condition, anaerobic microorganisms multiply, using decomposable organic material as energy source and oxidizes soil components as electron acceptors. These compounds are reduced, following a thermodynamically determined sequence: nitrates, manganese oxides, ferric oxides, and hydroxides, sulfates, CO_2 and sometimes phosphates (Ponnamperuma , 1965).

Chemically, flooded rice soils are characterized by absence of oxygen in the system leading to differentiation of soil layers, an oxidized surface layer zone and an underlying reduced zone due to constant flooding of fields during rice growth (Reddy *et al*., 1984). The thickness of the aerobic zone can vary considerably (Reddy, 1982). The differentiation of the oxidized and reduced layers in paddy soils is influenced by its physical, chemical and biological properties. When light textured soils are flooded, differentiation occurs slowly and the oxidized layer appears to be fairly thick but not well defined. By contrast, in heavy textured soils, differentiation proceeds rapidly and the oxidized layer is thin but well defined. Again, for strongly reduced soils, differentiation of the two layers occurs quickly and the oxidized layer is rather thin (Hasebe and Iimura, 1982); for weakly reduced soils, the situation is just the opposite.

According to Hasebe *et al.* (1987), a moist paddy soil, after incubation for 20 days under flooded conditions at 25°C, differentiated into two layers, a 1 cm thick oxidized layer and the underlying reduced layer, while an air dried soil, after flooding for 5 days, divided into two layers, although the oxidized layer was only 1 mm thick. Another factor influencing differentiation is the depth of the floodwater and its dissolved oxygen content (Yoshida and Padre, 1974). When the floodwater layer is deep, differentiation occurs slowly. But when the floodwater layer is shallow and contains large amount of dissolved oxygen, differentiation occurs quickly (Zhao-liang, 1997). These physicochemical and biological changes are of great practical importance for the behaviour of nitrogenous fertilizers applied to rice soils.

2.4.2. Urea-N transformation in paddy soil

Various consecutive and simultaneous chemical reactions occur when urea is applied to paddy soil (Figure 2.1). When applied to paddy soil urea undergoes hydrolysis leading to the formation of ammonium (NH_4^+), a very unstable ion in the soil system.

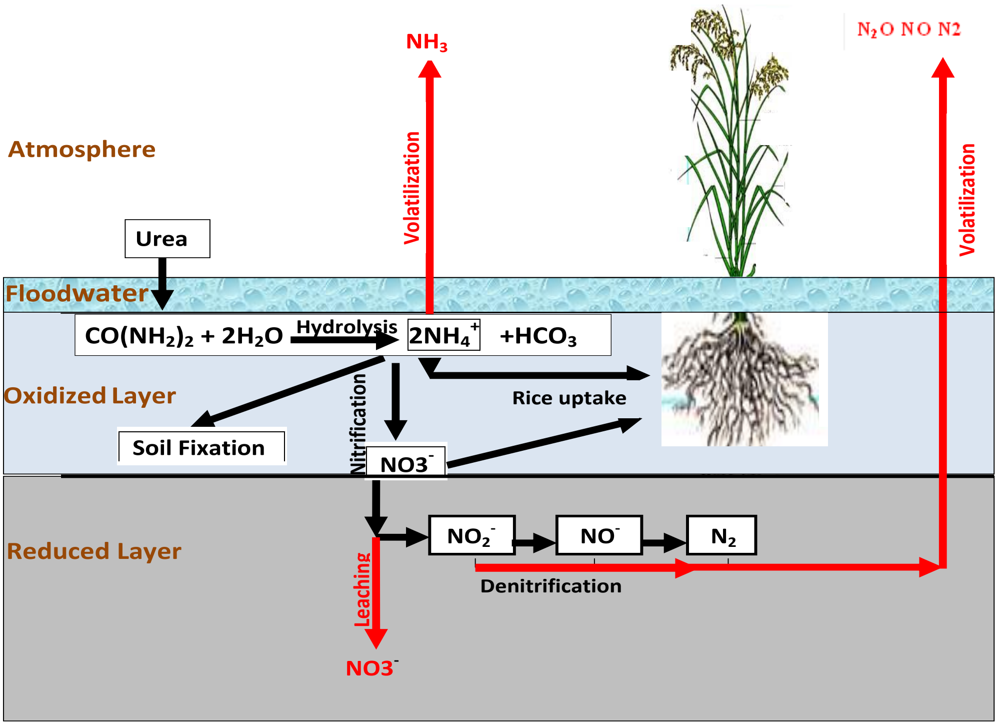


Figure 2.1 : Urea-N dynamic in flooded rice soil system (adapted from Fageria (2013)

The NH_4^+ formed can be: (i) volatilized into ammonia (NH_3) form or absorbed by plant root, (ii) be temporarily adsorbed by soil mineral and organic particles, be fixed by soil microorganisms or (iii) oxidized into Nitrate (NO_3^-) that in turn can be absorbed by rice root or lost out from the root zone with leaching water or, constitute in reduced conditions a precursor for denitrification that successively leads to emission of nitrous, nitric oxides, and nitrogen gas (Dobermann and Fairhurst, 2000).

2.4.2.1. Hydrolysis of urea

Once applied to rice growing soil, urea dissolves quickly and moves freely with water in the soil body. In contact with soil and in presence of urease (enzyme), the dissolved urea undergoes hydrolysis process which is the breaking down of urea ($CO(NH_2)_2$), resulting in ammonium carbonate, an unstable compound that can quickly be transformed to NH_3 gas (Merigout, 2006) (equation 2.1). Urease needed for hydrolysis is produced in the soil by organisms and can function outside them (Camberato, 2001). The hydrolysis process creates a high pH in the vicinity of the urea and OH^- ions are released. Urea hydrolyzes in wet soil under the action of urease into ammonia and carbon dioxide can be described by the following equation (Krajewska, 2009).

$$CO(NH_2)_2 \rightarrow HNCO + NH_3 \xrightarrow{H_2O} H_2CO_3 + 2NH_3 \qquad [2.1]$$

The rate of urea hydrolysis will depend on the environmental factors affecting urease activity. Among these factors is the presence of urease itself that is important for hydrolysis to occur. But this is a rare limiting factor in soil, since microbes and plants produce urease that can act outside living organisms. High number of urease speeds up hydrolysis.

Another factor that affects hydrolysis of urea is soil pH. The rate of urea hydrolysis increases when the soil pH increases from 5 to 9, but pH does not limit the process in most agricultural soils. In fact, the initial reaction of urea hydrolysis increases the alkalinity of the soil solution to pH > 9 due to the formation of ammonium carbonate. However, the subsequent conversion of ammonium to nitrate is an acid-forming process, offsetting the initial and temporary pH spike.

Urea hydrolysis rate increases with soil temperature, but even in the cooler soil, hydrolysis is generally complete within a week. High soil moisture increases urease activity. High level of soil organic matter and crop residues also increases urea hydrolysis rates and volatilization. This is largely because the urease, which is necessary for hydrolysis, is produced by microorganisms that are more active in the presence of organic material than in mineral soil (Jones *et al*., 2007).

The N-product (NH_4^+) released during the hydrolysis of urea in the soil solution is subject to a series of transformations such as ammonia volatilization, immobilization, fixation, and nitrification-denitrification. These processes approach their maximum values within 6 to 10 days following urea application (Zhao-liang, 1997) and their rate differs with the soil environment (Cheng *et al*., 1989). The fixation-release of ammonium results in a steady and long lasting uptake of applied N by the plant, and reduces N loss (Wen and Zhang, 1986).

2.4.2.2. Nitrification

In a highly saturated or flooded rice soil, nitrification occurs in the thin oxidized surface layer. Nitrification is governed by microorganisms that convert ammonium-N or ammonia-N to nitrate via nitrite (equations 2.2 and 2.3). Nitrification is a major pathway through which N can be lost from soil ecosystems (Banning *et al*., 2015). By oxidizing the NH_4^+ that is released from applied urea, microorganisms derive energy for their subsistence (Zhao-liang, 1997). The nitrification occurs in two steps in the soil system and is represented by the following equations (Fageria, 2009).

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H^+ \qquad [2.2]$$

$$2NO_2^- + O_2 \leftrightarrow 2NO_3^- \qquad [2.3]$$

Microorganisms involved in the nitrification process are mainly autotrophs; however, heterotrophic organisms can also act. Chen *et al. (*1981) reported that few species of bacteria such as *Arthrobacter* and fungi such as *Aspergillus flavus* can produce nitric acid when an ammonium salt is the only N source. The amounts of nitrite and nitrate formed by heterotrophic bacteria are far lower than those formed by the autotrophic bacteria. Factors that influence the nitrification process are soil pH, soil potential redox, soil moisture and soil organic content.

Soil pH is one of the major factors affecting nitrification (Dancer *et al.,* 1973). The autotrophic nitrifying organisms grow well if the pH ranges from 6.6 to 8.0, although each of the individual specie has its optimum range. Soil texture controls soil aeration and water permeability so that sandy soils are better aerated and more permeable than clay soils and therefore are suitable for nitrification process.

The redox potential of the soil is another factor that affects nitrification. It is usually considered that when the medium is oxidized autotrophic nitrification will occur. Chen *et al. (*1981) reported that, in mildly aerobic conditions, the oxidation of ammonium to nitrate was carried out jointly by autotrophic and heterotrophic bacteria and only heterotrophic nitrification took place when the redox potential was low. Soil moisture also controls nitrification in soil. Flooding or extreme moisture content that prevails in paddy field is unfavourable for the activity of autotrophic nitrifying microbes in soil. Organic matter in the soil inhibits naturally nitrifying bacteria; but organic matter does not always retard the oxidation of ammonium. This is because when organic matter is added to soil, extra ammonium is produced for nitrification, and the propagation of autotrophic and heterotrophic nitrifying organisms is stimulated, thus increasing the nitrifying activity in soil (Zhao-liang, 1997).

2.4.2.3. Denitrification

Denitrification follows the nitrification process in the soil. When the oxidized product of ammonium, nitrate (NO_3^-) moves downward and reaches the reduced layer where oxygen is lacking, it is used as an electron acceptor by the facultative anaerobes during the oxidation of soil organic matter and other organic materials (Kennedy, 1992). Denitrification is the reduction of NO_3^- to a series of steps to nitric oxide (NO), nitrous oxide (N_2O), and nitrogen gas (N_2), which are released in to the atmosphere (Reddy and Patrick, 1986). The dentrification process follows the equation below (Liang-mo, 1997).

$$\mathbf{NO_3^-} \rightarrow \boldsymbol{NO_2^-} \rightarrow \boldsymbol{NO} \rightarrow \boldsymbol{N_2O} \rightarrow \boldsymbol{N_2} \qquad [2.4]$$

The amount of N lost due to denitrification, varies from negligible to 46% of the applied N depending on urea application practice and crop establishment methods (Buresh and De Datta, 1990). Fillery and Vlek (1982) reported that denitrification losses from N-fertilizer were 5–10% in continuously flooded rice-cropped soils, while in the fallow soil the loss was around 40% of the applied N. ^{15}N studies indicated that denitrification rate is higher in underground saturated soils under rice cultivation compared to soils under wheat cultivation (Xing *et al*., 2002), suggesting that saturation of paddy soil favors reduction condition (Choudhury and Kennedy, 2005).

Nitrification is tightly integrated with the reductive process of denitrification, in which NO_3^- is converted to gaseous N_2, and both nitrification and denitrification are responsible for the production of nitrous oxide (N_2O), one of the critical greenhouse gases and the dominant ozone-depleting substance emitted from soils.

2.4.3. N loss ways from fertilizers in paddy field and their environmental pollution

2.4.3.1. Ammonia-N volatilization

- ***Mechanism and extent***

Ammonia loss consists of a sequence of chemical and physical processes and the amount of ammonia volatilized is governed by different factors that influence the processes. The reactions following ammonium based fertilizer application that lead to ammonia volatilization can be represented as follow (Gui-xin, 1997).

$$\begin{gathered}\textit{N-Fertilizer}\\ \downarrow\\ NH4^{+}_{Exchangeable} \leftrightarrow NH4^{+}_{In\ solution} \leftrightarrow NH3_{Gas\ in\ soil} \leftrightarrow NH3_{Gas\ in\ atmosphere} \qquad [2.5]\end{gathered}$$

Ammonia loss from flooded rice fields following urea application has been investigated in many studies. Results indicated that the amount varied greatly with experimental conditions and in many case, ammonia constitutes a very important way of applied N-fertilizers in paddy fields (Simpson and Freney, 1988; Cai, 1992). Amounts of ammonia volatilization loss in rice soils range from negligible to 60% of N applied (Xing and Zhu, 2000). Fillery *et al*. (1982) reported ammonia volatilization of 40% of the total applied N to flooded soil when the wind is strong and the weather is sunny.

- *Factors controlling ammonia volatilization*

Ammonia loss from paddy field varies greatly with weather conditions such as temperature and wind speed, soil properties: CEC, moisture content, organic matter content, and pH (De Datta, 1987), and some management practices such as fertilizer source and mode of application (Choudhury and Kennedy, 2005). Influences of some of the factors are described as below.

Cation exchange capacity (CEC): Soils with high CEC adsorb ammonium and decrease its concentration in the soil solution. Therefore, the concentration of NH_3-N and its volatilization are reduced (Keller and Mengel, 1986). Qu (1980), Yao and Guan (1983) reported negative correlation of ammonia volatilization with soil CEC. Vlek and Craswell

(1979) conducted lysimeter experiment and obtained 35% N loss by ammonia volatilization on sandy loam paddy soil with low CEC while on clay soil with high CEC ammonia volatilization was only 10%.

Soil pH: Low ammonia volatilization losses occur in acid soil while in alkaline soils, losses are high (De Datta, 1978). Increasing amounts of ammonia loss with soil pH are reported in many studies (Ryan *et al.*, 1981). However, the floodwater pH is rather the factor controlling ammonia volatilization rate when the paddy soil is flooded (Gui-xian, 1997).

Temperature: Ammonia volatilization potential is positively correlated with the soil environment temperature since high temperature enhances the potential for ammonia loss (Zhao *et al*., 1986). High temperature increases first the rate of urea hydrolysis and further, the ratio of NH_4^+ to NH_3 in the liquid and gaseous phases (Mulvaney and Bremner, 1981). For instance, an increase in temperature from 45°F to 60°F (7°C to 16°C) can double volatilization loss when moisture content is kept the same (Ernst and Massey, 1960).

Wind: Ammonia loss rate increases linearly with wind speed (Leuning *et al.*, 1984). High wind speed enhances ammonia volatilization rate by promoting the rapid transport of ammonia away from the soil or flood water surface. Denmead *et al.* (1982) explained that at higher wind speeds, the enhanced volatilization was due to better mechanical mixing of the N solution, which replenished ammonia at the water surface.

Soil moisture: Soil moisture content is a major factor of ammonia loss in the paddy system since the presence of water is the first condition for the applied urea dissolution as well as hydrolysis. Volatilization of surface applied urea increases linearly as soil water content increases until the soil reaches saturation (Al-Kanani *et al*., 1991). Ferguson and Kissel

(1986) showed through incubation studies that ammonia loss did not occur when moisture content for urea hydrolysis is too low. Therefore, extreme soil moisture content to flooding conditions that prevail in paddy soil makes vulnerable these soils to high ammonia losses when N-fertilizers are apply (Ferguson and Kissel, 1986).

***Soil organic matter content*:** High soil organic matter content increases urea hydrolysis rates and volatilization (Rochette *et al.*, 2009) because urease enzyme is released by organic matter. Organic matter induces higher soil pH which in turn increases ammonia in solution. Organic matter increases moisture holding capacity of the soil, which also increases ammonia in solution for volatilization. However, soil organic matter can prevent N ions from movements in the soil and therefore reduce their vulnerability to losses (McInnes *et al*, 1986).

- ***Environmental impacts of N-ammonia loss***

Ammonia has been known to drive important atmospheric chemical processes. Once released into the atmosphere, ammonia is returned to the soil as either gaseous ammonia or ammonium ion. The ammonium ion can combine with nitrate, sulfate, nitric acids and incorporated into aerosol or be part of the ionic mix found in cloud and raindrops (Azam *et al.*, 2002; Reeves *et al.*, 2002). Aerosols and smog formed contribute to significant respiratory and cardiovascular problems for human being and animals (Gay and Knowlton, 2009).

Deposition of emitted NH_3 on natural ecosystems also results in several biological and chemical disorders (Stevens *et al.*, 2004). Transport and deposition of ammonia emitted from agricultural systems cause enrichment in N nutrients known as eutrophication in terrestrial and aquatic systems (Matson *et al.*, 1997). Eutrophication in turn induces undesirable effects as proliferation of aquatic algae and macrophytes leading to depletion of the dissolved oxygen in the water body followed by decreasing of water clarity and quality. As a consequence, ammonia deposition affects species diversity and predator-parasite systems **(**Reeves *et al*., 2002).

- ***Ways of Reducing Ammonia Volatilization***

There are several ways to reduce ammonia volatilization in the soil-water system. These include application of soluble salts of calcium, potassium, and magnesium, the use of urease inhibitors and coated fertilizers; deep placement of nitrogen fertilizers; and use of modified forms of urea. These strategies are described in detail at the section 2.3.2.

2.4.3.2. Ammonium-N and nitrate-N leaching

Nitrate, as well as ammonium is lost through leaching out of rice root zone. However, nitrate-N is the easily lost form because of its negative charge. NH_4^+ is positively charged and can be adsorbed by soil mineral particles and organic compounds. The nitrate leaches with percolated water through the soil and joins the grandwater (Velu and Ramanathan, 2001; Xing and Zhu, 2000). The amount of fertilizer N leached varies depending mainly on the soil properties and the fertilizer application practice (Choudhury and Kennedy, 2005). Marko *et al*. (2002) reported that more than 98% of N leached was in NO_3^- form.

- ***Environmental Pollution Impact of NO_3^-***

The product of nitrification (NO_3^-) is highly mobile in soil matrice, and thus can be readily leached downward and pollute groundwater. Excessive N concentration of nitrate in the drinking has been recognized to cause methemoglobinemia or blue baby syndrome, abortions in women and increased risk of non-Hodgkin’s lymphoma (Ward *et al*., 1996). Moreover, the nitrate ions can be converted into nitrosoamine causing hypertension or gastric cancer (Phupaibul *et al*., 2002). Drinking water containing more than 10 mgL^{-1} of NO_3^- is considered as toxic for human consumption (Shrestha and Ladha, 1998).

When nitrate and nitrite contaminated groundwater is used for irrigation, the accumulated nitrate can be returned into the food chain through plant uptake. Consumption of excessive nitrate contaminated food is also reported hazardous.

- ***Ways to reduce the N-leaching***

Strategies to limit NO_3^- and NH_4^+ leaching comprise those of reducing ammonia volatilization in order to slow the free ammonium ion that is the precursor of the nitrification processs. In addition, nitrification inhibitors (as dicyandiamine: DCD and Nitrapyrin) are used to reduce NO_3^- formation process (See section 2.3.2.3). Puddling of the rice fields are also ways of reducing leaching losses (Keeney and Sahrawat, 1986; Rao and Prasad, 1980). Catch crops of deeper root can be grown in the transition period of two crops of rice to reduce fertilizer N leaching. These deep rooted crops can uptake nitrate from deep soil layers and therefore prevent NO_3^- leaching. Shrestha and Ladha (1998) reported the effectiveness of maize as catch crop in scavenging soil residual N for decreasing nitrogen leaching of rice root zone. Leaching of fertilizer N is driven by water. Thus increasing water use efficiency in rice cropping system can significantly limit NO_3^- leaching (Keeney, 1982).

2.4.3.3. Denitrification emissions

Nitrous oxide (N_2O), Nitric oxide (NO), and nitrogen gas (N_2) are series of products formed from denitrification process. They escape in gaseous form from the soil system to the atmosphere. The amount of N emission from denitrification varies with the type of soil. Zhu *et al*. (1989), estimated denitrification loss when urea was applied to a calcareous paddy soil and recorded an amount of denitrification loss of 33% of the applied N. On the same type of soil, similar amount of 37% was obtained by Cai (1992) in acid paddy soil.

- ***Environmental Pollution Impact of N_2O and NO emission***

Nitric oxide contributes to destroy tropospheric ozone. It is a major atmospheric pollutant that affects human health, agricultural crops, and natural ecosystems (Chameides *et al*. 1994; Matson *et al*., 1997). Nitric acid is derived from nitric oxide constitutes a principal component of acid deposition (Kennedy, 1992). Nitrous oxide too contributes to the greenhouse warming and the depletion of the stratospheric ozone layer (Bohlool *et al*., 1992). Nitrous oxide has a long half-life in the atmosphere, and is considered to have 300 times the global warming impact of CO_2 (Baggs *et al*., 2002).

- ***Ways of reducing denitrification losses***

In the nitrogen transformations in oxidized soil system, free ammonium ion is readily converted to nitrite, then to nitrate through the nitrification process followed by denitrification of the nitrate leading to nitrous oxide, nitric oxide and N_2 formation. So if the urea hydrolysis and nitrification are delayed or reduced, the denitrification loss will be reduced. Therefore, denitrification can be reduced by using coated-urea, urease and nitrification inhibitors (Keeney, 1982) and N-fertilizer management practices like urea deep placement (Ding *et al*., 2002; Savant and Stangel, 1990). Application of plant residues having high polyphenol content and high protein binding capacity may reduce nitrous oxide emissions (Baggs *et al*., 2002).

2.4.3.4. Runoff

Applied N losses can occur with erosion and runoff water. High surface runoff water can drain with dissolved applied urea or ammonium based fertilizers. Therefore, limiting surface runoff can reduce applied N loss by runoff. Measures such as fertilizer incorporation into soil and conservation tillage can reduce soil erosion and runoff, resulting in low loss of N (Leary *et al*., 2014).

2.5. Nitrogen Use Efficiency

2.5.1. Definition

Nitrogen use efficiency (NUE) is a very important concept for evaluating crop production systems. It is an index in determining the ability of plants to absorb and utilize nitrogen for growth and yields (Baligar *et al*., 2001). Fageria (2013) also defined nitrogen use efficiency as an approach in evaluating the fate of applied nitrogen fertilizers and its role in improving crop growth and yields.

In agronomic research, various indices are commonly used to assess the efficiency of applied N mainly for purposes that emphasize crop response to N (Novoa and Loomis, 1981; and Cassman *et al.*, 2002). The objective of Nitrogen use efficiency is to increase the overall performance of cropping systems by providing economically optimum nourishment to the crop while minimizing losses from the field and supporting agricultural system sustainability through contributions to soil fertility or other soil quality components. The N use efficiency addresses some, but not all aspects of that performance (Mikkelsen *et al.*, 2012). The most valuable NUE improvements are those contributing to overall cropping system performance (Fixen *et al*., 2012).

In field studies, Nitrogen use efficiency is either calculated based on differences in crop yield, or total N uptake with aboveground biomass between fertilized plots and an unfertilized control to estimate crop and soil recovery of applied N. However, measurement of NUE requiring careful experimentation and interpretation must consider potentially confounding factors (Dobermann, 2005).

A multitude of expressions and measurements have evolved to meet the needs of this diverse set of circumstances and all are commonly referred to as NUE. To be appropriately interpreted, the specific method used must be stated (Fixen *et al*., 2012). Dobermann (2007) published a review paper on the measurement and calculation methods of six common Nutrient use efficiencies. He stated these NUE terms and brought out their primary questions addressed, their applications and limitations. Earlier on, Baligar *et al*. (2001) suggested five common definitions and methods of calculating NUE in crop plants. They are described as follows:

(i) ***Agronomic efficiency*** **(AE)** is calculated as the difference in grain yield between the N fertilized and no N fertilized plots over the applied N rate. It constitutes the units of grain yield increase per unit of nitrogen applied. It reflects the direct production impact of an applied N-fertilizer.

(ii) ***Physiological efficiency*** **(PE)** is defined as the total biomass yield (grain and straw) increase in relation to the increase in rice N uptake. It helps to address the ability of the rice to transform the uptake nitrogen into economic yield.

(iii) ***Agrophysiological efficiency*** **(APE)** is defined as the difference in grain yield between the fertilized and the unfertilized plots over the difference in N uptake of the fertilized and the unfertilized plots.

(iv) ***Apparent recovery efficiency*** **(ARE)** is the difference in nutrient uptake in above-ground parts of the plant between the fertilized and unfertilized crop relative to the quantity of nutrient applied.

(v) ***Utilisation efficiency(UE) is the PE x ARE***

Regarding the above definitions it appears that NUE is a complex term involving more than one component. In this study the agronomic efficiency (AE), the recovery efficiency (RE) and the physiological efficiency (PE) that are indicated by Ladha *et al.*, (2005) would be used.

2.5.2. Improvement strategies of nitrogen use efficiency

The low NUE observed in cropping systems especially in paddy field is mainly attributed to losses of applied N-fertilizers through various pathways. Thus improving NUE implies the use of appropriate ways to reduce ammonia volatilization, nitrification and denitrification, leaching and runoff of applied N in the paddy system. Various management methods of N-fertilizer management as sources, rates, deep placement, split application, the use of modified forms of urea as coated-urea and urea supergranule, urease and nitrification inhibitors are used to improve NUE. Each strategy is described in detail in the following section.

2.5.2.1. Fertilizer management

- ***N source***

Nitrogen source is an important factor to limit N losses and increase N recovery by crops. Rice is mostly produced under redox conditions, thus, the source of nitrogen should be ammonium or ammonium containing fertilizers (Dillon *et al*., 2012). The reason behind is that, N-NH_4^+ is more stable in the reduced paddy soil and is in preference to NO_3^- for N uptake by rice plant.

- ***Judicious N-fertilizer rates***

Nitrogen dynamics in soil is very complex and a strategy of minimizing losses is to avoid its high concentration in the soil system. Many studies focused on the determination of rates and reported that above an optimal rate, NUE decreases. Kurtz *et al*. (1984) reported decrease in N uptake by rice with increased N rate application. Eagle *et al*. (2000) justified the decrease of nitrogen use efficiency by the increase of N supply. Similarly, Fageria (2013) pointed out that low nitrogen use efficiency indicates that N losses exceed the rate of rice N uptake or rice could not absorb or utilize N at high rate.

- ***Split N fertilizer rates***

Importance has been given to the need for good synchrony between rice demand of N and N-fertilizers supply throughout the rice cropping (Appel, 1994). The synchrony approach is justified by the fact that N losses increase with the amount of available N present in the soil system in a given time. Therefore, a good way of reducing losses and increasing N-fertilizers efficiency is to split the total required N rate into two or three applications. The practice of split N rates allows the synchronization of N application to the real time demand by the crop. Investigations have been made to find out the most suitable method for splitting nitrogen fertilizer application. Earlier studies indicated that increase of rice productivity depends widely upon the effect of N application at panicle initiation stage on certain yield components (Russo *et al*., 1991). Recently, investigations have indicated that three time N application, rather than two, is a more suitable practice to improve NUE of rice (Moletti *et al*., 1992). However, split N application recommended to increasing NUE doesn't always suit rainfed lowland rice because of adverse soil–water situations (Mohanty *et al*., 1999)

- ***N-fertilizers incorporation into soil***

Incorporation of urea into the soil is known to decrease ammonia loss compared with the surface broadcasting application (Padilla *et al*., 1990; Son and Buresh, 1993). Sommer *et al*. (2004) stated that incorporation of the N-fertilizer into the soil is the most common mitigation way of reducing NH_3-N loss. De Datta (1978) found that basal incorporation of N-fertilizer with the last harrowing rather than broadcast application at 10 to 21 days can substantially reduce N losses and increase grain yield. Rochette *et al*. (2014) summarized results of some laboratory/greenhouse experiments and reported that reductions in volatilization after incorporation to depths greater than 2.5 cm varied from 14 to 72% when urea was mixed into soil, from 27 to 66% when urea was applied uniformly at a given depth, and from 32 to 100% when urea was subsurface banded.

2.5.2.2. Use of slow release urea

- ***Coated urea***

The principle is coating urea with substances to ensure that urea is released over an extended period of time. The goal of fertilizer coatings is to slow the rate at which the urea granules dissolve, and hence reduce losses. The use of slow-release urea as well as nitrification and denitrification inhibitors is included in the techniques of Enhanced-Efficiency N-fertilizers: EENF (Stewart, 2008).

The most known coating element is sulphur. The product is called Sulfur-Coated Urea (SCU) where granules of urea are coated with varying thickness of sulphur. When SCU is applied to the soil, soil microorganisms oxidize first the coating sulphur allowing the urea to dissolve and hydrolyse (Jones *et al*., 2007). Earlier research proved that the reducing of ammonia volatilization of coated urea was superior to the prilled one (De Datta, 1985; Keeney, 1982).

Polymers are also used to coat urea. They act as a semi permeable membrane allowing diffusion of water toward the inside granule to dissolve and undergo hydrolysis. Polymer coating mechanism is different from that of sulphur-coating. The rate of release of polymer coated and its and agronomic effectiveness are affected by the solubility of the polymer, soil temperature, moisture, microbial activity, texture, organic matter, etc. (Christianson *et al*., 1988) and the choice of polymers that is made to match the desirable rate to specific crop demand (Jones *et al*., 2007). Combined with slower urea release, polymer coated urea reduces volatilization compared to conventional urea (Rochette *et al*., 2009). Xin *et al*. (2017) compared the release pattern of sulphur coated urea and polymer sulphur coated urea (PSCU) and reported that the release rate of PSCU was higher than the SCU in the laboratory and in the field as well.

Advantages of coated urea in the improvement of nitrogen use efficiency in rice cropping are well established but their use is not well adopted because of its relatively high cost. However, improvement on the technology of coating urea has lowered the cost of coated urea these days. But still, current polymer coatings may add 20% to the cost of urea.

- ***Urease inhibitors***

Urease inhibitors are one class of compounds that prevent the conversion of urea to NH_4^+. Inhibitors accomplish a reduction in NH_3 volatilization by slowing the rate of urea hydrolysis (Norman *et al*., 2009). Their use can help to delay hydrolysis of urea for 2 to 10 weeks (Jones *et al*., 2007). They allow urea to move into the deeper soil layer before hydrolysis and the ammonium released is then adsorbed by cation exchange complex of the soil (Freney *et al*., 1995).

Ordinary known and tested urease inhibitors are phenylphosphorodiamidate (PPD), N-(n-butyl) thiophosphoric triamide (NBPT), hydroquinone, phenylendiamine (Choudhury and Kennedy, 2005). Urease inhibitors properties of some products such as some benzoquinones thiourea,, 2–4 dinitro phenol, and boric acid were also reported (Bayrakli, 1990). Some results on the effect of the above mentioned urease inhibitors are as follows:

Rawluk *et al*. (2001) reported that ammonia volatilization loss was decreased by 28–88% due to NBPT. Laboratory and field experimental results demonstrated that application of urease inhibitors like hydroquinone and phenylendiamine increased agronomic efficiency of urea-N due to reduced ammonia volatilization loss in flooded rice soils (Abdel-Bary and Metwally, 2001). However, in a review article on urease inhibitors, Byrnes and Freney (1995) reported that application of phenyl phosphorodiamidate (PPDA) significantly increased rice grain yields in only two out of eight flooded-field rice trials. One of the reasons that users adduced was a rapid degradation of PPDA due to high pH or temperature of flooded water. Results of the test of NBPT on grain yield were not also consistent (Chien *et al*., 2009). Increased yield with NBPT were obtained by Norman *et al*. (2009) while Freney *et al*. (1995) and Aly *et al*. (2001) obtained no significant difference effect of NBPT compared to the conventional urea. Phongpan and Byrnes (1990) also reported similar results. Experimental results at the International Rice Research Institute (IRRI) revealed that addition of the urease inhibitor PPD along with urea reduced the ammonia loss by 12–22 kg N ha^{-1} (De Datta ,1985). The beneficial effects of other urease inhibitors (thiourea, hydroquinone, 2–4 dinitro phenol, and boric acid) were also reported (Bayrakli, 1990).

2.5.2.3. Use of Nitrification inhibitors

A potential tool to improve NUE and crop yield is nitrification inhibitors (Ferguson *et al.*, 2003). Nitrification inhibitors are chemicals that limit or cancel the conversion rate of ammonium to nitrate. These products affect the activity of nitrifying microorganisms (eg. *Nitrosomonas*) by inhibiting ammonium oxidation so that no nitrite is formed in the soil (Fageria, 2013).

Many chemical products have nitrification inhibiting properties but the most commonly known are DCD (dicyandiamide 65%N, $C_2H_4N_4$), Nitrapyrin (2-chloro-6-trichloromethyl) pyridine, and the 3,4-dimethylpyrazole phosphate: DMPP (Trenkel, 1997). Iron pyrite, phenylacetylene, encapsulated calcium and carbide are also used as nitrification inhibitors (Carrasco *et al.*, 2004; Blaise *et al.*, 1997).

Greatest benefit of nitrification inhibitors have been reported on coarse-textured and waterlogged soils (Fageria and Baligar, 2005). Also, beneficial effects of nitrification inhibitors are frequently observed at suboptimal N rates (Cerrato and Blackmer, 1990).

2.6. Technology of Urea Deep Placement (UDP)

2.6.1. Origin

Urea deep placement (UDP) is a technology based on the historical Japanese concept of deep placing N-fertilizers that aimed to reduce ammonia loss, denitrification, leaching and runoff of applied N to crops. From 1975; the International Fertilizer Development Centre (IFDC) proposed the use of Urea Supergranule (USG) instead of mudballs containing urea fertilizer to reach the same reduction of N losses and rice crop performances as achieved by Japanese way of deep placement of N-fertilizer (Savant and Stangel, 1990). The use of USG known as Urea Deep Placement (UDP) technology had been developed after 20 years research of IFDC with farmers, particularly in Bangladesh (IFDC, 2013). Although UDP has been known many years ago, its adoption was limited because of the unavailability of the USG material. This availability constraint has been remedied in Bangladesh in 1996 with the installation in several locations of some briquette machines capable of compressing the ordinary prilled urea of 3 mm diameter into larger size USG of 11 to 15 mm diameter. Farmers access to USG increased the adoption of UDP that resulted in significant improvement of rice productivity and saving of urea over the conventional broadcasting practice of prilled urea (Roy and Hammond, 2004). With regards to these advantages, the UDP technology had been extended to other Asia countries like India, Indonesia and Pakistan, and is being introduced in to Africa especially in Sub-Saharan Africa this last decade (Roy and Hammond, 2004).

2.6.2. Principle

The aim of UDP is to reduce N losses and therefore increase NUE and in turn, to improve rice productivity. It is established that, to reduce N losses via volatilization and leaching following N-fertilizer application to lowland rice, urea should be applied in the reduced layer of the soil to ensure availability of ammonium to rice plant (Gaudin, 1991; Fageria, 2013) and reduce nitrification.

According to IFDC (2013), UDP technology consisted of two key components. The first is to make available to farmers the USG obtained by converting the conventional Prilled Urea (PU) into the supergranules (USG) using briquette machine. The second key component is the deep placement at 7 to 10 cm of the USG material in the reduced zone of the paddy field. The reason for converting PU into USG is to facilitate its insertion into soil by hand (Chien *et al.*, 2009)**.** Once USG is deep placed by hand or applicator at the centre of four rice hills about 10 days after seedling transplanting **(**Savant and Stangel, 1990). In this technology, USG is applied only once for the crop season contrary to the PU that requires 2 to 3 or more applications (Rahman and Barmon, 2015). The deep placed USG releases gradually ammonium coinciding with the rice need over the growing season (IFDC, 2013).

2.6.3. Advantages associated with UDP technology in rice production.

Agronomic, economic, and environmental advantages of Urea deep placement technology are well established and documented. Deep-point placement of USG in anaerobic soil layer is reported to significantly reduce the N concentration in floodwater and in the oxidized surface layer. It reduces N losses through runoff, ammonia volatilization, and denitrification. It also reduces weed competition in the use of applied nitrogen by the rice crop, allows continuous N availability along the growing season. The use of USG improves rice yield components and yields (Savant and Stangel, 1990) and stimulates biological N fixation (Roger and Watanabe, 1986).

At agronomic point of view, the superiority of USG over PU has been reported in many investigations. Wani *et al*. (1999) stated that in rice production in India, USG induced higher

NUE and gave the best grain yield enhancement (9.5% to 33.8%) compared with some slow-release fertilizers and other modified sources of urea. Field investigations using ^{15}N labeled urea conducted at IRRI showed that N recovery with USG use was 65-96% against 32-55% for the conventional practice of PU broadcasting (Schnier, 1995). In Taiwan, Wang (2004) compared the effect of USG with urea top dressing on rice and reported that the use of USG promoted N uptake, high dry matter production, and high grain yield of rice compared with the conventional prilled urea application.

In Bangladesh, Bowen *et al*. (2005) reported average increased grain yield of 1120 kg ha^{-1} and an N saving of 70 kg ha^{-1} for USG use over farmers practice during winter season. The Bangladesh Rice Research Institute (BRRI) also noted the effectiveness of N loss reduction of 20-25% with the use of USG (BRRI, 2000). Improvement of 22.03% of rice grain yield of USG use over the conventional urea practice was also reported by Hasanuzzaman *et al*. (2009) in Bangladesh.

In the field laboratory of Bangladesh Agricultural University at Mymensingh Kabir *et al*. (2009) compared the effect of USG, PU and poultry manure on rice and reported that USG induced higher grain yield than PU while poultry manure produced similar grain yield with USG. In the same laboratory, experiments showed that up to 31.25% of urea was saved while using USG of 1.8g combined with other organic fertilizers (Naznin *et al*., 2013).

Investigations on the efficiency of USG had been also done in some countries of sub-Saharan Africa. In the Niger State of Nigeria, Tarfa and Kiger (2013) reported that NUE of UDP technology was increased by 40% and rice yield by 20-30%. In Burkina Faso, Bandaogo (2014) conducted a field work in Sourou valley and reported similar results of USG superiority over PU in terms of rice yield. Results also indicated significant increase of rice-N agronomic efficiency by 39.43 % and physiological efficiency by 24.23 % of USG over

PU. Similar trends of rice yield and yield components increment were also reported by Cisse (2011) on two different farmers paddy fields in Burkina.

In the Valley of Zio in Togo, Yaosse (2009) compared yield and yield parameters of rice with application of USG versus PU on three textural type of soils. He reported high increased yield of UDP on clay and sandy-clay-loam soil over prilled urea while on sandy-loam soil, no difference was obtained between USG and PU treatments.

Economically, experimental results indicated that saving of urea up to 40% can be made for the same rice grain yield compared with the usual broadcasting technique of urea application (Yamada *et al*., 1979; Kumar *et al*., 1989). Pasandaran *et al*. (1999) also reported that UDP technology showed urea rate saving of 25% and an average increase of 400 kg in rice yield in Indonesia. In a field study in Togo, Yaosse (2009) analyzed the economic benefit of UDP with the Value Cost Ratio (VCR) method. He reported that, VCR was higher for USG treatments (3.16-5.28) in all types of soils including the sandy loam than the PU treatment (2.46 to 4.1) indicating that USG use was economically more efficient compared with UP.

Besides the positive agronomic and economic impacts, UDP largely contributes to reduce the negative impacts of N-fertilizers use in the environment by reducing significantly N losses from the paddy field. UDP is reported to reduce runoff of N-fertilizers due to the negligible amount of N measured in floodwater while broadcasted and incorporated prilled urea continued to generate high amount of nitrogen in the floodwater (IFDC, 2013). Savant and Stangel (1990) indicated that, USG use contributes greatly to reduce N concentration in floodwater, and therefore reduce N in the runoff water so that it does not constitute a potential eutrophication concern. UDP reduces also nitrification-denitrification processes and contributes to reduce nitrous oxide emission in the atmosphere because placement forces

USG in the oxygen depleted layer, and thus nitrification is avoided and nitrous oxide emission is drastically reduced (IFDC, 2033).

Few research works have been done on USG use on upland crops. This is probably because of the difficulty of the deep placement of USG in a no well watered saturated soil. The test of USG on aerobic rice conditions was positive. A field micro-plot experiment conducted by Xiang *et al*. (2013), showed that USG deep placement increased grain yield of aerobic rice by 1.66 t ha^{-1} in continuous aerobic rice cultivation over the prilled urea . In a pot experiments study, the effects of different application methods of nitrogen indicated that N incorporation into soil and placement at a depth of 5-10cm of USG in the soil increased the vegetative growth parameters and grain yield of aerobic rice (Xiang *et al*., 2013).

The UDP had also been tested on other upland crops. On cabbage, Nazrul *et al*. (2007) found that application of USG at a depth of 8 cm at 10 days after transplanting gave the highest yields of 74,92 and 117,60 t ha^{-1} in two consecutive years. In Togo, Alfa-Toga (2011) reported no significant difference between USG and PU on yield and yield parameters of maize.

2.7. Summary of the literature review

From to the above literature review, it is evident that nitrogen is a key element for plant growth in general and rice production in particular. In almost all paddy fields, nitrogen is the major limiting nutrient and is required in large amounts compared with the other two major nutrients (phosphorus and potassium). Lack of N supply to rice crop is detrimental to the yield and grain quality.

Thus, rice farmers use more and more nitrogen fertilizers to sustain rice yield. In paddy fields, urea is the major N-fertilizer applied because of its high N concentration (46%) and its relatively low cost compared with all other N-fertilizers. However, low nitrogen use efficiency is recorded with urea under lowland rice system because its use is associated with many loss pathways, leading to negative environmental impacts. Losses are estimated up to 80% through ammonia volatilization, nitrate leaching, nitrous and nitrogen gas emissions, and as a result, rice Nitrogen Use efficiency is usually low.

To improve the use efficiency of N, it is important to find strategies to reduce N losses. Various techniques had been tested and among these are management practices such as incorporation of urea into soil by puddling, split application to synchronize the N-fertilizer supply to N demand of crop, the use of inhibitors or coating materials to slow urea hydrolysis or ammonium nitrification. The use of coated urea and inhibitors is characterized by limited adoption because of the high cost and are not known by small rice farmers in Africa.

In lowland paddy fields, the split method into two to three applications at different stage of rice growth is recommended. But as urea is still broadcasted in the oxidized layer of the soil system, losses remain very high. The use of Urea Surpergranules (USG), the compacted form of urea granular, known as Urea Deep Placement (UDP) technology is reported to have an advantage of improving nitrogen use efficiency of rice. UDP is reported to minimize applied N losses in paddy system and therefore mitigates negative environmental impacts, improves rice yield, saves the quantity of urea usage and reduces weed competition. Thus, UDP is a promising technology that is being promoted in African countries. The literature review indicated that in general, some aspects of the technology (such as its effect on ammonia emission) have not yet been investigated, particularly in Africa, little is known about this technology. Therefore, research on the UDP needs to be conducted to provide adequate data before a sustainable extension of the technology.

CHAPTER THREE

3.0. MATERIALS AND METHODS

3.1. Experimental sites and soils used

3.1.1 Soils used for the greenhouse experiment

The greenhouse experiment was carried at the SINNA Garden of University of Ghana, Legon using four paddy soil samples collected from Togo and Ghana. Soils from Togo were collected at Kovie and Mission-Tové in the valley of Zio, and those collected in Ghana were from the Soil and Irrigation Research Centre (SIREC) at Kpong and at Ashiaman irrigated scheme, all in the Accra Plaines (Figure 3 1).

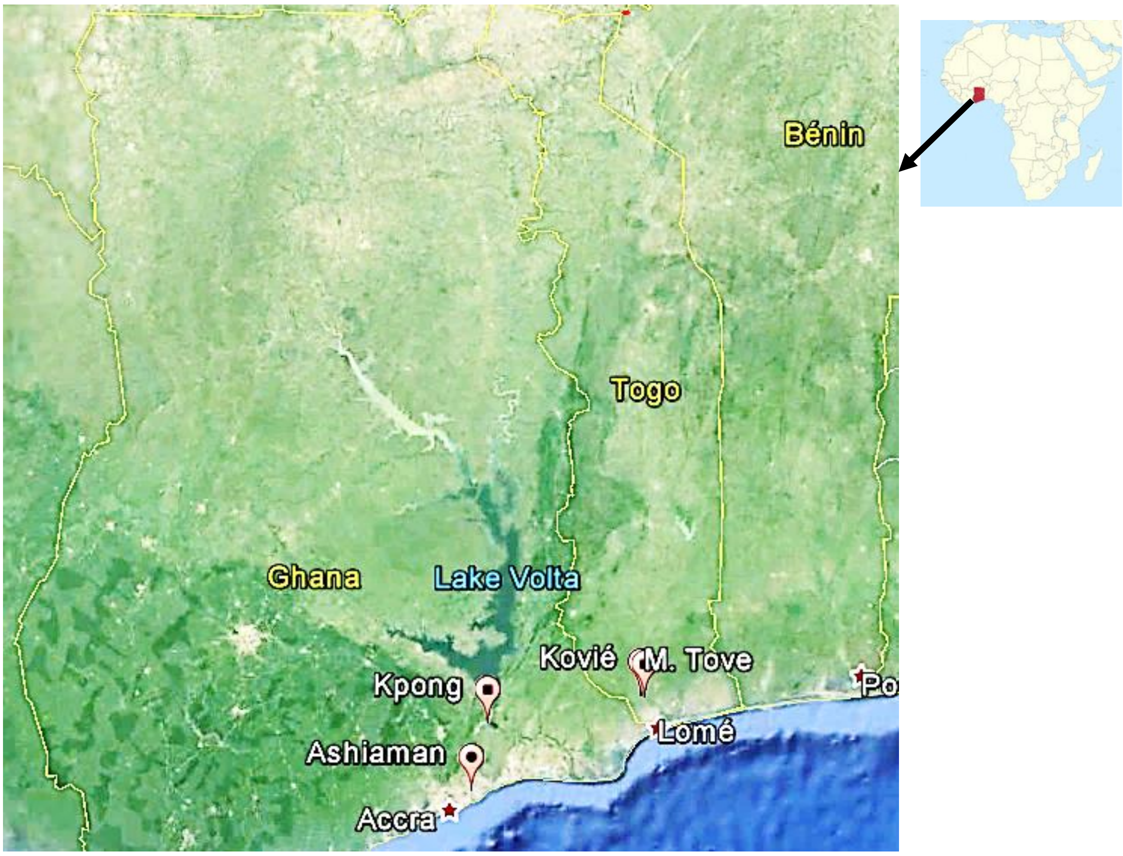


Figure 3.1 : Map showing soil sampling sites (Googlesatellite image, 2018)

The Zio valley is located at 22 km north of Lome in Togo. Soils within the valley were classified by Millette (1964) as Fluvisols. Soils from Mission-Tové belong to the Voudou series while those from Kovié belong to Canne series. These series are hydromorphic soil complexes on alluvial clayey and clay loam respectively.

Kpong is located within the lower Volta basin of the Coastal Savannah agro-ecological zone of Ghana (Figure 3.1). Soil and Irrigation Research Centre (SIREC) of University of Ghana where the soil sample was collected is located at latitude 6° 09 N, longitude 00° 04’ E and at an altitude of 22 m above sea level. Locally, the soil is tropical black clay classified as Akuse Series (Amatekpor *et al.*, 1993), and as Vertisols (Brammer, 1967). Vertisols are defined as deep black soils containing more than 30% clay, often dominated by 2:1 clay mineral (smectite and montmorillonites). Therefore, it changes in volume with soil moisture resulting in deep cracking when dried, and swelling and sticky when wet (Soil Survey Staff, 1996).

Ashiaman is located at the north-west side of Accra. The soil sample was collected at 05° 41’ 37’’ N, and 00° 02’ 03’’ E. Soils of the area were developed under Dahomeyan formation and classified as Bumbi series. It is found in valley bottoms and along lower slope margins of depressions. Bumbi series comprises deep, black and heavy clay in which calcium carbonate concretions are found below 70 cm (Asiamah, 1995). The soils are plastic and impervious when moist but hard and cloddy when dry. The soil is described as slightly acid to a depth of 45 to 60 cm above which it becomes neutral and alkaline (Brammer, 1960).

The soils from Togo and Ghana were all collected on fields being cultivated for two cropping seasons each year. Blanket fertilization rates ($N-P_20_5-K_2O$) applied were 76-30-30 in Togo (ITRA, 2010) and 88.5-42.5-42.5 in Ghana (as indicated by technicians of SIREC) using compound fertilizer NPK (15-15-15) and urea (46% N).

A total of 500 kg soil samples of each soil was randomly collected from the puddled layer (0-30 cm) and sent to University of Ghana for pot experiment. Sub-samples of these soils were air dried, passed through a 2 mm sieve and sent to analyse their initial physico-chemical properties.

3.1.2. Description of the field experimental site

The field study was conducted in the irrigated Valley of Zio-Togo in two consecutive cropping seasons in 2017 (March-July and August-November). The cultivated area for rice in the valley is estimated to be 1000 ha but the valley potentiality is more than 2000 ha. Irrigation has been made possible by a dam constructed on the Zio river in the Alokoegbe village.

3.1.2.1. Climate

The area of Zio Valley is located in the Coastal Savannah agro-ecological zone in Togo. The area is characterized by an average temperature of 26°C, average air humidity of 81% and average rainfall of 1100 mm (De Souza, 2000). The area also experiences two rainy seasons per year (Figure 3.2): the first rainy season (March-July) and the second one (September to November). The area experiences two trade winds that occur in the two dry seasons: The Harmattan (Saharan anticyclone) that brings dry air and dust from the Sahara desert and the second the Monsoon, which brings humid air from the Atlantic Ocean (southwest).

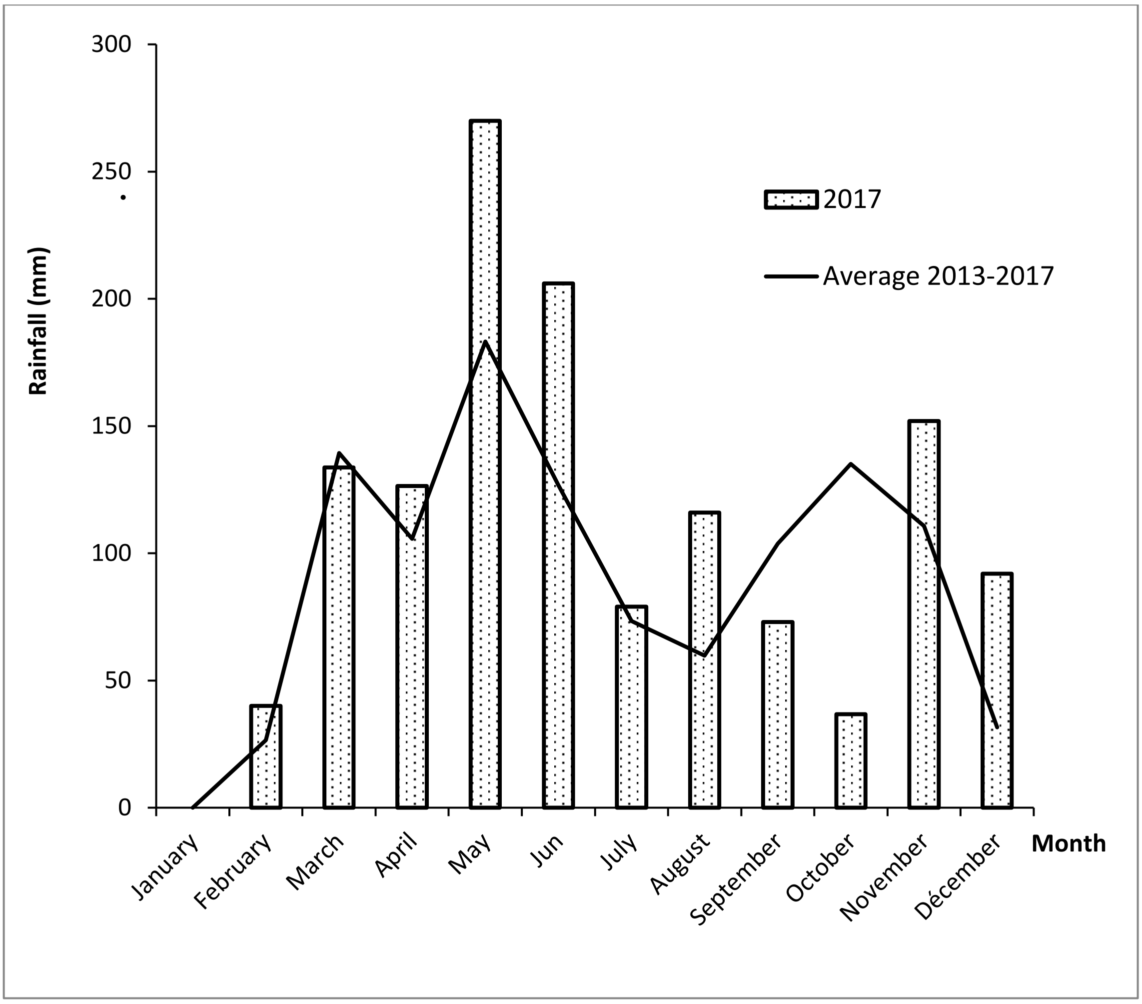


Figure 3.2 : Annual rainfall distribution in the valley (Source: ICAT Agence Golfe, 2017)

3.1.2.2. Soils

Soils of the area are of hydromorphic, clayey or clay sandy culluvio-alluvial soils and are as Fluvisols lying on Oxisols (USDA) or ferralsols (FAO/UNESCO). The major types of these soils were classified as Canne, Seme, Sio, Mono, Doukpo and Voudou series by Millette *et al*. (1964). Figure 3.3 shows the distribution of the soils in the area. The geology of area is of gneisses rocks of Proterozoic age.

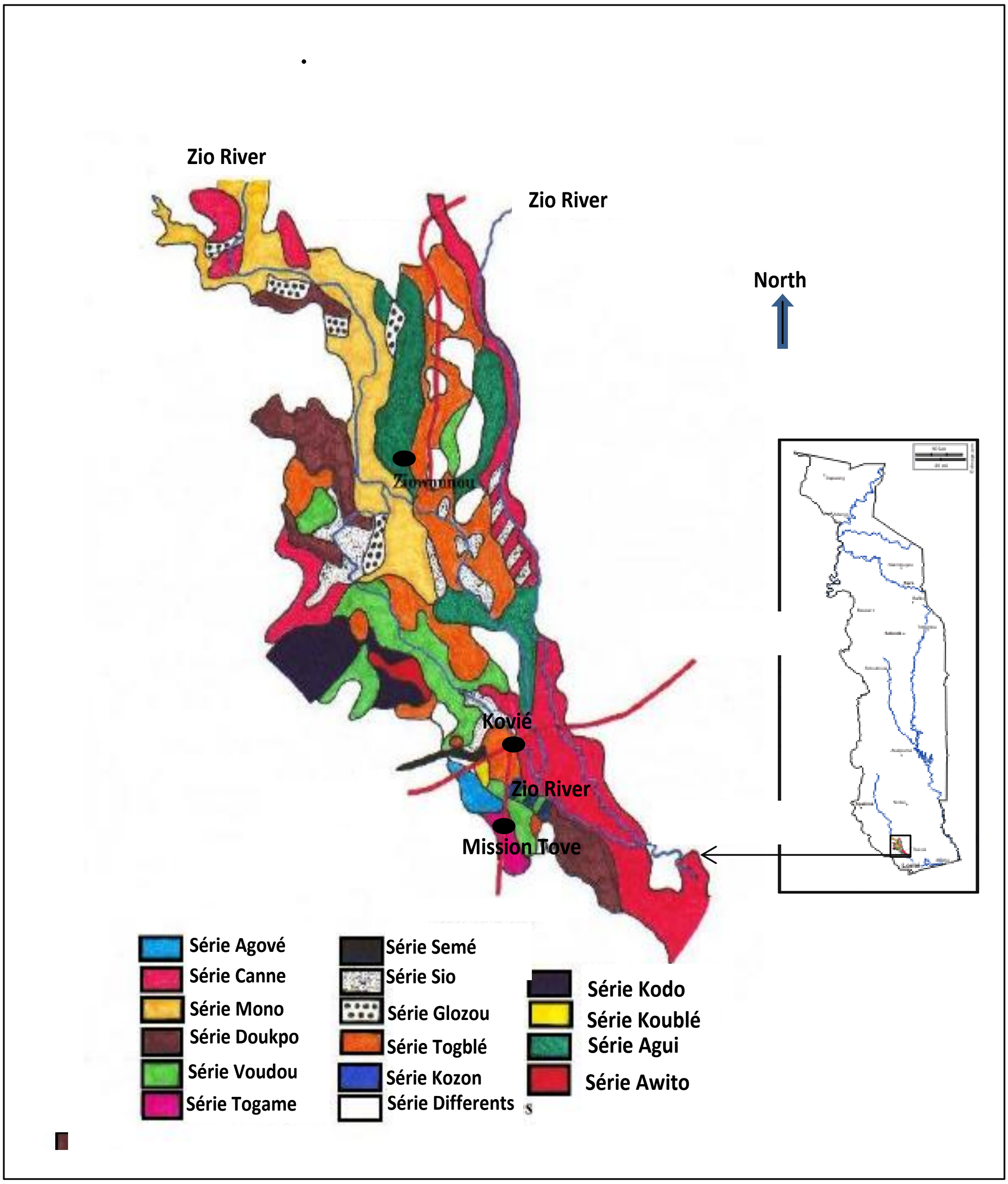


Figure 3.3 : Soil map of the irrigated Valley of Zio (Millette, 1964)

3.1.2.3. Rice production in the irrigated valley of Zio

The valley of Zio covers a total area of 2900 km^2 (De Souza, 2000). Basically, 600 hectares was under irrigated scheme for rice production up to 2013 before being increased to 900 ha by PARTAM Project.

Historically, the valley had traditionally been cultivated by farmers for rainfed lowland rice before successive contracts were signed by the government of Togo with Taiwanese (1965-1971), and Chinese (1972-1979) to develop irrigated rice production in the area. During these periods, the initial area of 18 ha cultivated with rainfed rice had been increased to 126 ha irrigated scheme by Taiwanese between 1965 and 1971, and to 350 ha by Chinese from 1972 to 1979. The traditional rice production system shifted from rainfed to irrigation with water pump and further to gravity irrigation system with the construction of a dam in 1980 by Chinese on the Zio River in the village of Aloekoegbe. Furthermore, several projects implemented by the government and NGO have promoted irrigated rice production in the area (Meertens, 2001). The current project, “Projet d’Amelioration des Terres Agricoles de Mission-Tové series (PAFRTAM)” had also worked from 2013 to 2015 to develop irrigated lowland rice area of 300 ha. With the irrigation production system, since the Chinese time in 1980, individual farmers have also developed private irrigated lowlands estimated to be 300 ha has made the total irrigated lowland scheme of Zio Valley to 950 ha (Meertens, 2001).

3.2. Soil and plant analysis

3.2.1. Soil analysis

3.2.1.1. Particle size

Modified method of Bouyoucos hydrometer method by Day (1965), was used to determine the soil texture of the soil samples. After sieving the soil sample (through a 2 mm sieve), forty grammes (40 g) were weighed into a dispersing bottle and hydrogen peroxide (1:1, soil: solution) was added to destroy the soil organic matter. Then, 100 mL 5% calgon (sodium hexametaphosphate (Na_3PO_3)) solution was added. The suspension was then agitated on a mechanical shaker for 2 h in order to disperse the soil into its various particles (sand, silt and clay). After shaking, the suspension was transferred into a graduated sedimentation cylinder and topped up to 1000 mL. After agitating vigorously with a plunger, the suspension was left to stand. Five minutes after, a hydrometer was immersed into the suspension and a reading (A) was recorded. This first reading corresponded to both silt and clay content. A second hydrometer reading (B) that corresponded to clay content only was recorded after 5 hours standing. After these readings, the decanted suspension was poured directly onto a 47 µm sieve to determine the sand content. The suspended residue was thoroughly washed with water to get rid of any clay and silt particles, and then transferred into a moisture can of known weight and dried in an oven at 105° C for 24 h.

The weight (C) of the oven dried sand was taken and the particle distribution of the soil sample was calculated with formula 3.1; 3.2 and 3. 3 below and the proportions of the different particles were used to determine the soil texture using the USDA textural triangle (Appendix 1).

$$\% \, Clay \quad = \frac{5 \; hours \; reading}{40} \times 100 \qquad [3.1]$$

$$\% \, Silt \; = \frac{5 \; minutes \; reading - 5 \; hours \; reading}{40} \times 100 \qquad [3.2]$$

$$\% \, Sand \; = \frac{Weight \; of \; oven \; dried \; sand}{40} \times 100 \qquad [3.3]$$

Where : A = 5 hours hydrometer reading;

B = five minutes hydrometer reading;

C = oven dried weight of the sand particles;

40 = weight in gramme unit of the sample.

3.2.1.2. pH

Soil pH was measured in 1:1 (soil : water) suspension using a glass electrode pH meter, model PL700-PV. Twenty grams (20 g) of the sieved soil sample was weighed in triplicate into beakers and 40 mL of distilled water was added. The suspension was then stirred continuously for about 60 min and left to stand for 15 min to allow particles to settle. After standardizing the pH meter with pH 4.0 and 7.0 solutions, the pH of the sample solution was determined by carefully introducing a Pracitronic MV 8 8 pH glass electrometer into the sample solution.

3.1.2.3. Organic carbon

Walkley and Black (1934) method was used to determine the organic carbon content of the soil samples. A 0.5 g sieved soil sample was weighed into an Erlenmeyer flask and 10 ml of 1 N potassium dichromate ($K_2Cr_2O_7$) solution and 20 mL of concentrated sulphuric acid (H_2SO_4) were added. The content of the flask was well swirled to ensure good contact of soil with the solution and the suspension was allowed to stand for 30 min for combustion. Distilled water (200 ml) was added to the suspension and allowed to cool.

The remaining dichromate in the suspension after oxidation of the organic materials in the soil was titrated against 0.2 N ferrous ammonium sulphate $Fe(NH_4)_2(SO_4)_2$ solution after 10 ml of 85% orthophosphoric acid and 1 ml indicator solution (barium diphenylamine sulphate) were added. A sharp colour change to green indicated the end point. A blank without any soil sample was used as control. The carbon content (%C) was computed as follows :

$$\% C = \frac{0.0033 \times (10 - DN) \times 1.33}{W} \times 100 \qquad [3.4]$$

Where: D = Titre value of ferrous ammonium sulphate solution (mL)

N = Normality of ammonium ferrous sulphate solution ($Fe(NH_4)_2(SO_4)_2$)

W = Soil sample weight of (g)

1.33 = Correction factor

0.003 = The milliequivalent weight of carbon (g) ($12/4*10^{-3}$)

3.2.1.4. Available Phosphorus

To determine available phosphorus, Bray I method (Bray and Kurtz 1945) was used for soils collected at Kovie (Canne and Seme series) and Mission-Tové (Voudou series) in Togo because their pH values were below 7.0 (5.6 and 6.3 and 5.9). Olsen method (1954) was used for Akuse series and Bumbi series because their pH values were above 7.0 (8.1 and 7.9).

3.2.1.4.1. Bray I method

Five (5) grammes of the sieved soil was weighed into an extraction bottle. Fifty (50) mL of Bray I solution (0.03M NH4F + 0.025M HCl) was added and the suspension was shaken with on mechanical shaker for 3 min after which, it was left to settle. The supernatant was filtered through a N° 42 Whatman filter paper into a 100 mL volumetric flask and topped up to the volume with distilled water. Five (5) mL aliquot (in triplicate) of the filtered solution was pipetted into a 100 mL volumetric flask. Similarly, a series of standard solution of 0, 1, 3, and 5 mg P L^{-1} were prepared by pipetting respectively, 0, 5, 15 and 25 ml of 20 mg P L^{-1} solution into labelled 100 ml volumetric flask and 50 mL Bray I solution was added, and the solution was made up to the 100 mL mark with distilled water. Ammonium Molybdate and ascorbic acid reagents were added for blue colour development. A blank solution without soil sample but containing all the reagents was used to calibrate the spectrophotometer in addition to the standards previously prepared.

The phosphorus concentration in the solution was measured by reading a resultant colour intensity using a UV-Spectrophotometer (Philips PU 8620) at a wavelength of 712 nm. An average value of the readings of the three replicates (R) was recorded and used to calculate the soil available P as follows:

$$P(mg\ kg^{-1}) = \frac{Spectrophotometer\ reading\ \times Volume\ of\ extract}{Aliquot \times Weight\ of\ soil\ sample} \qquad [3.5]$$

3.2.1.4.2. Olsen method

One (1) gramme of soil sample was weighed into an extraction bottle and 50 mL of 0.5 M $NaHCO_3$ solution was added and shaken for 30 min. The mixture was filtered through a Whatman No. 42 filter paper. An aliquot of 10 mL was taken, 10 mL sulphuric acid (H_2SO_4) was added and the mixture was centrifuged at 3000 rpm for 15 min. The concentration of the P in the sample was then determined after colour development using the Murphy and Riley (1954) method as described in section 3.3.1.4. The colour intensity was read on the UV spectrophotometer at a wavelength of 712 nm and the P was calculated using the formula in [3.5].

3.2.1.5. Total N

Total nitrogen was determined by the Kjeldahl (1883) method. A 2.0 g sieved soil sample was weighed into 300 mL micro Kjeldahl flasks. A 1.0 g of digestor accelerator (10 g of K_2SO_4 + 1.0 g $CuSO_4.5H_2O$+0.1 g Selenium) was added and about 1 mL distilled water was added to moisten the soil. Five (5) ml concentrated sulphuric acid (H_2SO_4) was also added. The mixture was digested on the digestor until the digest became clear. The digested solution was left to cool down, transferred into a 50 mL volumetric flask and made up to the volume with distilled water. An aliquot of 5 mL of the digested solution was collected into Markham distilled apparatus for distillation, a 5 mL of 40% NaOH solution was added and the mixture was distilled. The distillate was collected into 5 ml of boric (2%) acid to which were added two to three drops of a mixture of methyl red and methylene blue indicator solution. The distillate was titrated with 0.01 N HCl from green to an indicator reddish end point. Total nitrogen was calculated as follows:

$$\%N = \frac{N \ \times X \times 0.014 \times Volume\ of\ extratant}{W \ \times V} \times 100 \qquad [3.6]$$

Where: N = Normality of HCl

X = Titre volume of HCl (mL);

V = volume of aliquot used for the distillation (mL);

0.014 = Milliequivalent of Nitrogen;

W= Weight of the soil sample digested (g).

3.2.1.7. Extraction of Exchangeable Bases

Exchangeable bases (calcium, magnesium, potassium and sodium) in the soil were determined in 1.0 *M* ammonium acetate extract (Black, 1986). Five grammes (5 g) of the soil sample was weighed into a 200 mL extraction bottles and fifty (50) mL of 1 M ammonium acetate (NH_4OAc) solution buffered at pH 7.0 was added. The bottles were covered and the samples shaken on a reciprocating shaker for 1 hr. The suspension was filtered through a filter paper (No. 42 Whatman). The concentrations of the basic cations (Ca, Mg, K and Na) in the filtrate were read on an atomic absorption spectrometer (AAS). The AAS was calibrated with existing standards for Ca, Mg, K and Na, respectively and the absorbance for each element noted. Exchangeable bases were calculated as follows:

$$X(Cmol_c kg^{-1}) = \frac{R \times Volume\ of\ extract \times 10^{-3}(g) \times\ 10^{2}(cmol) \times E}{Weight\ of\ soil \times 10^{6}\ x\ (\mu g) \times M} \qquad [3.8]$$

Where X = Basic cation

R = AAS (Atomic absorption spectroscopy) reading in mg L^{-1}

E = Charge of basic cation

M = Atomic mass of basic cation

3.2.1.8. Cation exchange capacity (CEC)

After filtration of the digested soil sample in section 3.2.1.6, the residues were immediately leached with four portions of 50 mL methanol into an empty plastic bottle and leached again with 50 mL portion of acidified 1 M KCl. A 5 mL aliquot of the leachate was pipetted and transferred to Kjeldahl flask; 5 mL of 40% NaOH was added and then distilled into a 5 mL of 2% boric acid. The distillate was titrated against 0.01 N HCl and the soil sample's CEC in cmol kg^{-1} was calculated as the ammonium ion concentration in the filtrate using equation 3.6 in section 3.2.1.5.

3.2.2. Nitrogen (N) content of rice straw and grain

For nitrogen concentration in rice straw and grain, 0.2 g of the milled sample was weighed into a 250 mL volumetric flask and 5 mL concentrated sulphuric acid (H_2SO_4) was added. The mixture was immediately swirled to allow good contact of the plant sample with the sulphuric acid. The mixture was left overnight to allow dissolution of the plant sample by the acid. Thereafter, the solution was heated and drops of hydrogen peroxide (H_2O_2) were added while heating until a completely clear solution was obtained. The digested plant sample was cooled by adding distilled water. The solution was poured into a 100 mL volumetric flask and made up to the volume with distilled water.

A 5 ml aliquot of the digest was pipetted into a Markham distillation apparatus. A 5 mL of 40% NaOH was added and the mixture distilled. The distillate was collected into a 50 mL Erlenmeyer flask containing 5 mL 2% boric acid that received earlier some drops of a mixing solution of red and methylene blue prepared as indicated in section 3.2.1.5. The distillate was then titrated against 0.01 M HCl solution. The concentration of nitrogen in the plant sample was calculated using the equation 3.6 in the section.

3.3. Experimentations

3.3.1. Experiment 1 : Ammonia loss and nitrogen use efficiency of rice under different depths of urea supergranule application in the selected paddy soils

3.3.1.1. Experimental design

A pot experiment was carried out in the Sinna Garden at the University of Ghana to assess ammonia loss and nitrogen use efficiency under different depths of urea supergranule (USG) application. A randomized complete design (RCD) layout with three replicates was used. Two (2) factors were studied. The first factor was the type of paddy soil at four levels: Akuse and Bumbi series (collected at Kpong and Ashiaman in Ghana) and Canne and Voudou series (collected at Kovie and Mission-Tové in Togo).

Table 3.1 : Description of the different type of urea

Treatments		Description
A	Ctl	Control without any N-fertilizer application
	PU	Prilled Urea (conventional Urea) applied at soil surface
	USG 0cm	Urea Supergranule applied at soil surface
B	USG 4cm	Urea Superganule placed at 4 cm depth
	USG 8cm	Urea Superganule placed at 8 cm depth
	USG 12cm	Urea Superganule placed at 12 cm depth
	USG 16cm	Urea Superganule placed at 16 cm depth

The second factor was the type of urea with 7 levels. It included a control (without any N-fertilizer application), the recommended mode of prilled urea (PU) and the application of USG applied at the soil surface and at four different depths: 4, 8, 12 and 16 cm (Table 3. 1). The PU and USG were applied at the same rate of 1.8 g pot^{-1} (equivalent of 52 kg N ha^{-1})

3.3.1.2. Pot preparation and rice transplanting

Rice seed used was the IR-841 variety bred by IRRI in 1973. The seeds were obtained from the Institute of Agricultural Research in Togo (ITRA). The cycle duration is 120 to 130 days, with an average yield of 5 tons per hectare on farmers' field (MAEH, 2015). Nursery was done in plastic pots and seedlings were transplanted at 21-day old. Plastic pots of 40 cm diameter at the top and 30 cm high of 35 L capacity were filled with 30 kg of soils leaving a height of 3 cm for flooding. The pots were flooded for 3 days and puddled by hand the day before rice transplanting. Each pot received four hills of seedling at transplanting at a planting spacing of 20 cm x 20 cm (Figure 3.4).

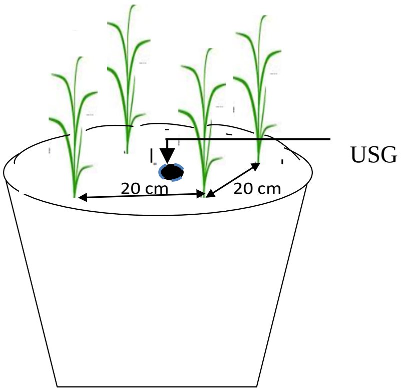


Figure 3.4 : Rice transplanting and USG placement in the pot

3.3.1.3. Fertilizer application

Triple Super Phosphate (TSP; 46% P_20_5) and Muriate of Potash (MOP, 60% K_20) were applied as basal fertilizers based on the blanket recommendation rates in Togo (Aboa *et al*, 2010) of 30 P_2O_5 kg ha^{-1} and 30 K_2O kg ha^{-1} (Table 3.2). In the USG pots, one granular of 1.8 g was deep placed between the 4 hills of rice, 10 days after transplanting (DAT) (Figure 3.4). In the PU pots a total rate of 1.8 g pot^{-1} of urea was equally split in three applications (10, 45 and 70 DAT), and uniformly broadcasted.

3.3.1.4. Weed control and irrigation

The pots were regularly watered and a layer of 3 to 4 cm of water under rice plants was maintained. Weeds were controlled by hand picking to avoid competition for nutrients with the growing rice.

Table 3.2 : Amount of fertilizers applied per pot

Nutrient sources	Nutrient Rate (kg ha^{-1})	Nutrient Rate (g pot^{-1})	Fertilizer rate (g pot^{-1})
TSP (P_2O_5)	30	0.50	1.1
KCl (K_2O)	30	0.50	0.8

SG (N)	52	0.83	1.8
PU (N)	52	0.83	1.8

3.3.1.5. Measurement of ammonia volatilization

The amount of Ammonia volatilized from the paddy soil was collected by a modified closed chamber described by Wang *et al.* (2004) and Faqir and Malik (1983). The chamber was made of a 25 cm high grey PVC tube. The top of the tube was tightly sealed with a plastic film to avoid entry of atmospheric air, and the bottom side of the tube was driven 2 cm deep into the soil (Figure 3.5).

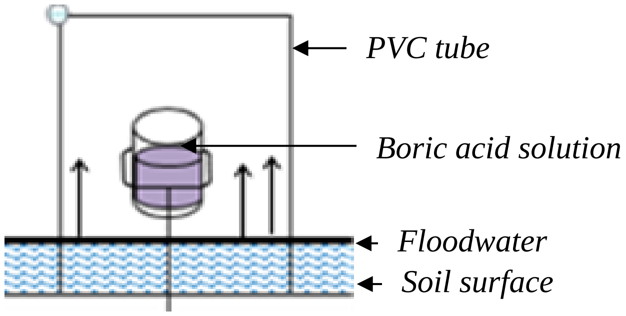


Figure 3.5 : The ammonia loss collection device.

Inside the chamber, a plastic beaker containing 20 mL of 0.5 M boric acid was installed on a stand wire support. The boric acid solution was to absorb the volatilized ammonia. The collection chamber was installed between the four hills of rice in each pot immediately after the first fertilizer application (10 DAT).

On the sampling day, the boric acid container was collected and immediately replaced with fresh boric acid. Ammonia collection was carried out every 2 days during the first week, every 4 days during the next two weeks, and later, every 10 days up to rice maturity. In all, 20 ammonia trappings had been done over the period of the experiment from the first urea application to the rice physiological maturity.

In the laboratory, NH_3-N trapped by the boric acid was determined by titration with 0.01 M HCl. The amount of ammonia-N collected per pot was then calculated with as follows:

$$NH_3\ (\%) \quad = \quad \frac{TC_{HCl} \ \times 0.014 \times S}{s \ \times N_r} \ \times \ 100 \qquad [3.12]$$

Where : T = titre volume of HCl (mL);

C_{HCl} = normality of HCl;

0.014 = milliequivalent of N;

s = cross section of the chamber (cm^2);

S = surface area of the pot and (cm^2);

Nr = Amount of N applied (g).

3.3.1.6. Agronomic parameters measurement and harvesting

Plant height was recorded at active tillering (25th DAT), flowering (75 DAT) and harvest stages. Data on the number of tillers, the length of panicles, and weight of 1000 seeds were collected at harvest.

At full maturity, the rice was harvested from each pot. The number of tillers was counted; the length of each panicle was measured and the mean value was recorded per pot. Grains were separated from the rest of the plant. The panicle residues were added to rice straw, put in labelled envelops and oven dried at 75° C to constant weight. Similarly, the rice grains were oven dried. Grain yield was adjusted to 14% moisture content. Straw and grain samples were milled using an electric grinder. Total N in both grain and straw was determined as described in section 3.2.1.5.

3.3.2. Experiment 2 : Efficiency of different rate of urea deep placement on growth, yield and nitrogen use efficiency of rice

3.3.2.1. Experimental design

The field study was carried out in the irrigated Valley of Zio in Togo with the aim of assessing the effect of different rates of USG applied at 8 cm depth compared with PU application, the conventional method of N fertilization. Experiments were conducted on in the year 2017 on three different soil series (Canne, Seme and Voudou series) during the first season (March-July) and repeated during the second season (August-November). The physicochemical properties of the soil are presented in Table 4.1 in section 4.1

Table 3.3: Some characteristics of the rice varieties used (MAEP, 2015)

Rice variety	Breeder/ Source	Introduction/ year	Height at maturity (cm)	Panicle length (cm)	Maturity (Days)	1000 gains weight (g)	Average yield (t ha^{-1})
IR-841	IRRI	1973 By ITRA	100	25-30	120-130	22-24	4
TG-405	Africa Rice	1995 By ITRA	125	24-28	105-115	23-25	5

Three factors were studied. The first factor was the rice varieties: IR-841 and TGR-405 of different maturity cycles of 130 and 105 days respectively (Table 3.3). The second factor was the urea type; prilled urea (PU) and Urea Supergranule USG) and the third factor was the nitrogen rate: 0, 52, 78 and 104 kg ha^{-1} (Table 3.4). At each site, the experiment was laid out in a randomized complete block design with three replications.

Table 3.4 : Treatments for field experiment

Treatment	Description

IR-841 N_0	IR 841 with No N-fertilizer
IR-841 PU N_{52}	IR 841 with Prilled Urea at 52 kg N ha^{-1}
IR-841 PU N_{78}	IR 841 with Prilled Urea at 78 kg N ha^{-1}
IR-841 PU N_{104}	IR 841 with Prilled Urea at 104 kg N ha^{-1}
IR-841 USG N_{52}	IR 841 with Urea supergranule at 52 kg N ha^{-1}
IR-841 USG N_{78}	IR 841 with Urea supergranule at 78 kg N ha^{-1}
IR-841 USG N_{104}	IR 841 with Urea supergranule at 104 kg N ha^{-1}
TG-405 N_0	TG 405 with No N-fertilizer
TG-405 PU N_{52}	TG 405 with Prilled Urea at 52 kg N ha^{-1}
TG-405 PU N_{78}	TG 405 with Prilled Urea at 78 kg N ha^{-1}
TG-405 PU N_{104}	TG 405 with Prilled Urea at 104 kg N ha^{-1}
TG-405 USG N_{52}	TG 405 with Urea supergranule at 52 kg N ha^{-1}
TG-405 USG N_{78}	TG 405 with Urea supergranule at 78 kg N ha^{-1}
TG-405 USG N_{104}	TG 405 with Urea supergranule at 104 kg N ha^{-1}

3.3.2.2. Land preparation and rice transplanting

Different nurseries were established for the two varieties of rice and seedlings were grown for 20 days before transplanting. The plots were first puddled using power tiller, after which the two different nursery beds were established. The nurseries were covered with net against birds and rats attack. Ten days after the first puddling, the herbicide glyphosate was applied to control all emerged weeds. Twenty (20) days after puddling, unit plots of 3 m x 3 m (9 m^2) were made, puddled again and levelled using hoes as shown in Figure 3.6. The following day, the 21-days old seedlings were transplanted by hand at a spacing of 20 cm x 20 cm. The population at transplanting was 250,000 rice plants per hectare (225 plants per unit plot).

Figure 3.6 : Layout of the field experiment

The plots were made in such a way that each plot had independent irrigation and drainage ditches to prevent the spread of water and fertilizers were constructed. Surface irrigation system was used and water supply was done as required throughout the vegetative growth. Weeds were carefully controlled by hand picking to avoid nutrients competition with rice.

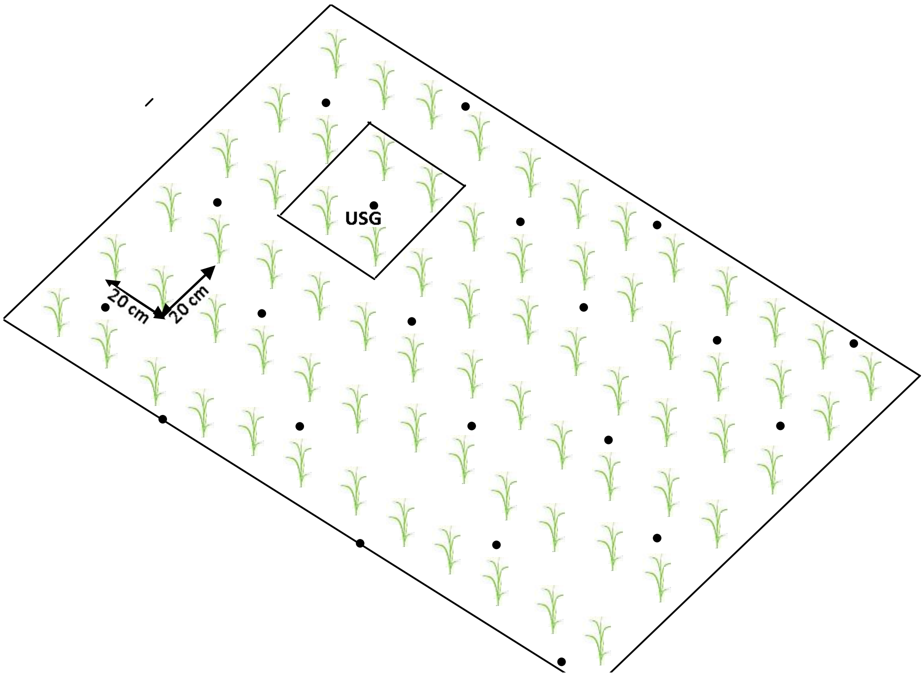


Figure 3.7 : Method of USG application in the field

For fertilization, the recommended rates of phosphorus (13 kg P ha^{-1}) and potassium (25 K ha^{-1}) in the form of triple superphosphate (TSP, 46% P_20_5) and Muriate of Potash (KCl, 60% K_20), were uniformly applied as basal fertilizers just before rice transplanting. All treatments including the control received the recommended rate of P and K (Table 3.5).

Table 3.5 : Rate of P and K fertilizers applied to treatments

Nutrient source	Nutrient rate (kg ha^{-1})	Fertilizer rate (kg ha^{-1})	Fertilizer rate (g / 9 m^2)
TSP (46% P_20_5)	30 P_20_5	65 TSP	59 TSP
KCl (60% K_20)	30 K_20	50 KCl	45 KCl

On the prilled urea plots, PU rate was equally split into three applications and broadcasted in the flood water under rice on the 10, 45 and 70 days respectively after transplanting (DAT). On the USG plots, urea briquette was deep placed only once at 8 cm depth in between 4 rice hills. One briquette of 1.8 g was applied to treatments 52 kg N ha^{-1}, one briquette of 2.7 g to treatment 78 kg N ha^{-1} and 2 briquettes of 1.8 g to treatments 104 kg N ha^{-1} (Table 3.6)

Table 3.6 : Rates of PU and USG fertilizers applied to treatments

Source of N	Treatment			
	Control	52	78	104
Urea Supergranule (USG)	No N-fertilizer	1 USG of 1.8 g Per 4 hills	1 USG of 2.7 g per 4 hills	2 USG of 1.8 g per 4 hills
Pilled Urea (PU)	No N-fertilizer	112 g per unit plot	153 g per unit plot	224 g per unit plot

3.3.2.3. Data collection

Plant height was recorded at the stages of active tillering (25th DAT), flowering (75 DAT) and at harvest. Data on the number of tillers, the length of panicles, and weight of 1000 seeds were determined at harvest as described for pot experiment in section 3.3.1.5. The only defference was that on the field all parameters were measured on 3 randomly 1 m² selected on each unit plot and the average was the data recorded for the treatment. To avoid undesirable border effects and edge water infiltration, observation and parameters were taken in the middle of each unit plot away from the borders.

The selected 0ne (1) m^2 were harvested on each unit plot, the grains and straw were oven dried at 75^o C for 3 days and weighed. Samples of straw and grain were collected, milled and sent to laboratory for the determination of N.

3.3.3. Experiment 3. Evaluation of the effect of seedling age and time of USG application on rice growth, yield and nitrogen use efficiency.

3.3.3.1. Experimental design

This study was carried out in pots (same pots used in the greenhouse experiment in section 3.3.1.2) in open field in the irrigated valley of Zio at Kovié using Canne series where the field experiment was conducted.

Two factors were studied in this experiment. The first factor was the seedling age (10, 14, 21 and 28-day old) and the USG application time (0, 7, 14 and 21 DAT). The experiment included a control treatment that did not receive N-fertilizer application. In all there were of 20 treatments (Table 3.7).

Pot filling, puddling, nursery establishment and seedling transplanting, USG application and water supply were the same as described in the greenhouse experiment at University of Ghana. The age of the seedlings transplanting and the USG application time were different with regards to the treatments. The rice variety used was IR-841 as described in Table 3. 3, section 3.3.2.1.

Table 3.7 : Treatments in experiment 3

Treatment	Description
D_{10} 0	10 days age seedling + No USG
D_{10} DAT_0	10 days age seedling + USG at 0 DAT
D_{10} DAT_7	10 days age seedling + USG at 7 DAT
D_{10} DAT_{14}	10 days age seedling + USG at 14 DAT
D_{10} DAT_{21}	10 days age seedling + USG at 21 DAT
D_{14} 0	14 days age seedling + No USG
D_{14} DAT_0	14 days age seedling + USG at 0 DAT
D_{14} DAT_7	14 days age seedling + USG at 7 DAT
D_{14} DAT_{14}	14 days age seedling + USG at 14 DAT
D_{14} DAT_{21}	14 days age seedling + USG at 21 DAT
D_{21} 0	21 days age seedling + No USG
D_{21} DAT_0	21 days age seedling + USG at 0 DAT
D_{21} DAT_7	21 days age seedling + USG at 7 DAT
D_{21} DAT_{14}	21 days age seedling + USG at 14 DAT
D_{21} DAT_{21}	21 days age seedling + USG at 21 DAT
D_{28} 0	28 days age seedling + No USG
D_{28} DAT_0	28 days age seedling + USG at 0 DAT
D_{28} DAT_7	28 days age seedling + USG at 7 DAT
D_{28} DAT_{14}	28 days age seedling + USG at 14 DAT
D_{28} DAT_{21}	28 days age seedling + USG at 21 DAT

D_X = Seedling of X-day old, DAT_X = X Days after transplanting, USG = Urea Supregranule

3.3.3.2. Data collection

Plant height at different stages, number of tillers, length of panicles, weight of 1000 grains, dry yield of straw and grain were evaluated as described in the first pot experiments. Rice straw and grain samples were also collected, oven dried, ground and sent to laboratory for N content analysis.

3.4. Evaluation of Yields and Nutrient Use Efficiency

3.4.1. Grain yield and Straw yield

For the pot experiments, the grain yields in g pot^{-1} was the dry weight of harvest grain adjusted to 14% moisture content and the straw yield (g pot^{-1}) was the harvest dry weight of straw per pot.

For field experiment, the straw and grain yields were calculated as follows :

$$GY\ (kg\ ha^{-1}) = \frac{\frac{Dry\ Grain\ Weight\ of\ the\ treatment}{14\%\ humidity\ (kg)}}{Harvested\ area\ (m^2)}\ X\ 10{,}000 \qquad [3.13]$$

$$SY(kg\ ha^{-1}) = \frac{Dry\ Straw\ Weight\ of\ the\ treatment\ (kg)}{Harvested\ area\ (m^2)}\ X\ 10{,}000 \qquad [3.14]$$

Where : GY is the grain yield

SY is the straw yield

3.4.2. Evaluation of Nitrogen use Efficiency

Nitrogen use efficiency was evaluated by three methods: (i) the agronomic use efficiency (AE), (ii) the physiological use efficiency (PE) and (iii) the apparent N recovery efficiency (%RE). The parameters were calculated as follows:

$$AE = \frac{GY_N - GY_{N0}}{N_r} \qquad [3.15]$$

$$PE = \frac{BY_N - BY_{N0}}{U_N - U_0} \qquad [3.16]$$

$$\%RE = \frac{U_N - U_{N0}}{N_r} \times 100 \qquad [3.17]$$

Where :

Nr = the rate of N fertilizer applied (g pot^{-1} for pot studies and kg ha^{-1} for Field study);

GY$_N$ = grain yield with N application (g pot^{-1} for pot studies and kg ha^{-1} for field study);

GY_0 = grain yield without N application (g pot^{-1} for pot and kg ha^{-1} for field study);

BY_N = Total biomass yield (grain + straw) with N application (g pot^{-1} for pot studies and kg ha^{-1} for field study);

BY_0 = Total biomass yield (grain + straw) without N application (g pot^{-1} for pot studies and kg ha^{-1} for field study);

U_N = rice N uptake with N application; (gpot^{-1} for pot studies and kg ha^{-1} for field study)

U_0 = N uptake without N application; (gpot^{-1} for pot studies and kg N ha^{-1} for Field study)

3.4.3. Value Cost Ratio (VCR) analysis

To assess how beneficial was the urea mode of application, a simple value-cost ratio (VCR) analysis was computed after harvesting. The VCR is the quotient obtained from dividing the value of the yield increase by the cost of fertilizer applied to bring about the increased yield. The higher the VCR, the more profitable the treatment. If the VCR is more than one (1), it means that the option is profitable. However, because of the risk elements, a VCR value of at least two (2) is recommended for developing country farmers (FAO, 1981). VCR was calculated as follows:

$$VCR = \frac{(GY_N - GY_{NO})\ X\ R_p}{Nc} \qquad [3.18]$$

Where:

VCR= Value Cost Ratio

GYN = Grain yield with N applied treatment (kg ha^{-1})

GY0 = Grain yield without N application (kg ha^{-1})

Rp = Rice price

Nc = Nitrogen application cost

For the VCR calculation, fertilizers costs were based on the market prices in the experiment year. The USG price was increased by 2000 CFA over PU to cover transport and briquetting. The rice price at the harvesting time in the area was considered and the fertilizer application costs were dose indicated by farmers (Table 3.8).

Table 3.8: Prices considered for the Cost Value Ratio evaluation

Item	PU	USG	PU	USG
	FCFA		US $	
Price /kg	14 000	609	24,9	1,1
Price/bag of 50 kg	16 000	695	28,4	1,2
Application cost/ha	3000	3000	5,3	5,3
Number of application	2	1	2	1
Rice price	360		0.6	

3.5. Statistical Analysis

Data collected from the three experiments were subjected to analysis of variance (ANOVA) after a Shapiro-Wilk test for normality. The means were compared by Fisher's Protected LSD test at 5% level significance. The statistical analysis was done using the GenStat (12th edition, 2009) software. The data was computed, graphs and tables were drawn with Microsoft Excel software.

CHAPTER FOUR

4.0. RESULTS AND DISCUSSION

The result and discussion section is presented in five sub-chapters. It briefly presents the results on the physico-chemical properties of the soils used in the study. After, the results of the three experiments were presented followed each by discussions. Finally, a fifth sub-chapter presented a summary of the overall result.

4.1. Physico-chemical characteristics of the soils

The physical and chemical characteristics of the soils used in the study are presented in Table 4.1. The particle size analysis showed high sand content (73%) and relatively low clay (18%) and silt (9%) content for Voudou series. Compared to Voudou series, Bumbi and Seme series had lower sand content (64% and 57%) but higher clay content (27% and 34%). Canne and Akuse contained high clay proportions (73% and 50%, respectively). According to USDA texture classification Canne and Akuse series were classified as clay soil, Seme and Bumbi series as sandy clay loam soils and Voudou as sandy loam soil.

The Seme series can be described as slightly acidic (pH 6.3). Canne and Voudou were moderately acidic (5.6 and 5.9) while Akuse and Bumbi were alkaline soils (The pH were 8.1 and 7.9, respectively). Except for the Voudou series that showed a lower organic carbon content (0.7%), Canne, Seme, Akuse and Bumbi had moderate organic carbon content (1.91%, 1.2%, 1.61% and 1.44%, respectively).This may be due to accumulation of rice straw over time during previous cropping. Available phosphorus (Bray I) was relatively high in Canne series (32.1 mg/kg), and Seme (27 mg/kg). For Akuse and Bumbi, Olsen P was medium (24.1 and 21.6 mg/kg) while it was low in Voudou series (13.4 mg/kg). The cation exchange capacity (CEC) was high for Canne (39.6 cmol/kg), Akuse (34.2 cmol/kg) moderate for Bumbi (21.6 cmol/kg) and Seme (17.3 cmol/kg) but low for Voudou (5.2 cmol/kg).

Table 4.1: Some Physico-chemical properties of the soils used in the study

Properties	Soil type (Site)				
	Canne (Kovie-Ablotsri)	Seme (Hahome)	Voudou (Mission-Tové/Kouto)	Akuse (Kpong)	Bumbi (Ashiaman)
Sand (%)	11	47	73	40	64
Silt (%)	16	19	9	10	9
Clay (%)	73	34	18	50	27
Texture (USDA)	Clay	Sandy-Clay-Loam	Sandy-Loam	Clay	Sandy-Clay-Loam
pH (H_2O)	5.6	6.3	5.9	8.1	7.9
OC (%)	1.91	1.2	0.72	1.61	1.44
Total N (%)	0.29	0.15	0.09	0.25	0.16
Available P (mg/kg)	32.1	27.6	13.4	24.1	21.6
CEC (cmol/kg)	39.6	17.3	5.2	34.2	21.6
Ca (cmol/kg)	12.63	6.1	3.9	9.11	4.76
Mg (Cmol/kg)	1.62	1.46	0.33	1.49	0.41
K (cmol/kg)	0.11	0.09	0.06	0.09	0.07
Na (cmol/kg)	0.34	0.22	0.11	0.23	0.18

4.2. Results and discussion of the experiment 1 (Pot experiment)

4.2.1. Results

4.2.1.1. Ammonia volatilization rate with time

Figure 4.2.1 shows that in the four types of soils (Canne, Voudou, Akuse and Bumbi series) undetectable ammonia volatilization was recorded with the control treatment (without N application), but significant ammonia losses rates were recorded with the surface broadcasting of prilled urea (PU) and the deep placement of urea supergranule (USG) treatments ($p<0.05$). In general, volatilization occurred within the first 15 days following urea application. During this period, 90 to 98% of the total amount of ammonia loss took place. High volatilization rates were recorded on the 2nd day after PU application and on the 4th to 6th days after USG application.

4.2.1.2. Ammonia volatilization as affected by the soil type

The different soil types showed significant ($P<0.05$) influences on the total ammonia volatilization. Regardless of the urea application mode, the highest amount of NH_3 volatilization (13.67% of N applied) was recorded on Bumbi series followed by Akuse series (13.13%). The lowest ammonia loss was recorded in Canne series: 8.16% of the total N applied (Figure 4.2.2).

4.2.1.3. Ammonia volatilization as affected by urea depth of application

Total ammonia loss was significantly ($p<0.05$) affected by the depth of urea application. Across the soils, ammonia losses ranged from traces for the control to 37.2% with USG application at the soil surface (Figure 4.2.3). Surface application of USG increased ammonia loss by (18%) over the surface broadcasting of PU.

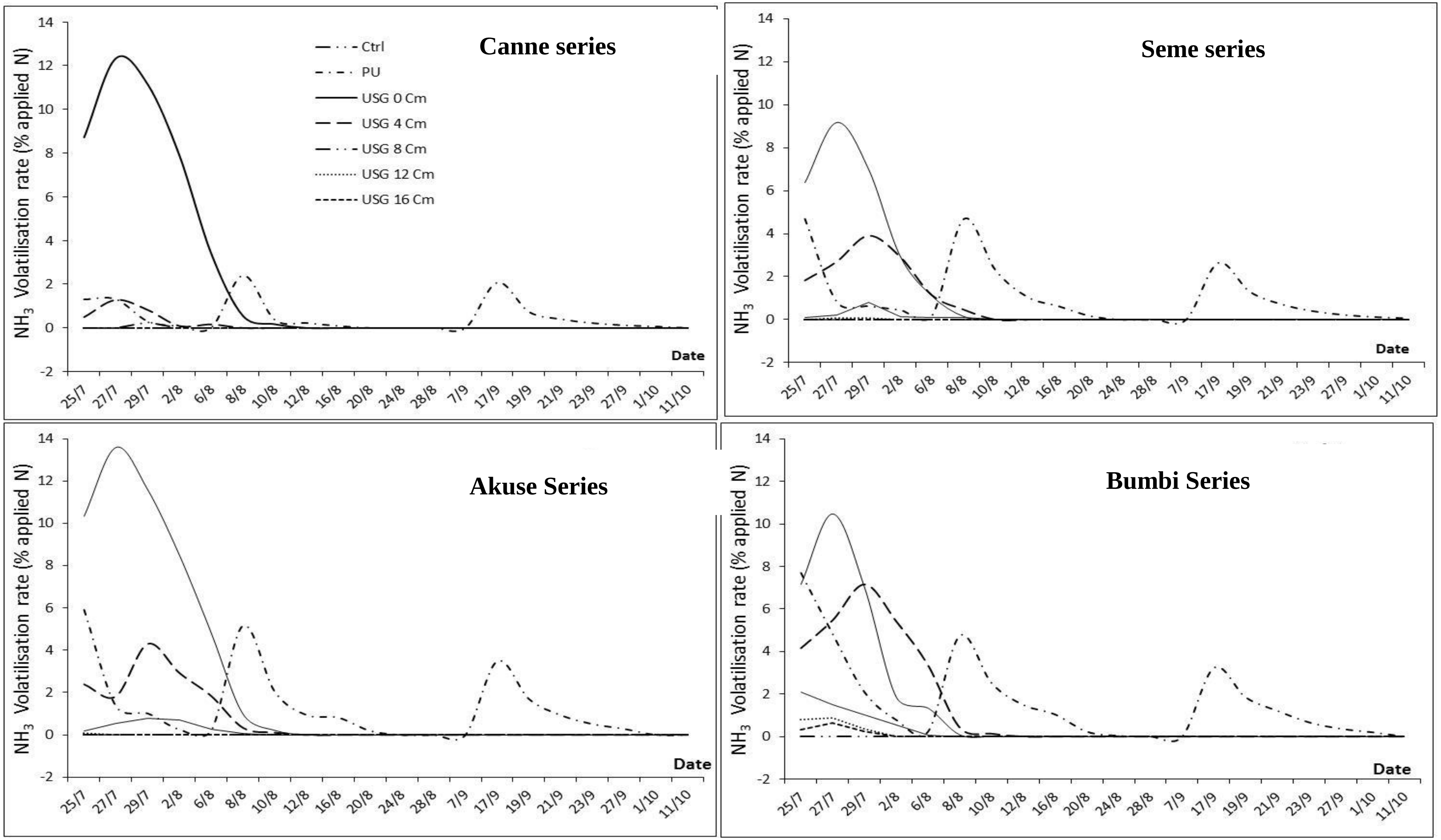


Figure 4.2.1: Variation of ammonia volatilization rate per type of soil and nitrogen application mode.

The results showed that ammonia loss was affected by the depth of USG application. Generally the total amount of ammonia loss decreased drastically with the depth of USG application. The deeper the USG was placed, the lower was ammonia loss. When USG was placed at 4 and 8 cm depths, volatilization amounts were respectively 13.9 and 2.7%, corresponding to a reduction of about 80%. At 12 cm and 16 cm depths, losses were respectively 0.6% and 0.3% corresponding to a reduction of 50%. Deep application of USG considerably reduced ammonia loss over PU.

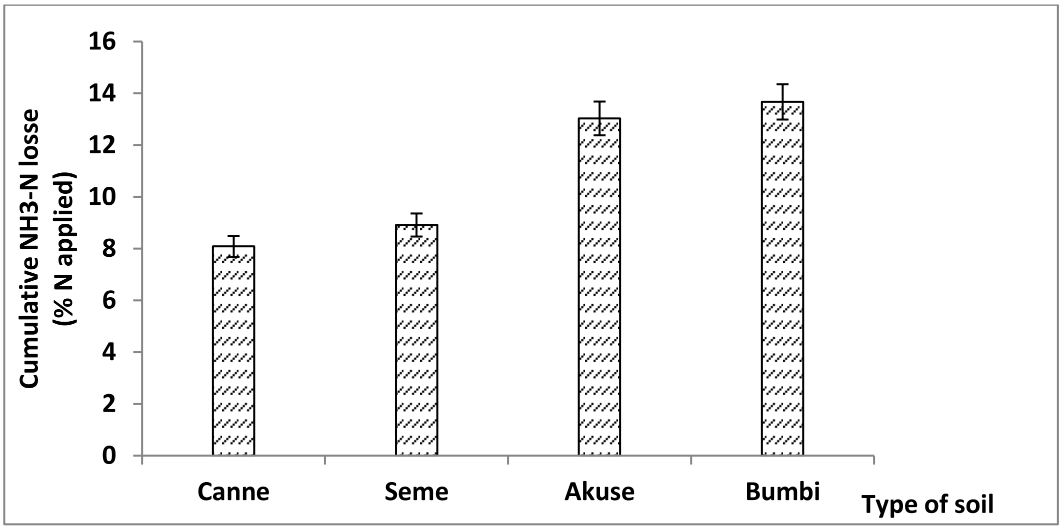


Figure 4.2.2: Cumulative ammonia volatilization per type of soil

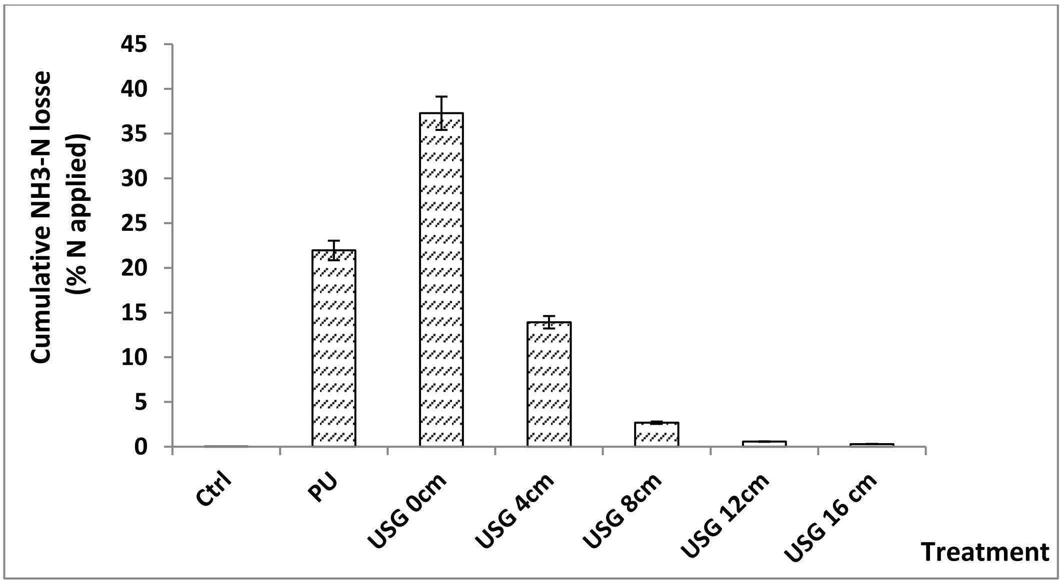


Figure 4.2.3: Cumulative ammonia volatilization per depth of USG application

4.2.1.4. Interaction between the type of soil and type of urea on ammonia loss

The interaction between the type of soil and the type of urea showed significant ($p<0.05$) influences on the total amount of ammonia volatilized. When USG was applied at the soil surface, Akuse series showed the highest amount of NH_3 loss (50% of N applied) followed by Canne series soil (44.23% of N applied). But when USG was deep placed at 4, 8, 12 and 16 cm, the highest ammonia losses were recorded with the Bumbi series (Table 4.2.1).

Table 4.2.1: Interaction of soil type and urea application mode on cumulative NH_3 loss (% of N applied)

Urea practice	Type of soil			
	Canne	Voudou	Akuse	Bumbi
Ctl	0.00 *a*	0.000 *a*	0.00 *a*	0.00 *a*
PU	9.76 *f*	21.05 *h*	24.80 *i*	33.18 *l*
USG 0cm	44.23 *m*	26.75 *j*	50.05 *n*	27.91 *k*
USG 4cm	2.86 *d*	12.95 *g*	13.72 *g*	26.11 *j*
USG 8cm	0.27 *ab*	1.44 *c*	2.56 *d*	5.22 *e*
USG 12cm	0.00 *a*	0.16 *a*	0.07 *a*	2.05 *cd*
USG 16cm	0.00 *a*	0.00 *a*	0.00 *a*	1.21 *bc*
Fpr	*< 0.001*			
LSD	*0.999*			
CV	*5.6*			

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

4.2.1.5. Effect of soil type on rice growth and yield

The soil type significantly (P<0.001) affected rice growth, yield parameters and yield. Canne series showed the highest performances in rice plant height (92.8 cm), total number of tillers (23 per pot), length of panicles (21.7 cm), weight of 1000 grains (27.3 g/pot), grain yields (69.2 g/pot) and straw yield (77.94 g/pot). The lowest rice parameters were recorded on Bumbi series. In general the effects of the different soils on rice characteristics studied were in the following order of the series: Canne > Akuse > Voudou > Bumbi (Table 4.2.2).

Table 4.2.2: Effect of soil type on rice yield components and yield

Type of soil	Plant height at harvest (cm)	Number of Tillers (/Pot)	Length of panicles (cm)	Weight of 1000 grains (g)	Grain Yield (g/pot)	Straw Yield (g/pot)	Harvest Index (%)
Canne	92.8 b	23 c	21.7 c	27.3 b	69.20 d	77.94 d	47.0 ab
Voudou	86.4 a	20 b	20.8 b	26.7 b	52.96 b	59.11 b	47.1 bc
Akuse	92.0 b	21 b	20.8 b	26.7 b	64.80 c	71.28 c	47.4 c
Bumbi	85.4 a	17 a	17.7 a	24.7 a	45.55 a	51.84 a	46.7 a
Fpr	*< 0.001*	*< 0.001*	*< 0.001*	*< 0.001*	*< 0.001*	*< 0.001*	*< 0.001*
LSD	*2.49*	*1.47*	*0.59*	*0.63*	*0.926*	*1.34*	*1.2*
CV	*4.5*	*11.5*	*4.7*	*3.9*	*2.6*	*3.3*	*0.9*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

4.2.1.6. Effect of urea application depth on rice growth and yield

Table 4.2.3 summarizes the effect of the depth of urea application on rice parameters. Rice growth, grain and straw yields were significantly *($P<0.05$)* affected by the urea mode of application.

Table 4.2.3: Effect of urea application mode on rice yield components and yield

Treatment	Plant height (cm)	Number of Tillers (/pot)	Length of panicles (cm)	Weight of 1000 grains (g)	Grain Yield (g/pot)	Straw Yield (g/pot)	Harvest Index (%)
Ctl	78.7 a	09 a	18.12 a	25.7 a	34.20 a	30.87 a	46.26 a
PU	84.0 b	24 c	20.57 b	26.8 bc	61.27 d	68.14 c	47.35 c
USG 0cm	78.6 a	15 b	18.07 a	26.2 ab	42.37 b	48.78 b	46.56 ab
USG 4cm	98.4 d	26 d	21.74 c	26.6 bc	74.48 f	81.94 e	47.62 c
USG 8cm	94.8 c	24 c	21.25 bc	26.3 abc	72.74 f	80.08 e	47.57 c
USG 12cm	95.5 cd	24 c	21.10 bc	26.0 ab	64.27 e	71.29 d	47.31 c
USG 16cm	94.3 c	24 c	20.82 b	27.6 c	57.56 c	65.33 c	46.77 b
Fpr	*< 0.001*	*< 0.001*	*< 0.001*	*< 0.001*	*< 0.001*	*<0.001*	*<0.001*
LSD	*3.29*	*1.94*	*0.78*	*0.83*	*1.22*	*2.944*	*0.3*
CV	*4.5*	*11.5*	*4.7*	*3.9*	*2.6*	*3.3*	*0.9*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

The highest plant height (98 cm) was obtained with the USG deep placed applied at 4 cm while the lowest plant height (79 cm) was recorded with the control treatment and the USG applied at the soil surface recorded similar height as the control.

The highest number of tillers (26) was recorded when USG was applied at 4 cm depth while the lowest (9) was obtained with the control. The number of tillers was statistically similar (24) for the split application of PU and placement of USG at 8, 12 and 16 cm depths, but higher than the USG applied at soil surface.

The panicle lengths were similar (21.5 cm) when USG was applied at 4, 8 and 12 cm depths but were higher than the split application of PU and USG deep placed at 16 cm which also exhibited similar (21 cm) performance. Among the treatments, the control and the surface application of USG showed similar but the lowest panicle length (18 cm).

The weight of 1000 grains was generally affected by the treatments. It was lower (25.7 g) for the control as compared with all other treatments that recorded similar performances (26.4 g on average).

The highest grain yield and straw yield (73 and 81 g pot^{-1} respectively) were obtained with the USG applied at 4 cm or 8 cm depth, followed by the USG applied at 12 cm depths. Compared with the broadcast PU, deep application of USG at 16 cm produced lower grain yield. The lowest grain yield (26 g pot^{-1}) was observed with the control.

The harvest index (HI) was statistically similar (47 on average) for USG applied at 4, 8 and 12 depths and PU which are the highest. The soil surface application of USG and its deep application at 16 cm also showed similar harvest index. The HI was the lowest with the control treatment.

4.2.1.7. Interaction effect between soil type and urea application depth on rice yield

Significant *($P<0.05$)* interaction effects were observed between the soil type and the type of urea on rice yield. On each type of soil, yield performance depended on the type of urea. The control showed the lowest yield (18.2 to 34. 8 g pot^{-1}) followed by the USG applied at the soil surface (30 to 41 g/pot) on all soil types (Table 4.2.4). However, the type of urea that showed the highest grain yield value varied upon the type of soil.

Table 4.2.4: Interaction effect of soil type and depth of urea application on rice yield (g pot^{-1})

Urea practice	Rice Yield (g pot-^{1})			
	Canne	Voudou	Akusse	Bumbi
Ctl	18.19 a	28.01 b	34.84 cd	25.22 b
PU	79.67 qr	73.03 npq	62.15lm	46.65 fgh
USG 0cm	38.33 de	40.33 def	41.67 ef	30.67 bc
USG 4cm	78.76 q	66.73 mn	71.72 np	53.90 jk
USG 8cm	95.23 t	63.3 lm	81.73 rs	52.40 ijk
USG 12cm	96.24 t	58.74 kl	74.9 npq	49.11 ghi
USG 16cm	87.69 s	52.70 ijk	71.61 np	45.44 fg
Fpr	*<0.001*			
LSD	*6.65*			
CV	*7*			

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

In Canne series, the highest grain yield (86 g pot^{-1} on average) was obtained with application of USG at both 8 and 12 cm depths. In Voudou series and Bumbi series, placement of USG at 4 cm or 8 cm depth showed the highest grain yields (65 and 53 g pot^{-1} on average respectively). In Akuse series, USG applied at 8 cm depth produced the highest grain yield (Table 4.2.4).

On Canne and Akuse series, application of USG at 16 cm depth produced higher grain yields (88 and 72 g pot^{-1} respectively) than the split application of PU (78 and 62 g pot^{-1} respectively). Conversely, in Voudou series and Bumbi series, the split application of PU produced higher grain yield (73 and 47 g pot^{-1} respectively) as compared with USG deep placed at 12 and 16 cm: 53 and 45 g pot^{-1} respectively (Table 4.2.4).

4.2.1.8. Agronomic use efficiency (AE) and recovery efficiencies (RE) of N as affected by the soil type and the type of urea.

Nitrogen use efficiency was significantly *($P<0.05$)* affected by the soil type. Regardless of the type of urea, the highest Agronomic Efficiency (65 g g^{-1}) and Recovery Efficiency (42%) were obtained in Canne series. Bumbi and Voudou series soils showed the lowest AE (26 g g^{-1} on average), while Bumbi series showed the lowest Recovery Effiency : 38% (Figure 4.2.4).

The different modes of urea application also significantly *($P<0.05$)* affected the rice nitrogen agronomic efficiency and recovery efficiency. Across the soils, the highest AE (47.5 g g-^{1} on average) was observed when USG was deep placed either at 4 or 8 cm depth, while the highest RE (70%) was obtained with USG 8 cm treatment. USG applied at the soil surface showed the lowest AE (9.84 g g^{-1}) and RE (18.6%). RE was similar for the split application of PU and the USG 16 cm treatment regardless of the type of soil (Figure 4.2.5).

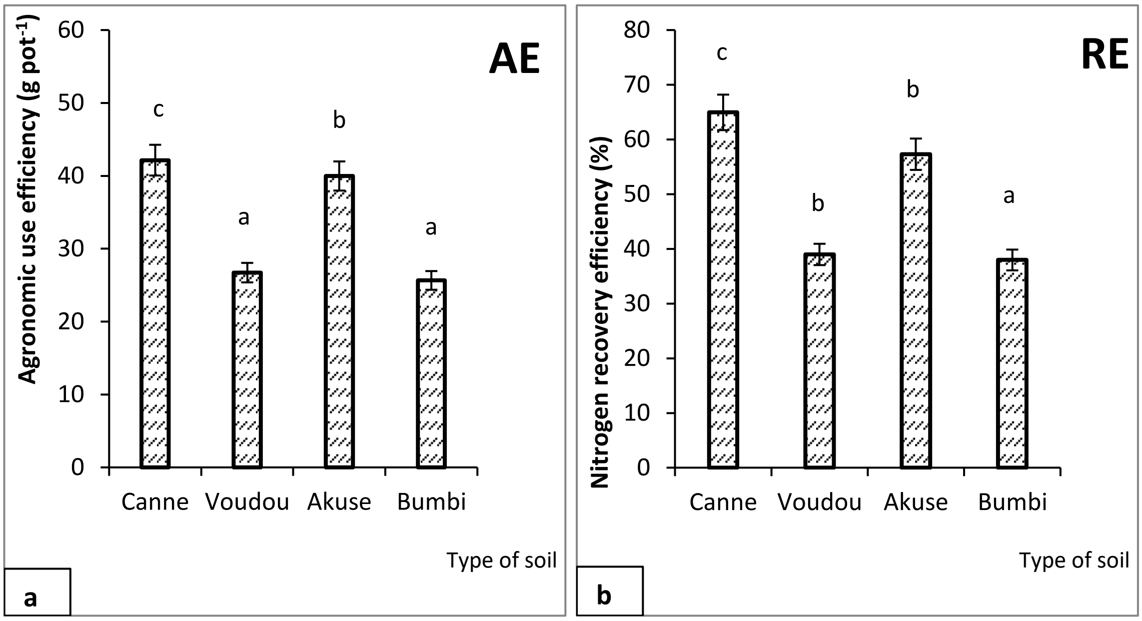


Figure 4.2.4: Effect of type of soil on the agronomic efficiency (a) and Nitrogen recovery efficiency (b)

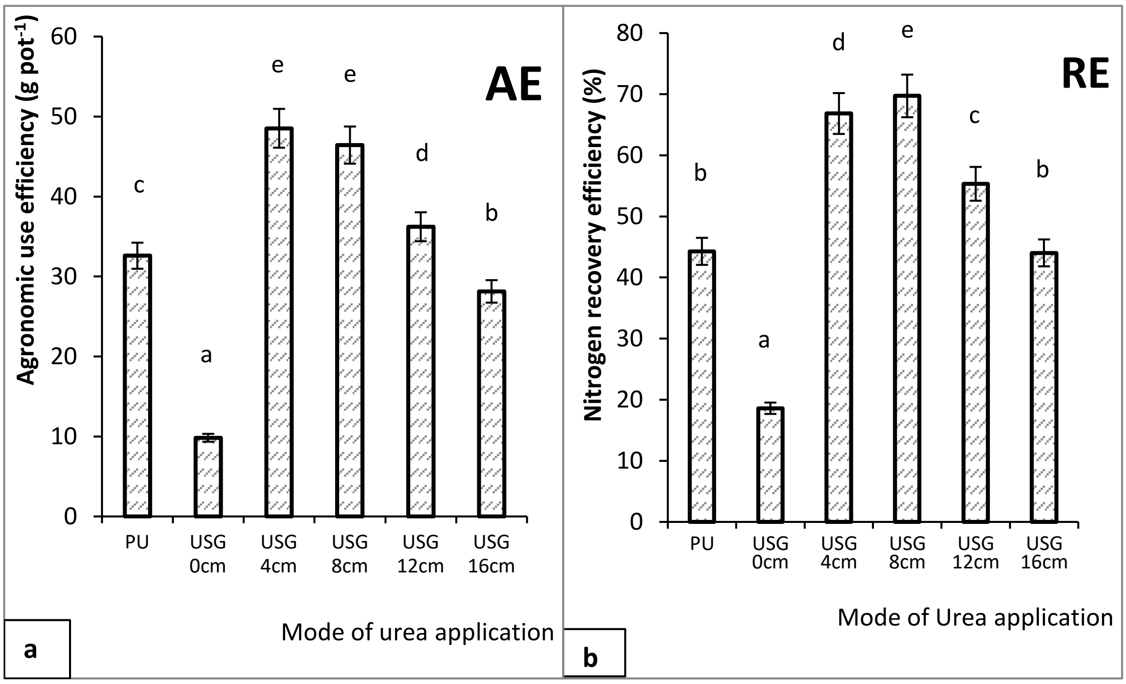


Figure 4.2.5: Effect of type of urea on the Agronomic efficiency (a) and Nitrogen recovery efficiency (b)

4.2.1.9. Agronomic use efficiency and recovery efficiency of N as affected by the interaction between the soil type and the type of urea

The results on the interaction effects between the soil type and the type of urea are summarized in Table 4.2.5. Results showed significant interaction effect *($P<0.05$)* between the treatments. The N use efficiency on a given soil depended on the type of urea. In Canne series the highest AE (57 g g^{-1} on average) was obtained with USG applied at 8 or 12 cm while the highest RE (84%) was shown by USG 8 cm treatment. In Akuse series, the highest AE (55 g g^{-1}) and RE (78%) were obtained when USG was placed at 8 cm depth. In Voudou series and Bumbi series, the highest AE (45 and 48 g g^{-1} respectively) and RE (64%) were obtained with USG deep placed at 4 cm (Table 4.2.5). In all soils, the lowest AE was obtained with the USG 0 cm treatment. Similar trend was shown with regards to the RE in the soils except the Bumbi series which showed the lowest RE (15%) with the USG 16 cm treatment. The PU exhibited higher AE and RE than USG 16 cm in Voudou series and Bumbi series. On the contrary, all USG deep placement treatments showed higher AE and RE than the PU on Canne and Akuse series.

Table 4.2.5: Interaction effect of soil type and type of urea on AE-N (g/g)

Treatment	Type of soil			
	Canne series	Voudou series	Akuse Series	Bumbi series
Agronomic use efficiency				
Ctl				
PU	34.37 ef	32.43 de	34.70 ef	28.92 d
USG 0cm	9.53 a	8.09 a	11.32 ab	10.40 ab
USG 4cm	51.10 kl	44.59 hi	50.29 jk	48.12 ijk
USG 8cm	58.35 m	37.93 fg	55.07 lm	34.38 ef
USG 12cm	55.45 m	23.28 c	46.44 ij	19.72 c
USG 16cm	44.13 hi	14.01 b	42.07 gh	12.37 ab
Fpr	*< 0.001*			
LSD	*4.35*			
Recovery efficiency (%)				
Ctl	-	-	-	-
PU	51.93 i	46.06 h	46.75 h	32.40 f
USG 0cm	25.58 d	13.33 a	15.90 b	19.59 c
USG 4cm	72.89 n	63.72 l	66.46 m	64.27 lm
USG 8cm	83.67 p	60.75 k	77.98 o	56.47 j
USG 12cm	78.89 o	29.25 e	73.35 n	39.83 g
USG 16cm	76.76 o	20.77 c	63.34 l	15.23 ab
Fpr	*<0.001*			
LSD	*2.24*			
CV	*2.7*			

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

4.2.2. Discussion

- ***Ammonia volatilization rate with time***

Ammonia volatilization rate was negligible in the control treatment but occurred significantly in all soils treated with either PU or USG. This implies that urea application was the predominant source in ammonia volatilization in the paddy soils. The negligible ammonia volatilization recorded in the control treatment can be attributed to the continuous mineralisation of the paddy soil organic matter and plant residue in the flooded rice soil (Faqir and Malik, 1983).

In the present experiment, more than 90% of the NH_3 loss took place within the first 15 days. This is in collaboration with earlier research findings. Vlek and Stump (1978) found that NH_3 volatilization occurred during the first few days following N fertilizer application and indicated that measurements should be done around that period. Ventura and Watanabe (1978) also reported that NH_3 loss is a quick process within 9 days following N fertilizer application. Hussain and Malik (1983) measured ammonia volatilization in flooded rice field and reported that losses were more during the first five days following N-fertilizer application. Sullivan *et al*. (2003) evaluated ammonia volatilization from a swine waste amended bermudagrass pasture and found that approximately 60% of total NH_3 volatilization took place within 4 days after N fertilizer application.

The rate of ammonia loss increased rapidly to reach a peak on the 2nd day following the PU application and 4th to 6th days following USG application and thereafter decreased to reach lower levels around the 15th day. Many researchers, Griggs *et al*., (2007), Zhong-cheng *et al*.,(2012). Liyanage *et al*. (2014) and Liu *et al*. (2015) also reported peaks of ammonia flux within 3 to 5 days following various N fertilizers application.

The changes in the ammonia loss can be attributed to the variation in the concentration of urea in the soil which constitutes the substrate for urease activity in the hydrolysis process. Thus, high enzyme activity follows high soil concentration of urea some few days after its application and later on, the decrease of urea concentration leads to low enzyme activity and consequently, low ammonia volatilization rate which is associated with urea hydrolysis. Also, the physico-chemical mechanisms such as nitrogen infiltration, nitrification, denitrification, immobilization and nitrogen absorption by plant roots contribute to the decreasing of ammonia volatilization rate (Zhang *et al*., 2011).

In this study, the peaks of ammonia loss with USG deep placement treatments were delayed for 2-4 days from the peak with surface application of PU. It can be concluded that the process of NH_3 loss was slower with USG application than with PU. This can be explained by the fact that USG was point placed and needed a lag period to dissolve and diffuse into the soil body before the process of hydrolysis intensifies.

- ***Ammonia volatilization as affected by the soil type***

Cumulative ammonia volatilization was affected by the type of soil. The differences observed in the amount of ammonia volatilized with the type of soils can be explained by the differences existing in their physico-chemical properties, especially the soil pH and CEC. Soil CEC plays an important role in NH_4^+ removal from the soil solution and therefore reduces N ammonia losses (Cai, 1997). According to Martin and Reddy (1997) and Jones *et al.* (2013), soil vulnerability for ammonia volatilization following urea application is strongly governed by its pH. Thus, high ammonia volatilization follows urea hydrolysis in alkaline conditions. Longo *et al.* (2005) found that, hydrolysis increases exponentially with pH while measuring urea hydrolysis in soils with pH ranging from 2.2 to 8.0 under laboratory conditions. Therefore, in the present experiment, Bumbi and Akuse series (pH 7.9 and 8.1 respectively) showed high ammonia losses probably because of their higher pH than those of Canne and Voudou series (pH 5.6 and 6.3 respectively).

Obcemea *et al*. (1988) recorded higher ammonia volatilization on sandy and low CEC soils than clayey soils with relatively high CEC. Zhenghu and Honglang (2000) carried out a stepwise regression analysis for eight soil characteristics data of 22 soils sampled from 17 sites and found that, soil pH and CEC were the two properties that were significantly correlated with ammonia volatilization and drew a regression equation as function of those two parameters. The sandy-clay-loam texture and lower CEC of Bumbi series may have contributed to its highest vulnerability to ammonia loss. Fenn and Kiessel (1976) reported more NH_3 emission from a lower CEC soil as compared to a higher CEC soil. The lower pH coupled with the higher CEC is the factor that would have reduced ammonia losses in Canne series clayey soils as compared with other soils. Heavy clay soils with high CEC has negative charge in their exchange sites on which the NH_4^+ released from the urea is adsorbed and used later on by plants when needed. On the other hand, in loamy sandy soil with low CEC, NH_4^+ adsorption is not effective because the soil particles could not hold enough NH_4^+ on the exchange site and thus the NH_4^+ is lost through NH_3 volatilization, leaching and other pathways (Obcemea *et al*., 1988).

- ***Ammonia volatilization as affected by urea type and depth of application***

The surface application of PU showed higher cumulative ammonia volatilization as compared with the deep application of USG. Ammonia volatilization decreased from 24.8% of applied N with PU surface application to 2.56% with USG deep placement at 8 cm depth in Akuse series, corresponding to a decrease of more than eight folds. This can be explained by the fact that deep placement of urea increases the fertilizer-soil contact leading to more NH_4^+ as non-exchangeable NH_4^+ retained on the soil. As consequence there could be a reduction of NH_4^+ concentration in floodwater and therefore a reduction of ammonia volatilization. Cao *et al*. (2013), Liu *et al*. (2015), and Hayashi *et al*. (2008) reported that NH_3 volatilization flux was correlated with NH_4^+-N in concentration in floodwater. Mohanty *et al*. (1999) reported that nitrogen deep placement resulted in a dramatic reduction in floodwater NH_4^+ concentration and consequently decrease in NH_3 volatilization. The decrease in ammonia volatilization with USG over PU observed in this study is in agreement with Bautista *et al*. (2001) and Sommer *et al*. (2004) who reported that point deep placement of urea fertilizers was effective application method in reducing ammonia loss. Liu *et al*. (2015) reported that USG deep placement treatment significantly decreased cumulative NH_3 volatilization by 15–40% compared with surface application treatment in two consecutive growing seasons. Liu *et al*. (2015) linked reduction in NH_3 volatilization to a lower urease activity that he observed under urea deep placement than under surface application. Lower urease activity under nitrogen deep placement treatments may lead to less NH_4^+ released from hydrolysed urea fertilizers in the soil and flood water and thus, a decrease in NH_3 volatilization.

Earlier studies have also shown that nitrogen deep placement can largely reduce NH_3 volatilization through reducing ammonium nitrogen (NH_4^+–N) levels in the floodwater (Xu *et al*., 2013; Mohanty *et al*., 1999; Cao *et al*., 1984, and Vlek and Craswell 1979).

Application of USG at zero (0) cm resulted in the highest ammonia loss as compared with any other urea treatment. This suggests that application of USG on the soil surface is a waste that may lead to environmental pollution.

In general, total amount of ammonia loss decreased with USG application depth. This is in agreement with Rochette *et al*. (2013) who found that ammonia loss following urea fertilizer application decreased with the depth of its incorporation in soil. The decrease of ammonia emission with depth of USG application may be due to the large amount of NH_4^+-N retained in the soil with increasing placement depths that lead to a decrease of floodwater NH_4^+ concentration and less ammonia loss in the atmosphere. Also, deeper placement of USG delays the diffusion of ammonium released from its hydrolysis process to the floodwater (Liu *et al*., 2015). The upward movement of NH_4^+ to the flooded water is very slow and controlled by the soil CEC (Liu *et al*., (2015). Rochette *et al*. (2014) reported that upward movement of NH_4^+ is more slowed with increasing depth of USG application. Sommer *et al*. (2004) indicated that the resistance to the upward diffusion of ammonium-N in the liquid and gaseous phases and the retention of NH_4^+-N on soil particles are increased when urea is deep placed.

Very low to negligible amounts of ammonia loss were recorded with USG 12 cm and USG 16 cm treatments. This is in accordance with the finding of Rochette *et al*. (2013) who reported that incorporation of urea at soil depths greater than 7.5 cm resulted in negligible NH_3 emissions.

The interaction effect of soil type and urea mode of application on ammonia losses was significant, meaning that the amount of ammonia lost at a given depth varied with the type of soil. This can be explained by the differences between the characteristics of the different soils. Akuse and Canne series are clayey and might not allow deep infiltration of the dissolved urea and therefore increased ammonia loss when USG was applied to the soil surface. Dissolved urea remaining at soil surface increases the NH_4^+ concentration in floodwater and leads to increasing ammonia volatilization. Bumbi and Voudou series soils are sandy-clay-loam and sandy-loam, textures which are relatively favourable for NH_4^+ infiltration into the soil body. Thus the ammonium concentration in the floodwater decreased leading to reduced ammonia loss (Hayashi *et al*., 2006)

- ***Rice growth, yield and nitrogen use efficiency as affected by soil type and urea mode of application.***

In general, deep placement of USG increased rice growth, yield, agronomic use efficiency (AE) and recovery efficiency (RE) of N over the surface application of PU or USG in all the soils. This is in agreement with earlier findings of the superiority of urea incorporation or deep placement into soil over its surface application on rice agronomic performances and N Use Efficiency (Bowen *et al*,. 2005; Kabir *et al.*, 2009; Bandaogo *et al*., 2015; Mohammad *et al*., 2014; Xiang *et al*., 2013; Bony *et al*., 2015 and Liu *et al*., 2015).

The higher rice growth, yield and NUE obtained with the USG deep application over the broadcast PU is due to the fact that USG establishes better N fertilizer-soil contact and thus increases fertilizer NH_4^+ retention on the soil particles and insures its continuous availability for plant uptake during the growing season (Savant and Stangel, 1990; Mohanty *et al*., 1999). De Datta and Craswell (1982) pointed out that USG as slow-release N fertilizer reduces total N concentration in soil surface and is likely to minimize loss through volatilization. As a result of reduced ammonia volatilization, the rice nitrogen uptake and NUE by plants increases under nitrogen deep placement. In addition, high fertilizer nitrogen losses under PU application subsequently results in lower rice nitrogen uptake and NUE as compared with USG (Chen *et al*., 2008). On the other hand, the surface application of PU may cause urea-induced toxicity leading to poor root growth during early growth and therefore reducing rice growth, yield and nutrient uptake as compared with USG deep placement (Manickam and Ramaswami, 1985). Deep placement of USG is effective because it reduces nitrogen loss by ammonia volatilization that is known to be the major cause of urea induced-toxicity (Haden *et al*., 2011). Qi *et al*. (2012) also observed poor root growth under PU application as compared with USG deep placement due to high ammonia toxicity.

The high NUE obtained with USG deep placement in the present study also agrees with the findings of other studies (Cao *et al*., 1984; Singh *et al*., 1995; Jaiswal and Singh 2001; Chen *et al*., 2008; Kapoor *et al*., 2008). In the present study, the lowest rice growth parameters, yield, AE and RE obtained with surface application of USG as compared with the broadcast PU was due to the highest ammonia loss observed with the treatment. Thus, with surface application of USG, rapid urea hydrolysis occurred at the restraint site of USG placement inducing direct emission of NH_4^+ in the floodwater leading to high losses of NH_3 in the atmosphere. There was least contact of the USG with the soil particles than the PU, which might imply lower retention of the released NH_4^+ resulting in lower N uptake, yield and NUE.

The highest rice growth parameters, yield and NUE were obtained with the application of USG at 8 or 12 cm depths in Canne series, 4 or 8 cm depths in Voudou series and Bumbi series and at 8 cm depth in Akuse series. The differences in the optimum depth of USG to obtain the best rice performances could be attributed to the differences in the soil properties. Baligar and Bennett (1986) stated that the physico-chemical properties such as bulk density, structure, texture, water holding capacity and organic matter content can affect plant growth, yield and NUE.

In general, 8 cm appeared to be USG application depth for the highest rice growth, yield and NUE in all the soils. The result is in accordance with Das *et al*. (2014) who worked on a silty loam soils, and recorded the best yield parameters and yield of rice with USG applied at 8 cm depth. Bony *et al*. (2015) tested USG application at 5 and 10 cm depths and reported that 5 cm depth produced best yield attributes, grain and straw yields as compared with 10 cm depth. In general, Savant and Stangel (1990) indicated that depth of USG placement should be 7-10 cm to give farmers adequate protection against probable N loss mechanisms (especially NH_3 volatilization) and to improve N availability to the rice plants. However, Eriksen and Nilsen, (1982a) observed highest yields with USG application at 2.5-15.0 cm depth and indicated that the deep application of USG was most efficient when it was placed at a depth of 5.0 cm.

Application of USG at 16 cm depth showed the lowest rice growth, yield parameters, grain yield, AE and RE as compared with all other depths of USG application in the soils of Bumbi and Voudou series. This implied that at 16 cm, nitrogen loss by leaching prevailed because only negligible ammonia losses were recorded in these soils. Voudou series and Bumbi series were sandy clay loam soils and on such soils, the UDP technology is not recommended because of their vulnerability to nutrient leaching (Savant and Stangel, 1990).

4.3. Results and discussion of experiment 2 (field experiment)

This subchapter is presented in two different sections: the results and discussion. The result section presents first data per planting of each of the three sites. At the end of the results on a site, comparison is made between the croppings to assess their influence on the various parameters evaluated. Following that, the general trends of the effect of the treatments on the rice growth, yield and nitrogen use efficiency across the sites and croppings were presented. Thereafter, a comparison among the sites with regards to growth and nitrogen use efficiency (NUE) was made. Finally, the results were discussed taking into consideration, the effect of the treatments on the parameters measured during each season at the three sites.

4.3.1. Results

Three factors were studied in this experiment: rice variety (IR-841 and TG-405), urea mode of application (Prilled urea (PU) and Urea supergranule (USG)) and nitrogen rate (0, 52, 78 and 104 kg N ha^{-1}).

4.3.1.1. Results at Ablotsri site

4.3.1.1.1. Results at Ablotsri site; season 1

- ***Rice growth, yield components and yield as affected by variety, urea type and nitrogen rate. Ablotsri site, Season 1***

The effects of treatments on rice growth, yield components and yield in the first planting at Ablotsri site are summarized in Table 4.3.1. The results indicate that the rice variety affected significantly *($P<0.05$)* the rice height and the panicle length. The TG-405 variety showed greater height (97 cm) compared with the IR-841 that showed a lower height (94 cm) at maturity. The same trend was obtained for the length of panicles where the longer panicle (23 cm) and the shorter panicles (22 cm) were respectively recorded with variety TG-405 and IR-841. The harvest index also was higher for the TG-405. On contrary, no significant effects *($P<0.05$)* of rice variety were observed on the number of tillers, weight or 1000 grains, grain and straw yields. (Table 4.3.1).

Table 4.3.1: Effects of rice variety, type of urea and nitrogen rate on rice growth, yield components and yield. *Ablotsri site, Season 1*

Treatments	Height (cm)	Number of tillers per hill	Length of panicles (cm)	Weight of 1000 grains (g)	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index
Rice variety							
IR-841	94 a	17	22.0 a	26.67	3998	4611	46 a
TG-405	97 b	17	23.6 b	26.77	4078	4620	47 b
Fpr	*<0.001*	*0.815*	*0.023*	*0.667*	*0.234*	*0.914*	*0.039*
LSD	*1.089*	*NS*	*1.097*	*NS*	*NS*	*NS*	*0.422*
Type of urea							
PU	94 a	16 a	22.1 a	26.6	3717 a	4175 a	47 b
USG	97 b	18 b	23.72 b	27.0	4359 b	5056 b	46 a
Fpr	*<0.001*	*<0.001*	*0.038*	*0.480*	*<0.001*	*<0.001*	*<0.001*
LSD	*1.089*	*0.720*	*1.097*	*NS -*	*134.6*	*155.4*	*0.422*
Nitrogen rate							
N0	71 a	10 a	17 a	24 a	1688 a	1969 a	46 a
N52	92 b	16 b	23 b	27 b	3294 b	4177 b	45 b
N78	108 c	21 c	25 c	28 c	5533 c	6156 c	47 c
N104	111 d	21 c	26 c	28 c	5638 c	6160 c	47 c
Fpr	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*
LSD	*1.541*	*1.018*	*1.552*	*1.371*	*190.4*	*219.7*	*0.597*
CV	*6.9*	*7.3*	*4.0*	*3.1*	*5.7*	*5.7*	*1.5*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

Considering the type of urea applied, significant *($P<0.05$)* effects were obtained on all the parameters except the weight of 1000 grains. The results showed greater height of rice plant (97 cm), more number of tillers per hill (18) and longer panicles length (23 cm) with urea supergranule (USG) and shorter rice plant (94 cm), lower number of tillers (16) and shorter panicle length (22 cm) with the prilled urea (PU). The Grain and straw yields were also greater with the USG than the PU. The USG produced higher grain yield (4359 kg ha^{-1}) and straw yield (5056 kg ha^{-1}) over the PU treatment that produced 3717 kg ha^{-1} of grain, 4175 kg ha^{-1} of straw (Table 4.3.1). However, the PU mode of nitrogen application induced significantly higher harvest index (47) than the deep application of USG one: 46 (Table 4.3.1). Generally, better performances of rice growth, yield and yield components were observed with the USG as compared to PU.

Nitrogen rate significantly *($P<0.05$)* influenced rice growth, yield components and yield at Ablotsri site during the season 1. Rice height increased significantly with increasing rates of N applied. The tallest rice plant (111 cm) was obtained with the N104 treatment while the shortest rice plant (71 cm) was obtained with the control (without N application). The highest number of tillers, length of panicle, weight of 1000 grains, grain yield, straw yield and harvest index were recorded both with N78 and N104, and the lowest parameters were recorded with the control. Grain yield increased from 1688 kg ha^{-1} for the control, to 3294 kg ha^{-1} for the N52 and to 5638 for the N104. Similar increases of straw yields with increasing N rates were observed (Table 4.3.1).

- ***Interaction effects of rice variety, type of urea and nitrogen rate on Rice growth, yield components and yield. Ablotsri site, Season 1***

The interaction effects between rice variety, type of urea and nitrogen rate on rice growth, yield components and yield are presented in Table 4.3.2. No significant *($P>0.05$)* interaction effects were observed between the variety and the type of urea on all the agronomic parameters. There was however significant *($P<0.05$)* interaction effect between the variety of rice and the N application rate. For both IR-841 and TG-405 varieties, plant height increased with increasing rate of N application.

Comparable results were obtained between the variety and the nitrogen rate except that the interaction resulted in a significant *($P<0.05$)* effect on rice plant height. The lowest rice plant height at maturity (71 cm) was obtained with the control and for both IR-841 and TG-405 varieties, while the highest height (114 cm) was recorded when N104 was applied to TG-405. At the same nitrogen rate of N104, IR-841 showed lower height (108 cm) as compared with the TG-405 (Table 4.3.2).

Although the interaction between the type of urea and nitrogen was not significant *($P>0.05$)* on the number of tillers per hill, the panicle length and the weight of 1000 grains, the interaction affected significantly the rice plant height at maturity, the grain yield, straw yield and the harvest index. The highest heights (110 cm) were observed with USG applied at N78 and N104, while the lowest rice height (71 cm) was obtained with the control treatment.

For the interaction between the mode of application and the nitrogen rate, the highest range of grain yield (5938-5992 kg ha^{-1}) was obtained with N78 and N104 applied in the form of USG and in the same way, the highest range of straw yield (6642-6450 kg ha^{-1}) was obtained with USG applied at N78 and N104. The harvest index (47) was higher with USG*N104, PU*N78 and PU*N104 treatments. The lowest rice growth and yield parameters were recorded with the control for all the interactions. The interaction between varieties, type of urea and nitrogen rate was not significant *($P>0.05$)* for all the measured parameters (Appendix 2).

Table 4.3.2: The interaction effects of variety, type of urea and nitrogen rate on rice growth, yield components and yield. *Ablotri site, Season 1*

Treatments	Height (cm)	Number of tillers per hill	Length of panicles (cm)	weight of 1000 grains (g)	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index
Rice Variety*Type of urea							
IR-841*PU	93	16	22	27	3702	4204	47
IR-841*USG	95	18	23	27	4294	5019	46
TG-405*PU	96	16	23	27	3731	4146	47
TG-405*USG	99	18	24	27	4425	5094	46
Fpr	*0.391*	*0.641*	*0.830*	*0.792*	*0.453*	*0.389*	*0.671*
LSD	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Rice Variety* Nitrogen rate							
IR-841* N0	71 a	10	18	24	1658	1962	46
IR-841*N52	89 b	15	23	26	3221	4046	45
IR-841*N78	107 d	21	25	28	5433	6171	47
IR-841*N104	108 de	21	26	28	5679	6267	48
TG-405*N0	71 a	11	17	24	1717	1975	47
TG-405*N52	94 c	16	24	27	3367	4308	44
TG-405*N78	109 e	20	26	28	5633	6142	48
TG-405*N104	114 f	20.5	26.27	28.1	5596	6054	48
Fpr	*0.002*	*0.275*	*0.245*	*0.960*	*0.478*	*0.201*	*0.109*
LSD	*2.179*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Type of urea* Nitrogen rate							
PU* N0	71 a	10	18	24	1763 a	2050 a	46.3 b
PU*N52	88 b	15	23	26	2692 b	3108 b	46.4 bc
PU*N78	106 d	19	25	28	5129 d	5671 d	47.5 de
PU*N104	111 e	20	26	28	5283 d	5871 d	47.3 de
USG*N0	71 a	11	17	24	1613 a	1887 a	46.1 b
USG*N52	96 c	17	24	27	3896 c	5246 c	42.6 a
USG*N78	110 e	22	26	28	5938 e	6642 e	47.2 cd
USG*N104	111 e	21	26	28	5992 e	6450 e	48.2 e
Fpr	*<.001*	*NS*	*NS*	*NS*	*<0.001*	*<0.001*	*<0.001*
LSD	*2.179*	*1.44*	*1.097*	*0.97*	*274.1*	*311.8*	*0.859*
CV	*1.9*	*7.3*	*4.0*	*3.1*	*5.8*	*507*	*1.6*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

- ***Rice NU and NUE as affected by the variety, type of urea and nitrogen rate; Ablotsri site season 1***

The effect of the treatments on total N uptake (NU), Nitrogen agronomic use efficiency (AE), physiological efficiency (PE) and nitrogen recovery efficiency (RE) are presented in Figures 4.3.1, 4.1.2 and 4.1.3. The results showed significant effects *($P<0.05$)* of rice variety on nitrogen uptake, and RE. The variety TG-405 was significantly higher in NU (65 kg ha^{-1}) than IR-841 (63 kg ha^{-1}). Recovery efficiency as well was higher for TG-405 (70%) than IR-841 (67%). Rice variety did not show significant effect on AE and PE (Figure 4.3.1).

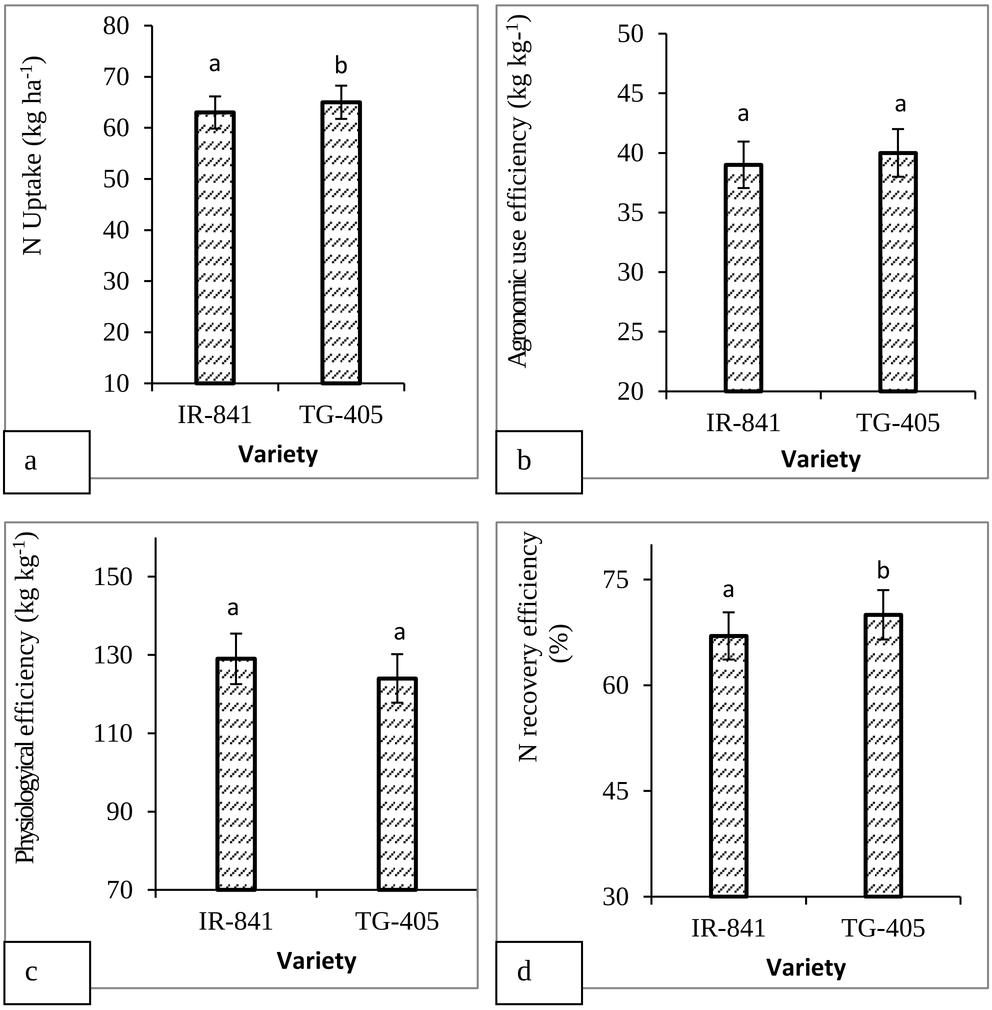


Figure 4.3.1: Effects of rice variety on NU (a), AE (b), PE (c) and RE (d) at Ablotsri site, season 1

In Figure 4.3.2 the type of urea induced significant *($P<0.05$)* effect on the NU and NUE, AE and RE of rice. The NU, AE, and RE were higher (74 kg ha^{-1}, 47 kg kg^{-1}; and 86% respectively) with USG than PU (55 kg ha^{-1}; 32 kg kg^{-1} and 51% respectively). On the contrary, PU showed higher PE (133 kg kg^{-1}) than USG (120 kg kg^{-1}).

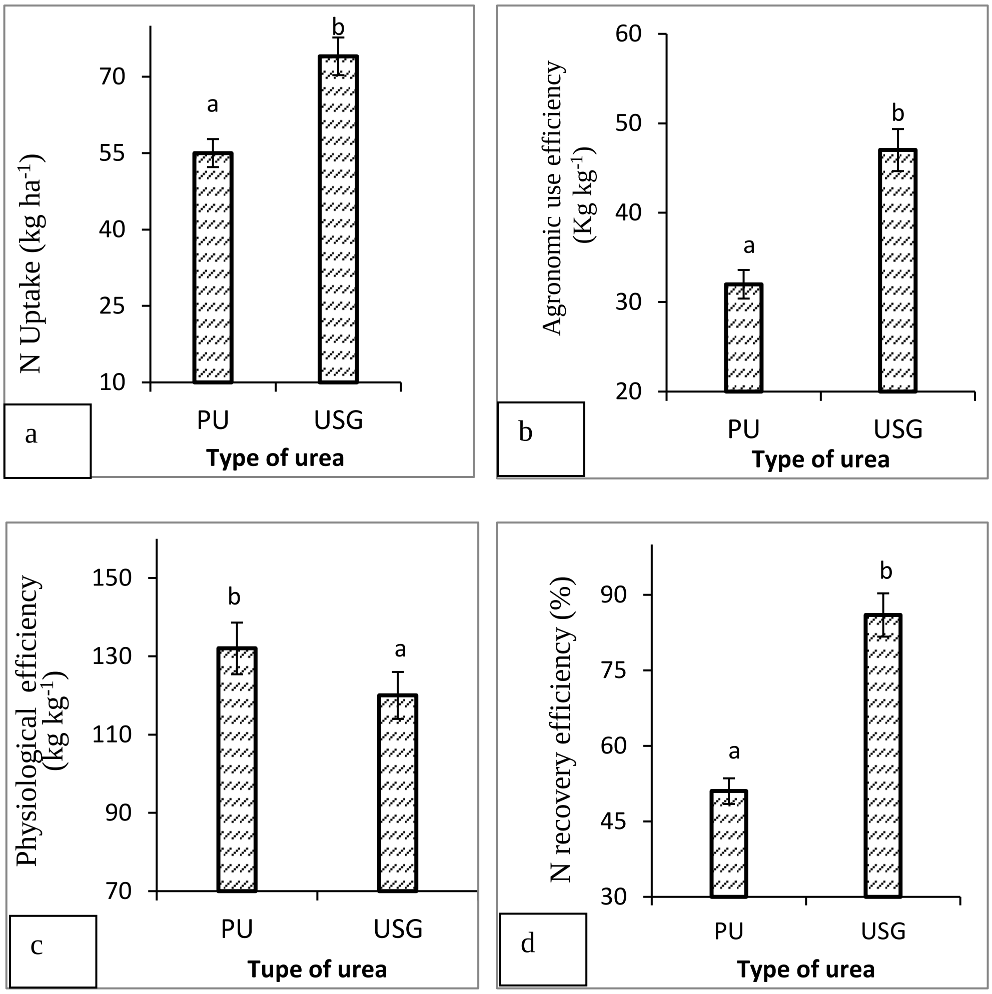


Figure 4.3.2: Effect of type of urea on NU (a), AE (b), PE (c) and RE (d) at Ablotsri site in season 1

The results indicated that the nitrogen uptake increased significantly *($P<0.05$)* with increasing rate of N application (Figure 4.3.3.a). The highest NU (91 kg kg^{-1}) was obtained with the N104 and the lowest (25 kg kg^{-1}) was recorded with the control. Significant effects of N rates were also obtained on AE and PE. However, these parameters increased first with N rates up to N78 and decreased when N rate was increased to 104 kg ha^{-1}. The RE, on the other hand, decreased significantly *($P<0.05$)* with increasing rates of N (Figure 4.3.3.d).

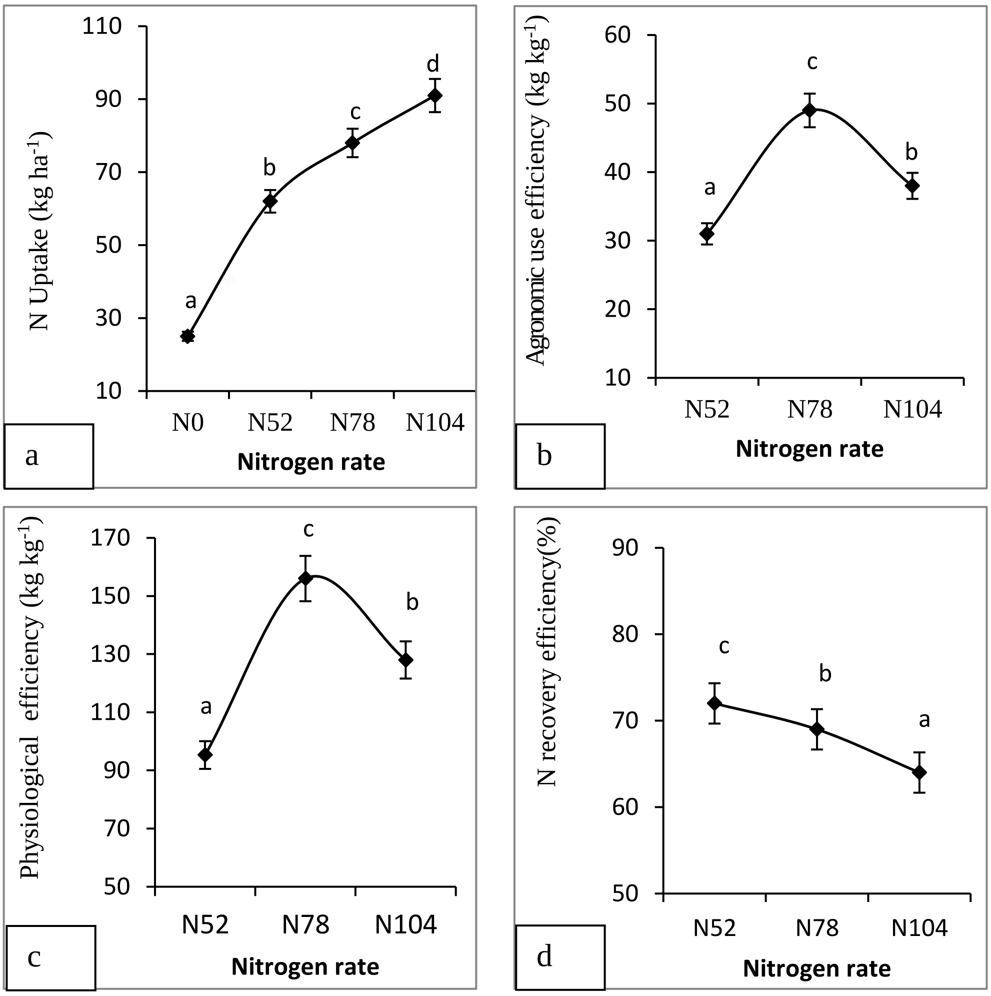


Figure 4.3.3: Effect of nitrogen rate on NU (a), AE (b), PE (c) and RE (d) at Ablotsri site in season 1

- ***Interaction effect of the treatments on rice NU and NUE. Ablotsri site, season 1***

The interaction effects among the different treatments on nitrogen uptake (NU) and use efficiency (NUE) are presented in Table 4.3.3. The results showed that the interaction among the rice variety and type of urea, among rice variety and nitrogen rate had not any significant effect *($P>0.05$)* on the NU, AE, PE and RE. However, the interactions among the type of urea and the rate of nitrogen showed significant *($P>0.05$)* effects on NU, AE and PE. The highest N uptake (108 kg ha^{-1}) was observed with USG *N104 followed by USG*N78 (91 kg ha^{-1}). The lowest NU (26 kg ha^{-1}) was obtained with the control.

The highest AE (55 kg ha^{-1}) was observed with the deep placement of USG at 78 kg N ha^{-1} while the lowest (18 kg ha^{-1}) was obtained with the surface broadcasting of PU at 52 kg N ha^{-1}. The same trend was observed for the PE where the highest (135 kg kg^{-1}) was observed with USG deep placed at N78 and the lowest (71 kg kg^{-1}) with the PU at the rate of 52 kg N ha^{-1}.

Table 4.3.3: Interaction effects of rice variety, type of urea and nitrogen rate on NU, AE, PE and RE. *Ablotsri site, Season 1*

Interactions	NU (kg ha^{-1})	AE (kg kg^{-1})	PE (kg kg^{-1})	RE (%)
Variety*Type of urea				
IR-841*PU	54	32	139	49
IR-841*USG	73	46	119	85
TG-405*PU	55	31	127	52
TG-405*USG	74	48	121	87
Fpr	*0.872*	*0.258*	*0.075*	*0.360*
LSD	*NS*	*NS*	*NS*	*NS*

Table 4.3.3 :(continuous)

Interactions	NU (kg ha^{-1})	AE (kg kg^{-1})	PE (kg kg^{-1})	RE (%)
Variety*Nitrogen rate				
IR-841* N0	25	-	-	-
IR-841*N52	62	30	92	71
IR-841* N78	77	48	160	67
IR-841* N104	90	39	135	63
TG-405* N0	25	-	-	-
TG-405 *N52	63	32	98	74
TG-405 * N78	80	50	152	70
TG-405 * N104	92	37	122	65
Fpr	*0.407*	*0.361*	*0.087*	*0.360*
LSD	*NS*	*NS*	*NS*	*NS*
Type of urea* Nitrogen rate				
PU * N0	26 a	-	-	-
PU *N52	54 b	18 a	71 a	54
PU * N78	65 c	43 c	177 f	51
PU * N104	74 e	34 b	151 e	47
USG * N0	24 a	-	-	-
USG *N52	71 d	44 c	120 c	90
USG * N78	91 f	55 d	135 d	87
USG * N104	108 g	42 c	106 b	81
Fpr	*<.001*	*<.001*	*<.001*	*0.392*
LSD	*2.315*	*3.607*	*12.25*	*NS*
CV	*3.1*	*7.6*	*8.1*	*2.2*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

4.3.1.1.2. Results at Ablotsri site; season 2

- ***Rice growth, yield components and yield as affected by variety, urea type and nitrogen rate. Ablotsri site, Season 2***

The Table 4.3.4 summarizes the effects of rice variety, type of urea and rate of nitrogen on the rice growth, yield components and yield. The plant height was significantly *($P<0.05$)* affected by the variety in the second season. As in the first season, TG-405 showed greater height than the IR-841. Likewise the TG-405 had greater grain yield and the harvest index than IR-841. However, no significant *($P>0.05$)* effects of the rice variety were observed on the number of tillers, the length of panicles, the weight of 1000 grains and the straw yield.

The type of urea significantly *($P<0.05$)* affected the plant height and length of panicles in the second season at Ablotsri site. The deep placement of USG showed significant increase in rice height and length of panicles over the PU surface broadcasting. Similarly, grain yield and straw yield were significantly influenced by the type of urea. The USG increased the grain yield and straw yield by 23% and 22% respectively over the PU. The type of urea showed no significant difference *($P<0.05$)* in the number of tillers, weight of 1000 grains and harvest index, (Table 4.3.4).

The nitrogen rate significantly *($P<0.05$)* affected the rice height, the number of panicles, the weight of 1000 grains, and the grain and straw yields. For plant height, the rate of 104 kg N ha^{-1} as well as 78 kg N ha^{-1} showed the highest performance. Similar trends were observed on the number of tillers per hill, the weight of 1000 grains and grain and straw yield. The N rate of 104 kg ha^{-1} produced the highest grain yield followed by the N78. Generally, the lowest parameters were recorded with the control (Table 4.3.4).

Table 4.3.4: Effects of rice variety, urea mode of application and nitrogen rate on rice growth, yield components and yield. *Ablotsri site, Season 2*

Treatments	Height (cm)	Number of tillers per hill	Length of panicles (cm)	Weight of 1000 grains (g)	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index
Rice Variety							
IR-841	93 a	16	22	26	3945 a	4631	46 a
TG 405	97 b	17	21	26	4228 b	4720	47 b
Fpr	*<.001*	*0.329*	*0.477*	*0.989*	*<.001*	*0.424*	*0.026*
LSD	*1.141*	*NS*	*NS*	*NS*	*112.2*	*NS*	*0.916*
Type of Urea							
PU	93 a	16	21 a	26	3667 a	4212 a	47
USG	98 b	17	22 b	27	4506 b	5139 b	47
Fpr	*<.001*	*0.186*	*<.001*	*0.113*	*<.001*	*<.001*	*0.798*
LSD	*1.141*	*NS*	*0.996*	*NS*	*112.2*	*222.9*	*NS*
Nitrogen Rate							
N0	71 a	10 a	17	24 a	1683 a	1944 a	46
N52	92 b	15 b	22	26 b	3733 b	4460 b	46
N78	108 c	21 c	24	28 c	5258 c	6025 c	47
N104	109 c	21 c	24	28 c	5671 d	6273 c	47
Fpr	*<.001*	*<.001*	*0.477*	*<.001*	*<.001*	*<.001*	*0.082*
LSD	*1.614*	*2.662*	*1.409*	*1.341*	*158.6*	*315.2*	*NS*
CV	*2.1*	*7.3*	*3.9*	*7.3*	*4.7*	*8.1*	*6.2*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

- ***Interaction effects of rice variety, type of urea and rate of urea on rice growth, yield components and yield at Ablotsri site in season 2***

The interaction effects among the treatments studied in the second season at Ablotsri site is presented in Table 4.3.5. Results indicate no significant interaction between the rice variety and the type of urea on the rice growth, yield components and yield, suggesting that the effect of the urea application mode on the parameters studied did not depend on the rice variety and vice versa.

The interaction effect among the rice variety and the nitrogen rate was not significant *($P>0.05$)* on the number of tillers, the length of panicles, the weight of 1000 grains, the grain and straw yields and the harvest index. However, the interaction was significant *($P<0.05$)* on the rice height. The highest height (113 cm) was recorded when nitrogen rate of 104 kg ha^{-1} was applied on TG-405. N78 and N104 applied on IR-841 showed statistically similar height (106 cm). The lowest rice height (71 cm) was recorded with the control without nitrogen supply (Table 4.3.5).

The interaction among the urea mode of application and the nitrogen rate affected the plant height, the grain yield and the straw yield. The plant height was the highest (110 cm) when USG was deep placed at 104 and 78 kg N ha^{-1}. The grain yield and straw yield were however the highest with the deep placement of USG at the rate of 104 kg N ha^{-1}. The interaction effects among the urea mode of application and the nitrogen rate on the plant height, grain and straw yields were the lowest with the control treatment (Table 4.3.5).

The interaction among the rice varieties, the urea mode of application and the nitrogen rate did not affect the growth parameters, yield components and yield. Results on the effects of these interactions are presented in Appendix 3

Table 4.3.5: The interaction effects of rice variety, type of urea and rate of urea on rice growth, yield components and yield at Ablotsri site in season 2

Treatments	Height (cm)	Number of tillers per hill	Length of panicles (cm)	Weight of 1000 grains (g)	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index
Variety*Type of urea							
IR-841*PU	91	16	21	26	3527	4158	46
IR-841*USG	96	17	23	27	4362	5104	46
TG-405*PU	94	17	21	26	3806	4267	47
TG-405*USG	100	17	22	27	4650	5173	47
Fpr	*0.388*	*0.641*	*0.058*	*0.709*	*0.941*	*0.856*	*0.851*
LSD	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Variety Nitrogen rare							
IR-841* N0	71 a	10	17	24	1575	1825	46
IR-841*N52	92 b	15	22	26	3604	4612	44
IR-841* N78	106 c	21	24	28	5042	5996	46
IR-841* N104	106 c	20	24	28	5558	6092	48
TG-405* N0	71 a	10	17	24	1792	2062	47
TG-405 *N52	93 b	16	22	26	3862	4308	47
TG-405*N78	109 d	21	24	28	5475	6054	47
TG-405*N104	113 e	21	24	28	5783	6454	47
Fpr	*<.001*	*0.275*	*0.449*	*0.800*	*0.482*	*0.171*	*0.082*
LSD	*2.282*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Type of urea* Nitrogen rate							
PU * N0	71 a	10	17	24	1633 a	1887 a	46
PU *N52	85 b	15	21	26	2742 b	3167 b	46
PU * N78	106 d	20	23	28	4933 c	5904 c	46
PU * N104	108 e	20	23	27	5358 d	5892 c	48
USG * N0	71 a	10	17	25	1733 a	2000 a	46
USG *N52	99 c	15	23	27	4725 c	5754 c	45
USG * N78	110 e	21	24	28	5583 d	6146 c	48
USG * N104	110 e	21	25	28	5983 e	6654 d	47
Fpr	*<.001*	*0.522*	*0.411*	*0.855*	*<.001*	*<.001*	*0.121*
LSD	*2.282*	*NS*	*NS*	*NS*	*226.3*	*443.2*	*NS*
CV	*2.1*	*7.3*	*3.9*	4.3	4.7	8.0	3.3

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

Rice nitrogen uptake and nitrogen use efficiency as affected by the variety, urea type and nitrogen rate. Ablotsri site, Season 2

The effect of the treatments on the nitrogen uptake and nitrogen use efficiency of rice at Ablotsri site in the second season are represented by Figures 4.3.4. The results indicate significant ($P<0.05$) effect of the rice variety on nitrogen uptake, physiological efficiency and recovery efficiency. TG-405 had higher NU (65 kg ha^{-1}), and RE (69%) than IR-841 (61 kg ha^{-1} and 66% respectively). The trend contradicts that of PE on which, IR-841 showed a significant ($P<0.05$) superiority over TG-405. Rice variety did not significantly ($P>0.05$) affect the AE (Figure 4.3.4).

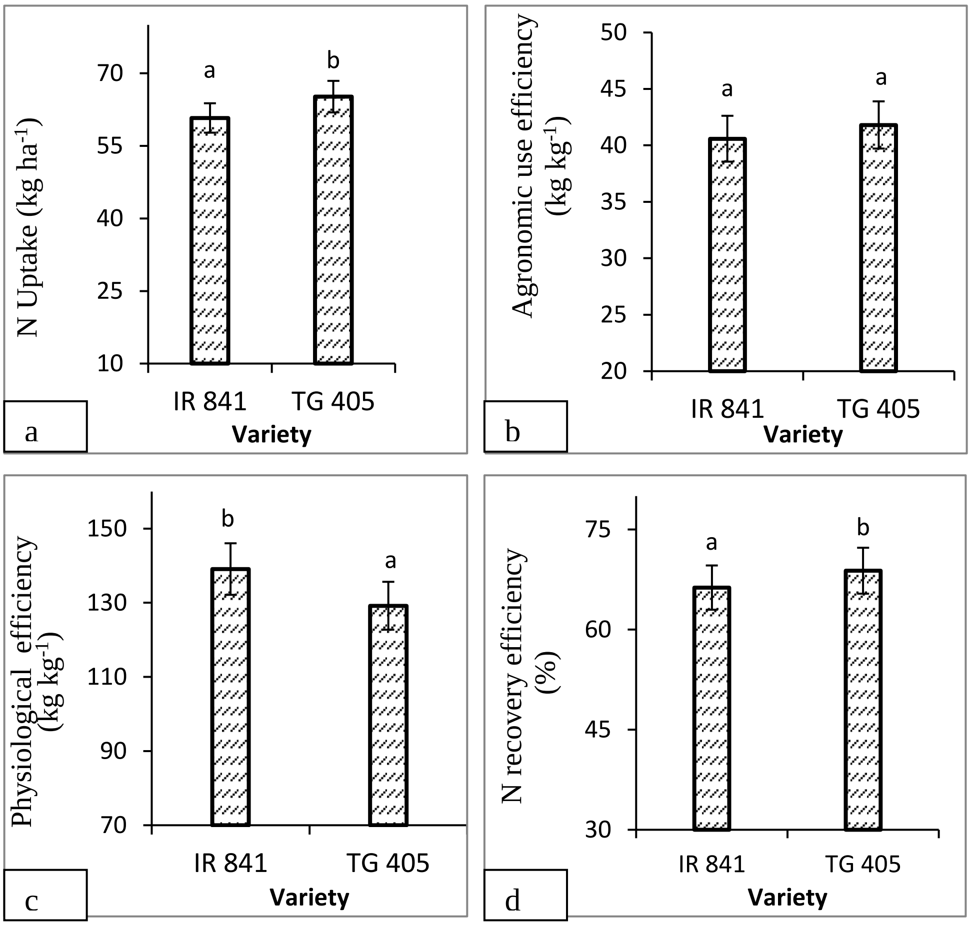


Figure 4.3.4: Effect of rice variety on NU (a), AE (b), PE (c) and RE (d) at Ablotsri site, Season 2

The nitrogen uptake and use efficiency were significantly *($P<0.05$)* affected by the type of urea (Figure 4.3.5). The NU, AE and RE were higher with USG (75 kg ha^{-1}, 49 kg kg^{-1}, 85% respectively) than PU (50 kg ha^{-1}, 33 kg kg^{-1}, 50% respectively). Inversely, the PU showed higher PE (144 kg kg^{-1}) than USG (124).

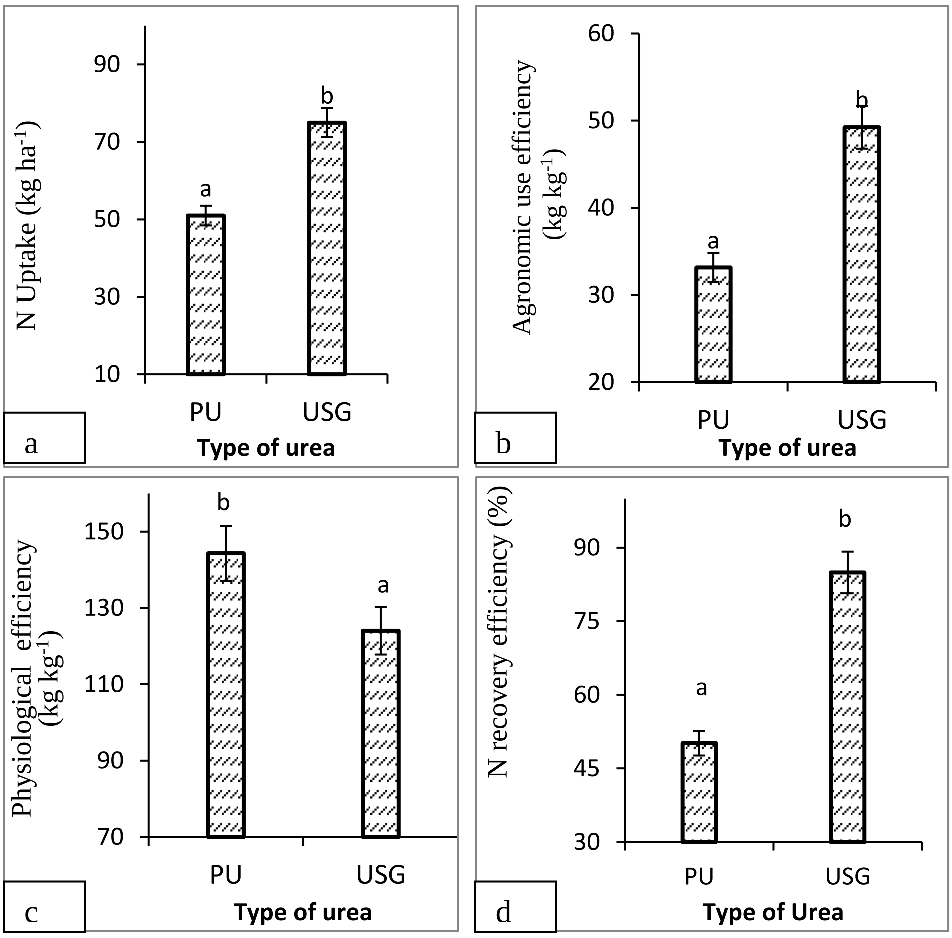


Figure 4.3.5: Effect of the type of urea on NU (a), AE (b), PE (c) and RE (d) at Ablotsri site in season 2

The rate of nitrogen showed significant *($P<0.05$)* effects on nitrogen uptake and N use efficiency of rice. NU increased with increasing rate of nitrogen application. The highest

NU (88 kg ha^{-1}) was obtained with N104 and the lowest (24 kg ha^{-1}) with the control (Figure 4.3.6.a).

Nitrogen rate of 78 kg ha^{-1} gave the highest performance of AE and PE: 46 and 151 kg kg^{-1} respectively (Figure 4.3.6.b and c). The RE decreased significantly with increasing rate of N. The higher RE (72%) was recorded by 52 kg N ha^{-1} followed by 78 kg ha^{-1} (69%) while the lowest was recorded with N rate of 104 kg ha^{-1} :62% (Figure 4.3.6.d).

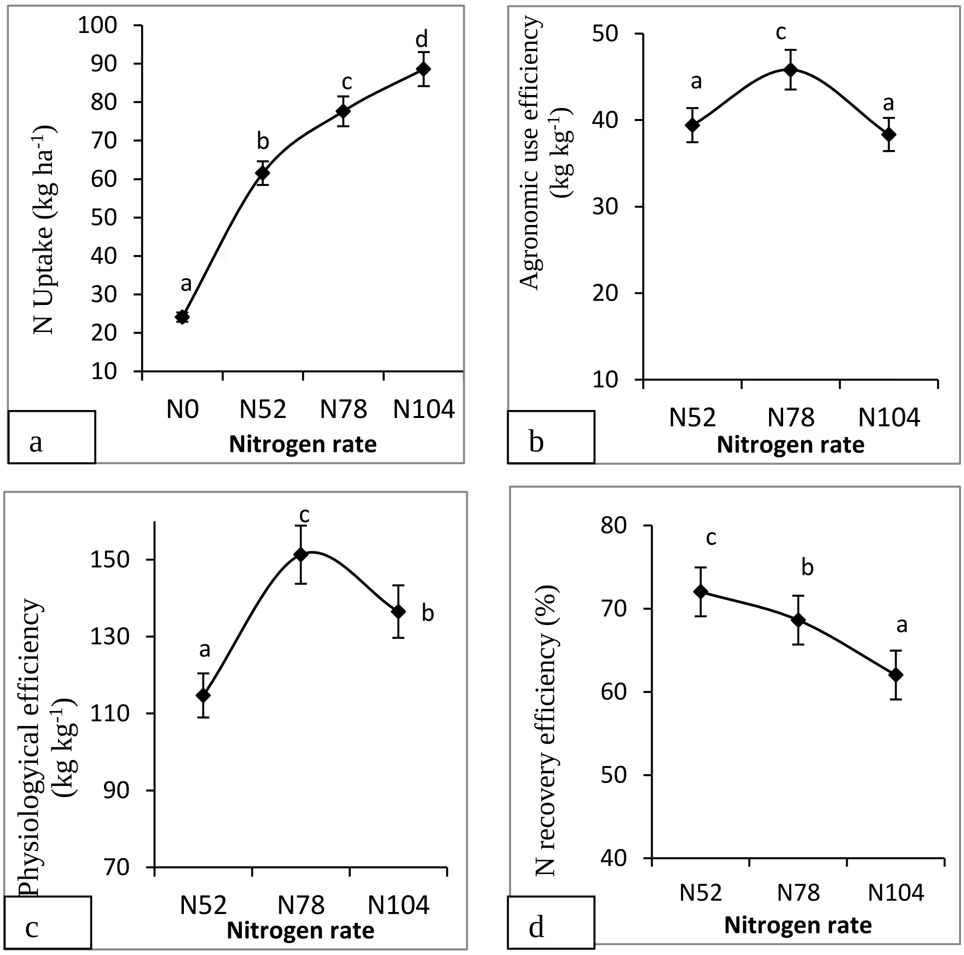


Figure 4.3.6: Effect of nitrogen rate on NU (a), AE (b), PE (c) and RE (d) at Ablotsri site in season 2

- *Interaction effects of rice variety, urea type and nitrogen rate on rice nitrogen uptake and nitrogen use efficiency. Ablotsri site, Season 2*

Results on the interaction effects among the treatments on the nitrogen uptake and use efficiency are presented in Table 4.3.6. Results showed no significant *($P>0.05$)* interaction effect of the rice variety and urea mode of application on the nitrogen uptake and use efficiency parameters of rice. Similarly, the interaction among the rice variety and the rate of nitrogen applied did not showed significant effect. These results suggest that the effects of the urea mode of application and the nitrogen rate on rice NU and use efficiency did not depend on the rice variety at Ablotsri site in the second season.

The interaction between the type of urea and the nitrogen rate significantly *($P<0.05$)* affected the NU, AE, and PE. The highest nitrogen uptake (108 kg ha^{-1}) was obtained with USG deep placed at N of 104 kg ha^{-1} while the lowest NU (22 kg ha^{-1}) was obtained with the control. In terms of AE, the best performance was obtained with the USG deep placed at 78 kg ha^{-1} while the highest PE was shown with the PU broadcasted at N rate of 104 kg ha^{-1}. For the RE, results showed no significant *($P>0.05$)* effect of the interactions between the urea mode of application and the rates of nitrogen applied (Table 4.3.6).

Table 4.3.6: Interaction effects of rice variety, type of urea and nitrogen rate on NU, AE, PE and RE. *Ablotsri site, Season 2*

Treatments	Nitrogen uptake (kg ha^{-1})	Agronomic efficiency (kg kg^{-1})	Physiology efficiency (kg kg^{-1})	Nitrogen Recovery (%)
*Variety*Type of urea*				
IR-841*PU	48	33	152	48
IR-841*USG	73	48	127	84
TG-405*PU	54	33	137	52
TG-405*USG	77	50.28	121	86
Fpr	*0.366*	*0.471*	*0.265*	*0.163*
LSD	*NS*	*NS*	*NS*	*NS*
*Variety*Nitrogen rate*				
IR-841* N0	23	-	-	-
IR-841*N52	60	392	122	71
IR-841* N78	75	44	157	67
IR-841* N104	86	39	139	61
TG-405* N0	26	-	-	-
TG-405 *N52	64	40	108	73
TG-405 * N78	80	47	146	70
TG-405 * N104	91	38.38	134	63
Fpr	*0.532*	*0.607*	*0.630*	*0.788*
LSD	*NS*	*NS*	*NS*	*NS*
Type of urea Nitrogen rate*				
PU * N0	22 a	-	-	-
PU *N52	50 c	21 a	85 a	54
PU * N78	62 d	42 c	183 e	51
PU * N104	69 e	36 b	164 d	45
USG * N0	26 b	-	-	-
USG *N52	73 f	58 e	144 c	90
USG * N78	93 g	49 d	119 b	86
USG * N104	108 h	41 c	109 b	79
Fpr	*<.001*	*<.001*	*<.001*	*0.325*
LSD	*2.735*	*4.053*	*15.00*	*NS*
CV	*3.7*	*8.2*	*9.3*	*3.2*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

4.3.1.1.3. Comparison of the rice growth, yield and nitrogen use efficiency between the two seasons at Ablotsri site

The Table 4.3.7 indicates the effect of growing season on the rice growth, yield parameters and yield. In general, results showed that the values were not significantly *($P<0.05$)* different during the two seasons. On average, rice height of 95 cm and 17 tillers number were recorded for both seasons. Similar trends of average weight of 1000 grains (27 g), grain yield (4062 kg ha^{-1}), straw yield (4046 kg ha^{-1}), and harvest index (47%), were obtained for the two seasons at Ablotsri site.

Table 4.3.7: Rice growth, yield components and yield as affected by the season at Ablotsri site.

Season	Height (cm)	Number of tillers per hill	Length of panicles (cm)	Weight of 1000 grains (g)	Grain Yield (kgha^{-1})	Straw Yield (kgha^{-1})	Harvest Index
Season 1	96	16.8	23.1	26.5	4038	4621	46.5
Season 2	95	16.5	23.3	26.6	4086	4670	46.6
Fpr	*0.269*	*0.235*	*0.053*	*0.248*	*0.264*	*0.366*	*0.586*
LSD	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
CV	*2.0*	*8.7*	*4.0*	*3.8*	*5.2*	*6.9*	*2.6*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

The Table 4.3.8 compares the nitrogen uptake and use efficiency during the seasons at Ablotsri site. The results showed that the nitrogen uptake (NU) and recovery efficiency (RE) did not vary from one season to another. However, the season significantly *($P<0.05$)* affected the agronomic use efficiency (AE) and the physiological efficiency (PE) which were higher in the second season (41 kg kg^{-1} and 134 kg kg^{-1} respectively) than in the first season (39 kg kg^{-1} and 127 kg kg^{-1} respectively).

Table 4.3.8: Rice nitrogen uptake and nitrogen use efficiency parameters as affected by season at Ablotsri site.

Season	Nitrogen uptake (kg ha^{-1})	Agronomic efficiency (kg kg^{-1})	Physiology efficiency (kg kg^{-1})	Recovery Efficiency (%)
Season 1	64	39 a	127 a	68
Season 2	63	41 b	134 b	67
Fpr	*0.054*	*0.027*	*0.009*	*0.084*
LSD	*NS*	*1.587*	*5.61*	*NS*
CV	*4.7*	*8.3*	*9.1*	*2.7*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

4.3.1.2. Results at Hahome site

4.3.1.2.1. Results at Hahome site; season 1

- ***Rice growth, yield components and yield as affected by variety, urea type and nitrogen rate. Hahome site, Season 1***

Results of the effect of rice variety, urea mode of application and nitrogen rate on rice growth, yield characters and yield are presented in Table 4.3.9. The rice variety did not show any significant *($P>0.05$)* effect on the plant height, number of tillers, weight of 1000 grains and harvest index. However, significant *($P<0.05$)* differences on the length of panicles, grain and straw yields were observed. The highest length of panicles (22 cm), grain yield (3611 kg ha^{-1}) and straw yield (4144 kg ha^{-1}) were recorded with TG-405 while the lower length of panicles (21 cm), grain yield (3357 kg ha^{-1}) and straw yield (3778 kg ha^{-1}) were recorded with the IR-841 (Table 4.3.9).

The type of urea produced significant *($P<0.05$)* effects on plant height, length of panicle, straw and grain yields while on the number of tillers, weight of 1000 grains and harvest index, no significant differences *($P>0.05$)* were observed. For the parameters where the type of urea was significant, the deep placement of USG performances were considerably higher compared with surface application of PU (Table 4.3.9).

The rate of nitrogen significantly *($P<0.05$)* influenced the growth and yield parameters. Increase in height, straw yield and grain yield were observed with increasing rates of nitrogen. However, similar and best performances in terms of number of tillers, and length of panicles were obtained with N rates of 78 and 104 kg ha^{-1}. For the 1000 grains, the rates of 52, 78 and 104 kg N ha^{-1} produced similar values but higher as compared with the control. The highest rice height (105 cm), grain yield (5156 kg ha^{-1}) straw yield (5662 kg ha^{-1}) and harvest index (48%) were recoded for N rate of 104 kg ha^{-1}. The lowest performances were all observed for the control without N application (Table 4.3. 9).

Table 4.3.9: Effects of rice variety, type of urea and nitrogen rate on rice growth, yield components and yield. *Hahome site, Season 1*

Treatment	Height (cm)	Number of tillers per hill	Length of panicles (cm)	Weight of 1000 grains (g)	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index
Rice Variety							
IR-841	92.1	12.1	21 a	25.6	3357 a	3778 a	46.82
TG 405	92.3	12.6	22 b	25.7	3611 b	4144 b	46.39
Fpr	*0.540*	*0.366*	*<.001*	*0.818*	*<.001*	*<.001*	*0.110*
LSD	*NS*	*NS*	*0.39*	*NS*	*92.3*	*128.2*	*NS*
Urea Mode of application							
PU	91 a	12	21 a	25	3177 a	3623 a	46.54
USG	93 b	13	22 b	26.	3792 b	4299 b	46.67
Fpr	*0.002*	*0.103*	*< 0.001*	*0.108*	*<.001*	*<.001*	*0.618*
LSD	*0.889*	*NS*	*0.39*	*NS*	*92.3*	*128.2*	*NS*
Nitrogen rate							
N0	72 a	7.58 a	17 a	24 a	1419 a	1667 a	45.99 a
N52	89 b	12 b	22 b	25 b	3056 b	3565 b	46.21 a
N78	103 c	14 c	24 c	26 b	4306 c	4950 c	46.53 a
N104	105 d	15 c	24 c	27 b	5156 d	5662 d	47.67 b
Fpr	*<.001*	*<.001*	*<.001*	*0.002*	*<.001*	*<.001*	*<.001*
LSD	*1.257*	*1.572*	*0.555*	*1.156*	*130.5*	*181.4*	*0.752*
CV	*1.6*	*15.3*	*3.1*	*5.4*	*4.5*	*5.5*	*1.9*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

Interaction effects between treatments on rice growth, yield components and yield at Hahome site, Season 1

The interaction effects among rice variety and urea mode of application, rice variety and nitrogen rate, type of urea and nitrogen rate were significant *($P<0.05$)* on rice grain yield and straw yield. The highest grain yields were obtained with TG-405*USG (4000 kg ha^{-1}), TG-405*N104 (5321 kg ha^{-1}) and USG*N104 (5379 kg ha^{-1}) and the highest straw yields were 4625 kg ha^{-1} for TG-405*USG, 5854 kg ha^{-1} for TG-405*N104 and 5917 kg ha^{-1} for USG*N104 (Table 4.3.10). The interactions IR-841*PU, IR-841*N0 and PU*N0 showed the lowest grain and straw yields. The interactions between variety, urea mode of application and nitrogen rate did not significantly *($P>0.05$)* affect the growth and yield parameters (Appendix 4).

Table 4.3.10. The interaction effects of variety, type of urea and nitrogen rate on rice growth, yield components and yield. *Hahome site, Season 1*

Treatments	Height (cm)	Number of tillers per hill	Length of panicles (cm)	Weight of 1000 grains (g)	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index
Variety x Type of urea							
IR-841*PU	92	11	21	25	3131 a	3523 a	47
IR-841*USG	93	13	22	26	3583 b	4033 c	47
TG-405*PU	91	12	22	25	3223 a	3723 b	46
TG-405*USG	93	13	23	26	4000 c	4565 d	46
Fpr	*0.268*	*0.445*	*0.545*	*0.913*	*0 001*	*0 013*	*0.849*
LSD	*NS*	*NS*	*NS*	*NS*	*130 5*	*181 4*	*NS*
CV	*1.7*	*15.1*	*9.7*	*5.6*	*4.5*	*5.5*	*1.9-*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

Table 4.3.10 (continuation)

Treatments	Height (cm)	Number of tillers per hill	Length of panicles (cm)	Weight of 1000 grains (g)	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index
Variety*Nitrogen rate							
IR-841*N0	72	8	17	24.5	1446 a	1696 a	46.1
IR-841*N52	89	11	22	25.5	2817 b	3262 b	46.4
IR-841*N78	103	14	23	26.3	4175 d	4683 d	47.1
IR-841*N104	104	15	23	26.3	4992 e	5471 e	47.7
TG-405* N0	73	8	17	24.2	1392 a	1638 a	45.9
TG-405*N52	89	13	22	25.3	3296 c	3867 c	46.1
TG-405*N78	102	15	24	26.4	4438 f	5217 e	45.9
TG-405*N104	105	16	25	26.8	5321 g	5854 f	47.6
Fpr	0.215	0.777	0.509	0.903	0.002	0.004	0.405
LSD	*NS*	*NS*	*NS*	*NS*	184.6	256.5	NS
Type of urea*Nitrogen rate							
PU * N0	72	7	17	24.1	1429 a	1679 a	46.0
PU *N52	89	12	22	25.3	2279 b	2633 b	46.4
PU * N78	102	14	23	25.9	4067 d	4771 d	46.1
PU * N104	103	15	24	26.1	4933 f	5408 f	47.7
USG * N0	72	8	18	24.6	1408 a	1654 a	46.0
USG *N52	90	12	22	25.5	3833 c	4496 c	46.1
USG * N78	104	15	24	26.9	4546 e	5129 e	47.0
USG * N104	106	16	24	27.0	5379 g	5917 g	47.6
Fpr	*0.377*	*0.672*	*0.832*	*0.942*	*<.001*	*<.001*	*0.376*
LSD	-	-	-	-	*184.6*	*256.5*	-
CV	*1.7*	*15.1*	*9.7*	*5.6*	*4.5*	*5.5*	*1.9*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

- ***Rice nitrogen uptake and use efficiency as affected by the treatments; Hahome site, season 1***

Results of the effects of the treatments on the NU, AE, PE and RE showed significant differences *($P<0.05$)* . The variety TG-405 showed the higher NU (59 kg ha^{-1}), AE (38 kg kg^{-1}), PE (131 kg kg^{-1}) and RE (67%), while the IR-841 showed lower NU (56 kg kg^{-1}), AE (38 kg kg^{-1}), PE (119 kg kg^{-1}) and RE (61%) (Figure 4.3.7).

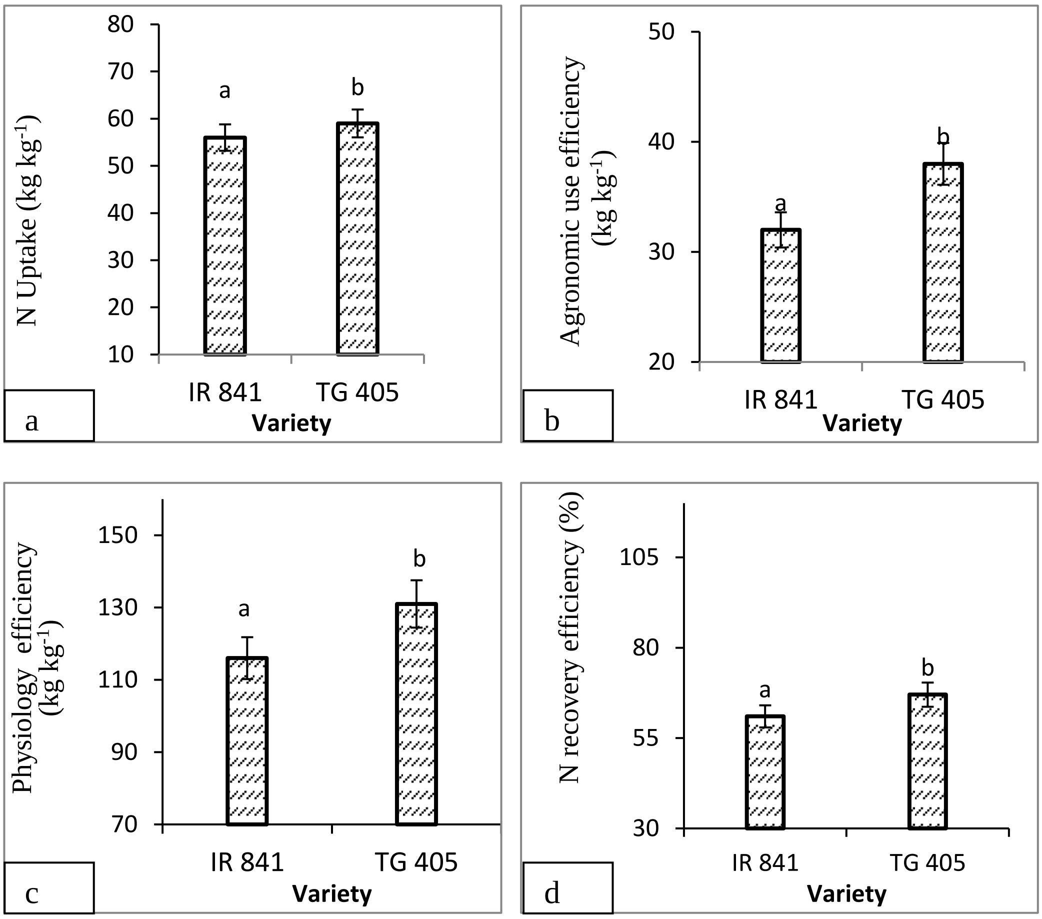


Figure 4.3.7: Effect of rice variety on NU (a), AE (b), PE (c) and RE (d) at Hahome site, season 1

The urea mode of application affected differently the nitrogen uptake and use efficiency parameters (Figure 4.3.8). NU, AE and RE were higher with the deep placement of USG as compared with the surface application of urea. However, the PE was higher with the PU (136 kg kg^{-1}) than USG (110 kg kg^{-1}) (Figure 4.3.8.c).

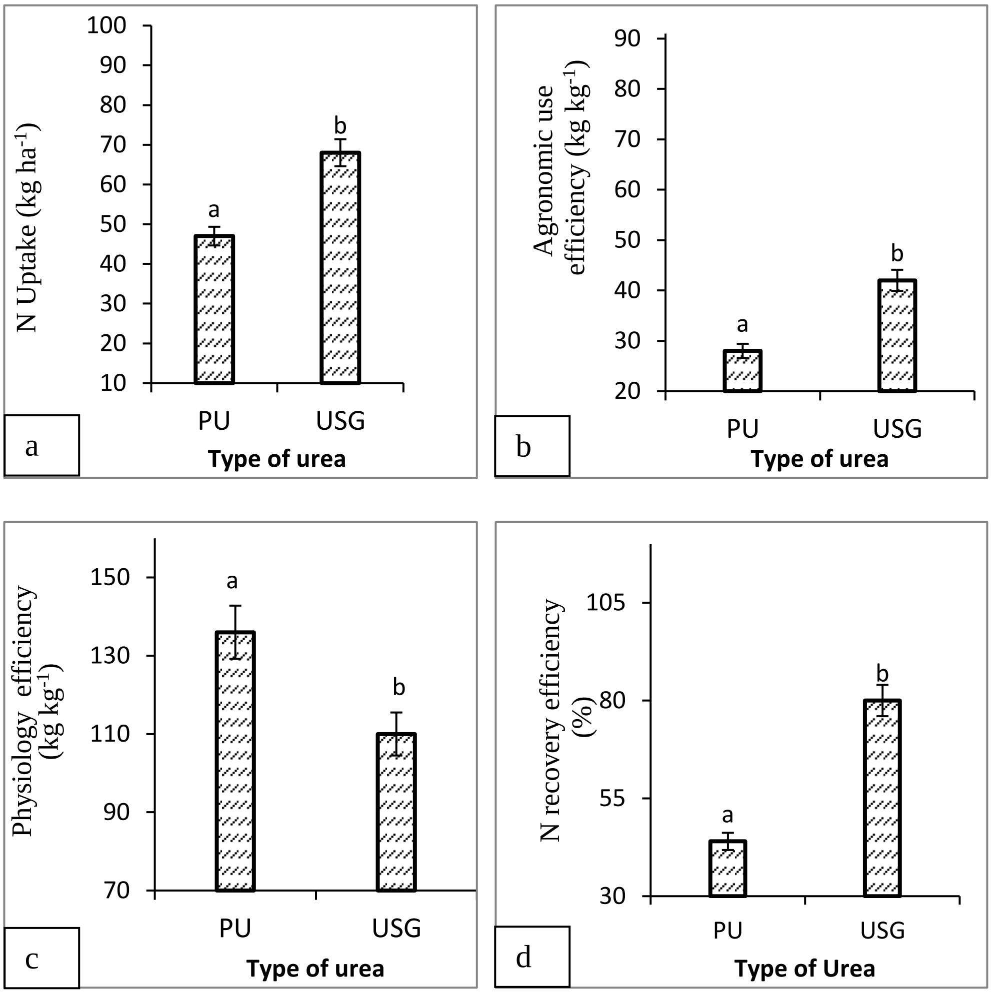


Figure 4.3.8: Effect of urea mode of application on NU (a), AE (b), PE (c) and RE (d) at Hahome site, season 1

The nitrogen rate also significantly *($P<0.05$)* affected the NU and the nitrogen use efficiency parameters. The NU increased with increasing rate of N. It was highest with N104 (81 kg ha^{-1}) and was lowest with N52 (21 kg ha^{-1}). The increase of N rate resulted in a decrease in RE. Similar pattern for AE and PE where obtained where N78 and N104 were not significantly different.

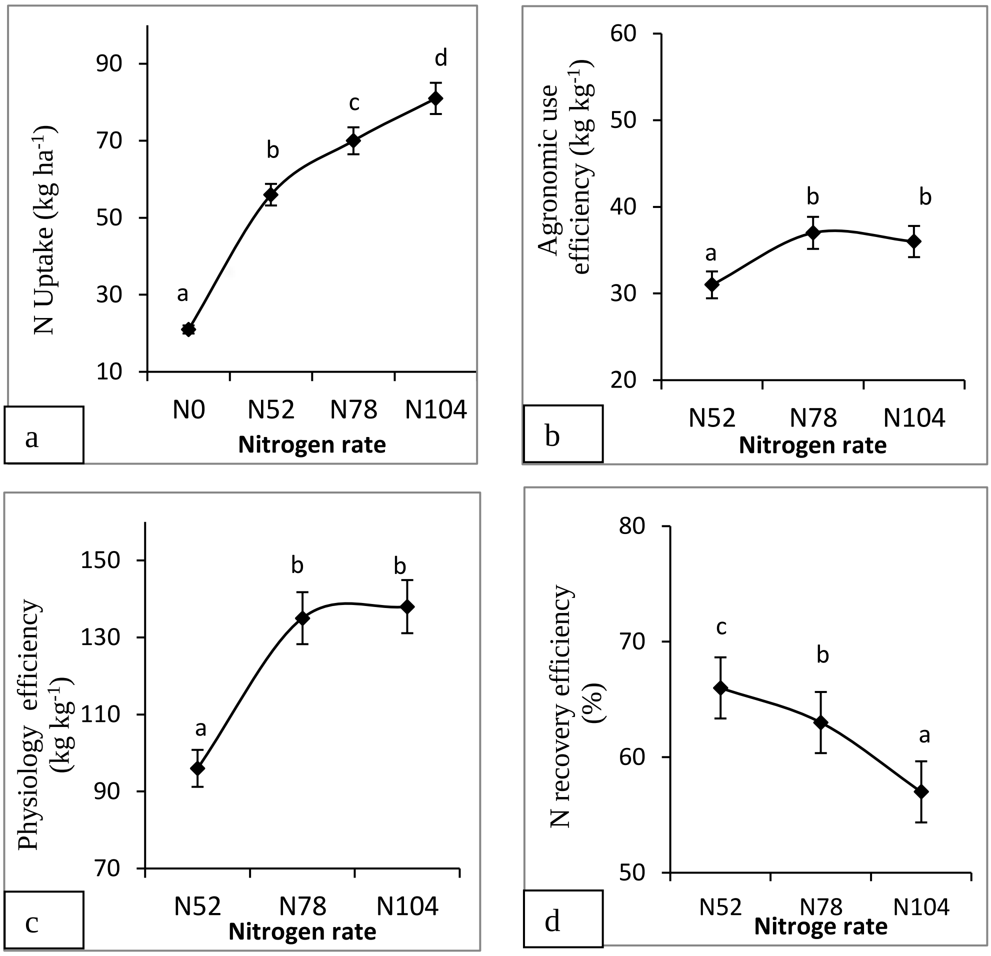


Figure 4.3.9: Effect of nitrogen rate on NU (a), AE (b), PE (c) and RE (d) at Hahome site; season 1

- ***Interaction effect of the treatments on rice nitrogen uptake and nitrogen use efficiency. Hahome site season 1***

The interaction effects among variety and the type of urea, variety and nitrogen rate, type of urea and nitrogen rate are summarized in Table 4.3.11. Results indicated *($P<0.05$)* significant effects of the interaction among variety and urea mode of application on AE and RE. They were respectively the highest (46 kg kg^{-1} kg and 82%) for TG-405*USG and the lowest (26 kg kg^{-1} and 42%) for IR841*PU. The interaction between variety and mode of application of urea did not show no significant difference on the NU and PE. Similarly, no statistical difference was observed for the interaction effect among variety and nitrogen rate on the NU, PE and RE.

Results revealed significant effects *($P<0.05$)* of the interaction among the type of urea and the rate of nitrogen on NU, AE, and PE. The highest NU (98 kg ha^{-1}) was recorded for USG*N104 and the lowest (21 kg ha^{-1}) for the control. USG*N78 and USG*N104 showed similar but highest AE. The interactions USG*52, USG*78, USG*104 were the same and highest for PE. The lowest AE and PE were obtained for PU*N52 (Table 4.3.11). The interaction between the variety, the type of urea and the nitrogen rate did not affect the NU and the nitrogen use efficiency parameters (Appendix 5)

Table 4.3.11: Interaction effects of rice variety, type of urea and *nitrogen rate* on NU, AE, PE and RE. *Hahome site, Season 1*

Treatments	Nitrogen uptake (kg ha^{-1})	Agronomic efficiency (kg kg^{-1})	Physiology efficiency (kg kg^{-1})	Recovery efficiency (%)
Variety*Type of urea				
IR-841*PU	46	26 a	130	42 a
IR-841*USG	66	37 c	101	79 c
TG-405*PU	48	30 b	142	46 b
TG-405*USG	69	46 d	119	82 c
Fpr	*0.560*	*0.009*	*0.421*	*0.030*
LSD	*NS*	*2.950*	*NS*	*3.460*

Table 4.3.11 (continuation)

Treatments	Nitrogen uptake (kg ha^{-1})	Agronomic efficiency (kg kg^{-1})	Physiology efficiency (kg kg^{-1})	Recovery efficiency (%)
Variety* Nitrogen rate				
IR-841* Ctrl	21	-	-	-
IR-841*N52	55	26 a	81	65
IR-841* N78	69	35 bc	129	61
IR-841* N104	79	34 b	136	56
TG-405* Ctrl	22	-	-	-
TG-405 *N52	57	37 bcd	111	68
TG-405 * N78	72	39 d	140	65
TG-405 * N104	83	38 cd	141	59
Fpr	*0.370*	*0.023*	*0.069*	*0.343*
LSD	*NS*	*3.613*	*NS*	*NS*
Type of urea* Nitrogen rate				
PU * N0	21 a	-	-	-
PU *N52	45 b	16 a	74 a	46
PU * N78	56 c	34 b	166 c	45
PU * N104	64 d	34 b	168 c	41
USG * Ctrl	21 a	-	-	-
USG *N52	66 d	47 d	118 b	86
USG * N78	85 e	40 c	104 b	81
USG * N104	98 f	38 c	109 b	73
Fpr	*<.001*	*<.001*	*<.001*	*0.232*
LSD	*3.022*	*3.613*	*15.26*	*NS*
CV	*4.5*	*5.110*	*10.4*	*5.8*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

4.3.1.2.2. Results at Hahome site; season 2

- ***Rice growth, yield components and yield as affected by the treatments. Hahome site; season 2***

The results of the effect of rice variety, type of urea and nitrogen rate on rice growth, yield components and yield are presented in Table 4.3.12. Results showed that the TG-405 expressed longer length of panicle (22 cm), higher grain yield (3464 kg ha^{-1}) and higher harvest index (47%) than the IR-841 whose length of panicles, straw and grain yields were 21 cm, 3301 kg ha^{-1} and 47% respectively. No significant (P>0.05) effect of rice variety was obtained for plant rice height, total number of tillers, weight of 1000 grains, and straw yield.

The deep placement of USG significantly (P<0.05) had higher plant height, number of tillers, and longer length of panicles than the PU. Likewise, the USG increased the grain and straw yields by 19% over the PU. However, the type of urea did not influence the weight of 1000 grains and the harvest index (Table 4.3.12).

The rate of nitrogen significantly *(P<0.05)* affected all the growth and yield parameters studied. The plant height significantly increased with increasing rate of nitrogen applied. The highest rice height was obtained with 104 kg ha^{-1}. N104 and N78 produced similar and highest number of tillers (16) and weight of 1000 grains (26 g). N52, N78 and N104 produced similar and higher length of panicles (22-24 cm) as compared with the control (16 cm). The grain and straw yields increased significantly with increasing rate of nitrogen. The harvest index also increased with increasing rate of N. The highest value (48) was observed with 104 kg ha^{-1}. However, the N0 and N52 were not significantly *(P>0.05)* different in terms of HI.

Table 4.3.12: Effects of rice variety, type of urea and nitrogen rate on rice growth, yield components and yield. *Hahome site, Season 2*

Treatments	Height (cm)	Number of tillers per hill	Length of panicles (cm)	Weight of 1000 grains (g)	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index
Rice Variety							
IR-841	93	12	21 a	25	3301	3819	46
TG-405	94	13	22 b	26	3464	3804	47
Fpr	*0.179*	*0.895*	*0.002*	*0.170*	*0.008*	*0.825*	*<.001*
LSD	*NS*	*NS*	*1.463*	*NS*	*117.7*	*NS*	*0.574*
Urea mode of application							
PU	93 a	12 a	21 b	25	3095 b	3475 a	47
USG	95 b	13 b	22 a	25	3670 a	4148 b	47
Fpr	*0.002*	*0.002*	*0.004*	*0.424*	*0.001*	*<.001*	*0.939*
LSD	*0.786*	*1.282*	*1.463*	*NS*	*117.7*	*133.8*	*NS*
Nitrogen rate							
N0	72 a	8 a	16 a	24 a	1358 a	1629 a	45.48 a
N52	91 b	11 b	22 b	25 b	2823 b	3350 b	45.67 a
N78	105 c	16 c	23 b	26 c	4285 c	4877 c	46.76 b
N104	107 d	16 c	24 b	26 c	5062 d	5390 d	48.44 c
Fpr	*<0.001*	*<0.001*	*<0.001*	*0.003*	*0.001*	*<0.001*	*<0.001*
LSD	*1.111*	*1.812*	*2.069*	*1.13*	*166.5*	*189.2*	*0.811*
CV	*7.1*	*8.7*	*5.8*	*7.4*	*5.9*	*6*	*2.1*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

- ***Interaction effects of rice variety, type of urea and rate of urea on Rice growth, yield components and yield. Hahome site, Season 2***

Table 4.3.13 represents the interaction effects among the treatments on rice growth, yield parameters and yield. The results indicated no significant *($P>0.05$)* interaction effect among the rice variety and the type of urea. Therefore, during the second season at Hahome site, the performance of a variety on rice growth, yield parameters and yield did not depend on the type of urea applied.

Similarly no significant effects were observed for the interaction between the rice variety and nitrogen rate with regards to rice growth and yield parameters (Table 4.3.13). These results implied that the rice growth and yields of each variety did not depend on the rate of nitrogen applied in the second season at HAhome site.

The interaction among the urea mode of application and nitrogen rate significantly *($P<0.05$)* affected the rice grain and straw yields. Higher rice grain yield was (5254 kg ha^{-1}) was obtained for USG*N104 followed by USG*N78 (4604 kg ha^{-1}). The lowest grain yield was recorded with the control (1375 kg ha^{-1}). The straw yield followed the same trend. However, for this parameter, the highest yield was obtained for USG*N104 (5629 kg ha^{-1}) followed by USG*N78 (5246 kg ha^{-1}) and PU*N104 (5150 kg ha^{-1}).

The interaction effect between mode of application and nitrogen rate was not significant ($P>0.05$) on the rice height, the length of panicles, the number of tillers, the weight of 1000 seeds and harvest index. Similarly, the interaction between the variety, the type of urea and the nitrogen rate did not show any significant effect on the growth and yield parameters evaluated in this study. The results of this interaction are indicated in appendix 6

Table 4.3.13: The interaction effects of variety, type of urea and nitrogen rate on rice growth, yield components and yield. *Hahome site, Season 2*

Interactions	Height (cm)	Number of tillers per hill	Length of panicles (cm)	Weight of 1000 grains (g)	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index
Variety*Type of urea							
IR-841*PU	93	12	20	25	2994	3477	46
IR-841*USG	94	13	21	25	3608	4160	46
TG-405*PU	93	12	21	25	3196	3473	47
TG-405*USG	95	13	23	26	3731	4135	47
Fpr	*0.679*	*0.513*	*0.515*	*0.89*	*0.498*	*0.875*	*0.669*
LSD	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Variety*Nitrogen rate							
IR-841* N0	71	8	16	24	1362	1667	45
IR-841*N52	90	11	21	24	2717	3342	45
IR-841* N78	105	15	23	26	4217	4879	46
IR-841* N104	107	16	23	26	4908	5388	48
TG-405* N0	73	7	17	24	1354	1592	46
TG-405*N52	92	11	23	26	2929	3358	47
TG-405* N78	105	16	24	26	4354	4875	47
TG-405*N104	107	16	25	27	5217	5392	49
Fpr	*0.166*	*0.314*	*0.825*	*0.658*	*0.279*	*0.96*	*0.666*
LSD	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Type of urea* Nitrogen rate							
PU * N0	71	7	16	24	1375 a	1650 a	46
PU *N52	90	11	21	25	2167 b	2592 b	46
PU * N78	104	15	23	26	3967 d	4508 d	47
PU * N104	107	15	24	26	4871 f	5150 e	49
USG * N0	73	8	17	25	1342 a	1608 a	45
USG *N52	92	12	23	25	3479 c	4108 c	46
USG * N78	106	16	24	26	4604 e	5246 e	47
USG * N104	108	16	24	26	5254 g	5629 f	48
Fpr	*0.775*	*0.892*	*0.84*	*0.815*	*<.001*	*<.001*	*0.901*
LSD	*NS*	*NS*	*NS*	*1.598*	*235.5*	*267.5*	*NS*
CV	2.1	8.7	5.8	5.4	5.9	6.0	2.1

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

- ***Rice nitrogen uptake and nitrogen use efficiency as affected by the variety, urea type and nitrogen rate. Hahome site, Season 2.***

Figure 4.3.10 shows the effects of the rice variety on the nitrogen uptake (NU). It shows that the NU, the physiological efficiency (PE) and the recovery efficiency (RE) were not significantly *($P<0.05$)* affected by the rice variety. However, the rice variety influenced the agronomic use efficiency (AE). The TG-405 showed higher AE (35 kg kg^{-1}) as compared with IR-841 (32 kg kg^{-1}).

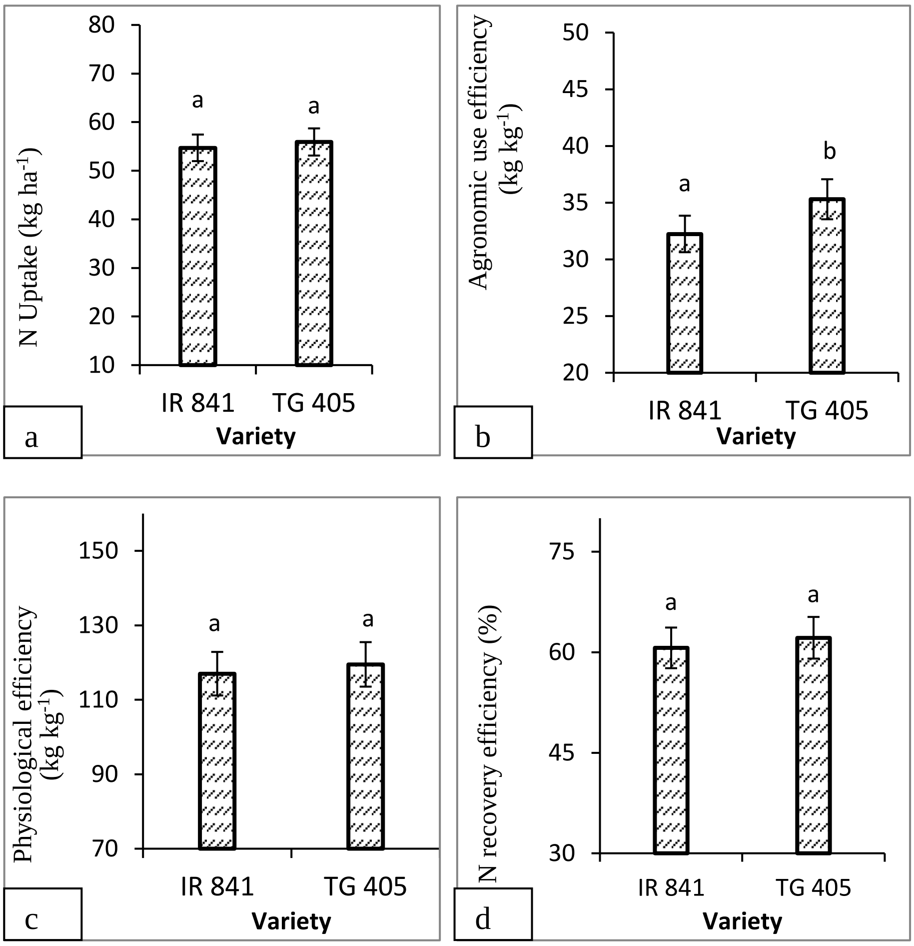


Figure 4.3.10: Effect of rice variety on NU (a), AE (b), PE (c) and RE (d) at Hahome site, season 2

The type of urea significantly *($P<0.05$)* influenced the NU and the different parameters of nitrogen use efficiency (Figure 4.3. 11). The USG significantly *($P<0.05$)* induced higher NU (65 kg ha^{-1}), and AE (40 kg kg^{-1}) over the PU that recorded lower NU (46 kg ha^{-1}) and AE (27 kg kg^{-1}) (Figure 4.3.11 a and b). Similarly, the RE was significantly higher with the USG (77%) than the PU (46%). On the contrary, the PE was higher for the PU (127 kg kg^{-1}) than TG-405 (110 kg kg^{-1}) (Figure 4.3. 11 c)

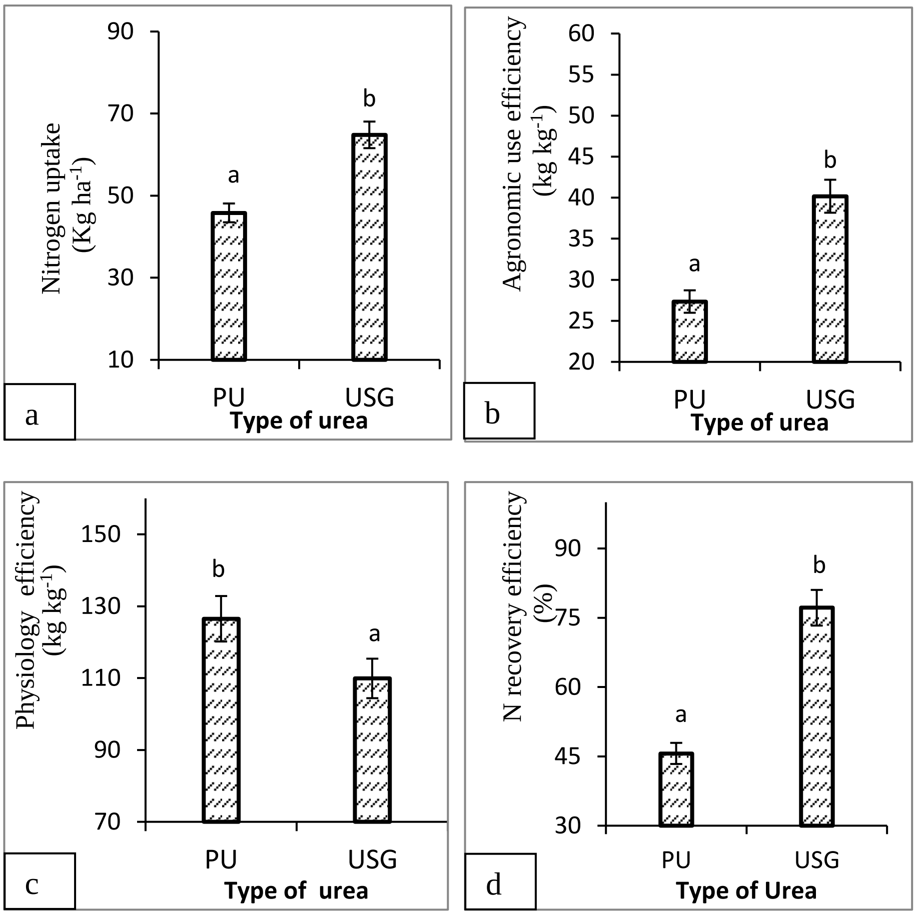


Figure 4.3.11: Effect of type of urea on NU (a), AE (b), PE (c) and RE (d) at Hahome site, season 2

Significant effects *($P<0.05$)* of the nitrogen rate were observed on the nitrogen uptake and nitrogen use efficiency, N physiology and recovery efficiencies. The N uptake increased significantly with increasing rate of N from 20 kg ha^{-1} for the control to 79 kg ha^{-1} for the N104. Similar and highest AE were obtained both with N78 and N104. The same trend was observed for the PE. The RE decreased significantly with increasing rates of nitrogen. RE dropped from 65 to 62 and to 57% for respective nitrogen rates of 52, 78 and 104 kg ha^{-1} (Figure 4.3.12).

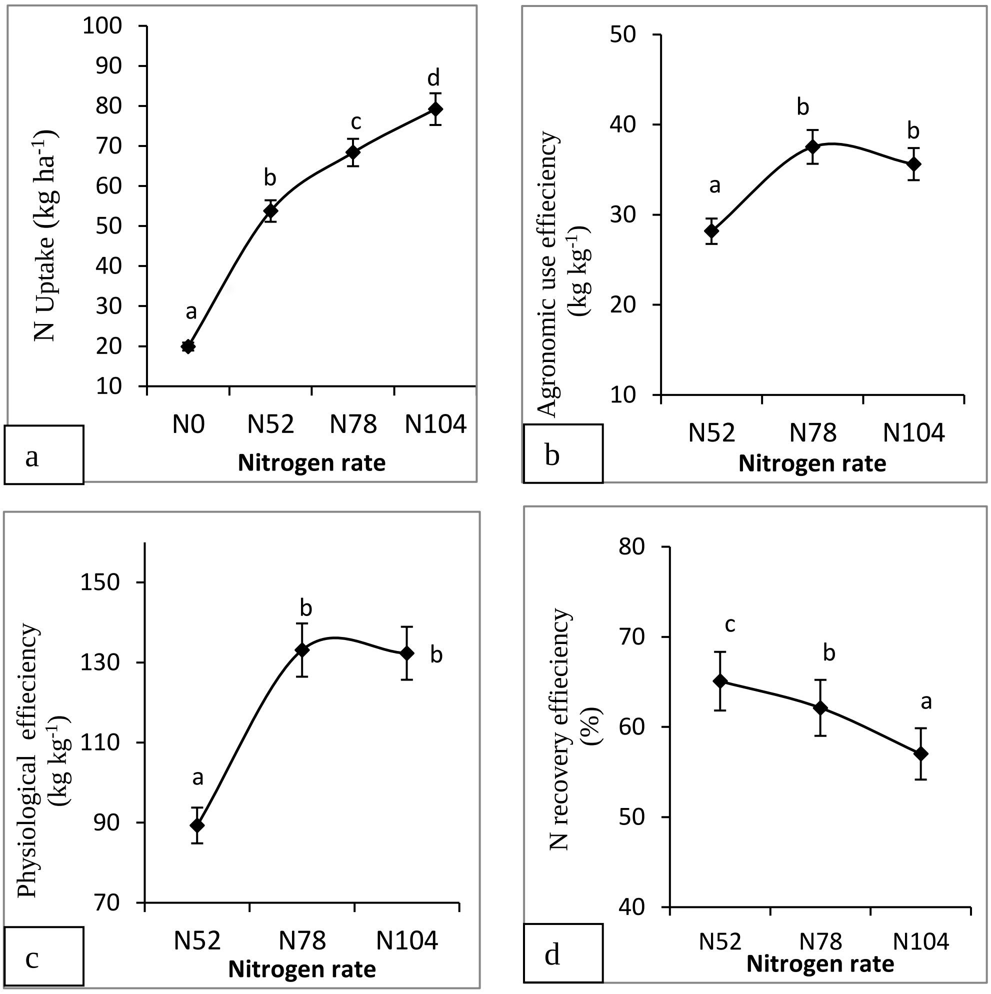


Figure 4.3.12: Effect of *nitrogen rate* on NU (a), AE (b), PE (c) and RE (d) at Hahome site, season 2

- ***Interaction effect of treatments on rice nitrogen uptake and nitrogen use efficiency. Hahome site, season 2***

Results of the interaction between the rice variety and the urea mode of application did not show any significant *(P>0.05)* effect on the nitrogen uptake (NU), agronomic use efficiency (AE), and the physiological use efficiency (PE). The interactions of the two varieties and type of urea produced statistically similar effect on each of the above parameters. However; the interaction between the variety and the type of urea on the recovery efficiency (RE) was significant *(P<0.05)*. Both IR-841*USG and TG-405*USG showed similar but greater RE (77 and 78%) when compared with IR-841*PU and TG-405*PU (44 and 48%). The lowest recovery efficiency (44%) was recorded when PU was applied to IR-841 (Table 4.3.14).

Neither the nitrogen uptake, nor the nitrogen use efficiency was significantly *(P>0.05)* affected by the interactions between the rice varieties and the rates of nitrogen applied leading to the conclusion that, the effect of nitrogen rate on NU, AE, PE and RE, did not depend on the rice variety (Table 4.3.14**)**.

Regarding the interaction between the urea mode of application and the nitrogen rate, significant effects were observed on the NU and nitrogen use efficiency. USG*N104 showed the highest NU (95 kg ha^{-1}) followed by the USG*N78. For AE and PE, the USG*N52, USG*N78 and USG*N104 showed similar but highest performance (Table 4.3.14). PU*N78 and PU*N104 showed similar results for AE and PE. The lowest AE and PE were observed for PU applied at 52 kg ha^{-1}. Contrarily to NU, AE and PE, the RE was not significantly affected by the interaction between the type of urea and the nitrogen rate (Table 4.3.14). The interaction effect between the rice variety, the type of urea and the rate of nitrogen was not significant (Appendix 7).

Table 4.3.14: Interaction effect of rice variety, type of urea and nitrogen rate on NU, AE, PE and RE. *Hahome site, Season 2*

Treatments	Nitrogen uptake (kg ha^{-1})	agronomy efficiency (kg kg^{-1})	Physiology efficiency (kg kg^{-1})	Nitrogen Recovery (%)
Variety*Type of urea				
IR-841*PU	45	25	127	44 a
IR-841*USG	65	39	107	78 c
TG-405*PU	47	30	127	48 b
TG-405*USG	65	41	113	77 c
Fpr	*0.231*	*0.271*	*0.583*	*0.030*
LSD	*NS*	*NS*	*NS*	*3.460*
Variety*Nitrogen rate				
IR-841*N0	20	-	-	-
IR-841*N52	54	26	84	66
IR-841*N78	67	37	134	61
IR-841*N104	78	34	133	56
TG-405*N0	20	-	-	-
TG-405*N52	54	30	95	65
TG-405*N78	69	38	132	63
TG-405*N104	81	37	132	59
Fpr	*0.483*	*0.718*	*0.446*	*0.343*
LSD	*NS*	*NS*	*NS*	*NS*
Type of urea* Nitrogen rate				
PU*No	20 a	-	-	-
PU*N52	45 b	15 a	68 a	49
PU*N78	55 c	33 b	154 c	45
PU*N104	64 d	34 bc	158 c	43
USG*N0	20 a	-	-	-
USG*N52	63 d	41 d	111 b	81
USG*N78	82 e	42 d	112 b	79
USG*N104	95 f	38 cd	107 b	71
Fpr	*<.001*	*<.001*	*<.001*	*0.232*
LSD	*3.757*	*4.248*	*16.56*	*NS*
CV	*5.8*	*10.5*	*11.7*	*5.8*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

- ***Comparision of the rice growth, yield, nitrogen uptake and nitrogen use efficiency between the two season at Hahome site***

Results of the effects of the season on the rice growth, yield components and yield are summarized in Table 4.3.15. The results revealed significant *($P<0.05$)* effect of the season on rice growth in terms of height grain yield and straw yield. Rice was significantly taller (94 cm) in the first season than in the second (92 cm). Even though statistically similar number of tillers (12), length of panicles (21.7-21.4 cm), and weight of 1000 grains (25.3-25.3 g) were recorded for the two seasons, season 1 produced greater grains and straw yields than the second season (3484 and 3282 kg ha^{-1}) at Hahome site (Table 4.3.15).

Table 4.3.15: Rice growth, yield components and yield as affected by season of cultivation.

Season	Height (cm)	Number of tillers per hill	Length of panicles (cm)	Weight of 1000 grains (g)	Grain Yield (kgha^{-1})	Straw Yield (kgha^{-1})	Harvest Index
Season 1	93.79 b	12.33	21.71	25.67	3484 b	3961 b	46.601
Season 2	92.19 a	12.48	21.40	25.33	3382 a	3811 a	46.589
Fpr	*<.001*	*0.637*	*0.140*	*0.238*	*0.006*	*0.002*	*0.949*
LSD	*0.722*	*NS*	*NS*	*NS*	*72.2*	*90.2*	*NS*
CV	*1.9*	*12.2*	*4.6*	*5.5*	*5.2*	*5.7*	*2.0*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

The nitrogen uptake was significantly affected by the growing season. Season 1 showed higher nitrogen uptake (57 kg ha^{-1}) compared with the second season (55 kg ha^{-1}). Both seasons had similar AE, PE and RE. (Table 4.3.16).

Table 4.3.16: Rice nitrogen uptake and nitrogen use efficiency parameters as affected by the season at Hahome site.

Source	Nitrogen uptake (kg ha^{-1})	Agronomic efficiency (kg kg^{-1})	Physiology efficiency (kg kg^{-1})	Recovery Efficiency (%)
Season 1	57 b	35	123	62
Season 2	55 a	34	118	61
Fpr	*0.005*	*0.179*	*0.131*	*0.357*
LSD	*1.171*	*NS*	*NS*	*NS*
CV	*5.1*	*9.5*	*10.9*	*5.5*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

4.3.1.3. Results at Kouto site

4.3.1.3.1. Results at Kouto site, season 1

- ***Rice growth, yield components and yield as affected by variety, urea type and nitrogen rate. Kouto site, Season 1***

Significant differences were obtained among the varieties for the plant height, length of panicles, grain and straw yields. All these parameters were significantly ($p<0.05$) higher with TG-405 than IR-841. However, the number of tillers, the weight of 1000 grains, and the harvest index were not statistically different ($P>0.05$) for the two varieties (Table 4.3.17).

The type of urea significantly affected the plant growth and grain yield. The USG significantly ($p<0.05$) increased the plant height, the number of tillers per hill, the length of panicles and the grain yield over the PU. However, no significant effect of the urea mode of application was observed on the weight of 1000 grains, the straw yield and harvest index (Table 4.3.17).

Consistently, the nitrogen rate significantly ($P<0.05$) affected rice growth, yield components and yield of rice. Both N78 and N104 produced similar and high plant height, number of tillers and weight of 1000 grains. The rice grain and straw yield increased with the N rate. The highest grain yield (4429 kg ha^{-1}) and straw yield (4883 kg ha^{-1}) were obtained with N104. Similarly increased harvest index wase obtained with increasing N rates (Table 4.3.17).

Table 4.3.17: Effects of rice variety, type of urea and nitrogen rate on rice growth, yield components and yield. *Kouto site, Season 1*

Treatments	Height (cm)	Number of tillers per hill	Length of panicles (cm)	Weight of 1000 grains (g)	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index
Rice Variety							
IR-841	93 a	12	21 a	26	2816 a	3206 a	46
TG 405	95 b	13	23 b	26	2959 b	3347 b	46
Fpr	*<.001*	*0.269*	*<.001*	*0.624*	*0.004*	*0.018*	*0.928*
LSD	*1.036*	*NS*	*0.468*	*NS*	*95.5*	*114.8*	*NS*
Type of urea							
PU	92 a	11 a	21 a	26	2830 a	3224	46
USG	95 b	13 b	22 b	26	2945 b	3329	47
Fpr	*<.001*	*<.001*	*<.001*	*0.158*	*0.020*	*0.071*	*0.053*
LSD	*1.036*	*0.926*	*0.468*	*NS*	*95.5*	*NS*	*NS*
Nitrogen Rate							
N0	71 a	7 a	17 a	21 a	1140 a	1379 a	45 a
N52	91 b	12 b	23 b	27 b	230. b	2702 b	46 b
N78	106 c	15 c	24 c	27 b	3673 c	4142 c	47 c
N104	107 c	16 c	25 d	28 b	4429 d	4883 d	48 d
Fpr	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*
LSD	*2.072*	*1.309*	*0.662*	*1.104*	*135.1*	*162.3*	*0.5762*
CV	*1.9*	*12.8*	*3.6*	*5.1*	*5.6*	*5.9*	*1.5*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

- *Interaction between the treatments on rice growth, yield components and yield. Kouto site, season 1*

The interaction effect between rice variety and urea mode of application did not show any statistical difference *($p>0.05$)* on the rice growth, yield components and yield (Table 4.3.18). Similarly no significant effects were observed for the interaction between the rice variety and nitrogen rate with regards to rice growth and yield parameters (Table 4.3.18). These results implied that the rice growth and yields of each variety did not depend either on the type of urea, or on the rate of nitrogen applied in the first season at Kouto site.

Regarding the interaction between the mode of application of urea and the nitrogen rate, significant differences *($p<0.05$)* were observed with regards to the plant height, straw yield and harvest index. The higher plant height (109 cm) was observed with both USG*78 and USG*104. The latter interactions also had the highest harvest index (47) while the highest straw yield (5104 kg ha^{-1}) was recorded with USG*104 alone. The interaction between the type of urea and the rate of nitrogen did not produce significant ($P>0.05$) effects on the number of tillers per hill, the length of panicles and the weight of 1000 grains (Table 4.3.18). Regarding the interaction between the three factors (rice variety, type of urea and *nitrogen rate*), No significant effect was observed on the rice growth, yield components and yield at Kouto site during the first season (Appendix 8).

Table 4.3.18: The interaction effects of the treatments on rice growth, yield components and yield. *Kouto site, Season 1*

Treatments	Height (cm)	Number of tillers per hill	Length of panicles (cm)	Weight of 1000 grains (g)	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index
Variety*Type of urea							
IR-841*PU	91	12	21	26	2765	3165	46
IR-841*USG	94	13	22	26	2867	3248	47
TG-405*PU	93	12	22	26	2896	3283	46
TG-405*USG	96	13	23	26	3023	3410	47
Fpr	*0.777*	*0.525*	*0.655*	*0.654*	*0.791*	*0.700*	*0.918*
LSD	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Variety*Nitrogen rate							
IR-841* Ctrl	70	8	17	21	1112	1333	45
IR-841*N52	90	11	22	27	2204	2571	46
IR-841* N78	105	15	23	27	3662	4150	47
IR-841*N104	106	16	24	28	4283	4771	47
TG-405* Ctrl	72	7	17	22	1167	1425	45
TG-405 *N52	93	11	23	27	2412	2833	46
TG-405 *N78	107	16	25	28	3683	4133	47
TG-405*N104	107	16	25	28	4575	4996	48
Fpr	*0.286*	*0.167*	*0.153*	*0.979*	*0.155*	*0.294*	*0.338*
LSD	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Type of urea* Nitrogen rate							
PU * Ctrl	71 a	7	17	21	1125	1375 a	45 a
PU *N52	90 b	11	22	26	2204	2654 b	45 a
PU * N78	104 d	15	23	27	3683	4204 c	47 b
PU * N104	105 d	15	24	28	4308	4662 d	48 c
USG * Ctrl	71 a	8	17	22	1154	1383 a	46 a
USG *N52	93 c	12	23	27	2412	2750 b	47 b
USG * N78	109 e	16	25	28	3662	4079 c	47 b
USG * N104	109 e	16	25	28	4550	5104 e	47 b
Fpr	*0.026*	*0.822*	*0.222*	*0.981*	*0.146*	*0.009*	*0.004*
LSD	*3.197*	*NS*	*NS*	*NS*	*NS*	*229.6*	*0.8148*
CV	*2.0*	*12.5*	*4.1*	*5.1*	*5.6*	*5.9*	*1.5*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

Rice nitrogen uptake and nitrogen use efficiency as affected by the variety, type of urea and nitrogen rate. Kouto site, Season 1

The results of the variety, type of urea and *nitrogen rate* effects on the nitrogen uptake in rice, and the different nitrogen use efficiency parameters are presented in Figures 4.3.13, 4.3.14 and 4.3.15. The rice variety did not significantly (p>0.05) affect the NU, the AE, the PE and the RE (Figure 4.3.13).

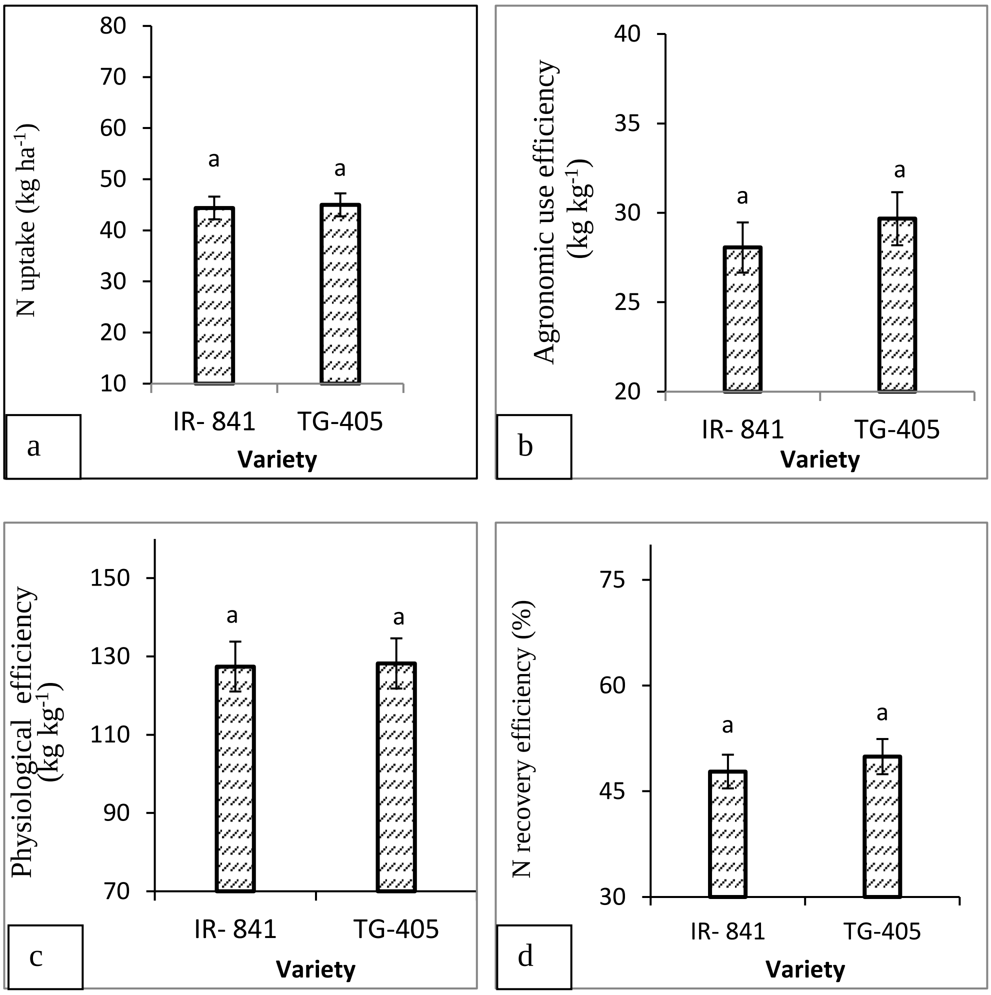


Figure 4.3.13: Effect of rice variety on NU (a), AE (b), PE (c) and RE (d) at Kouto site, season 1

However, the type of urea significantly *($P<0.05$)* affected the NU, the PE and the RE. The USG showed higher NU (49 kg ha^{-1}), PE (116) and RE (55%) than the PU (41 kg ha^{-1}, 43 kg kg^{-1}and 43% respectively). The AE was similar for USG and PU (Figure 4.3.14).

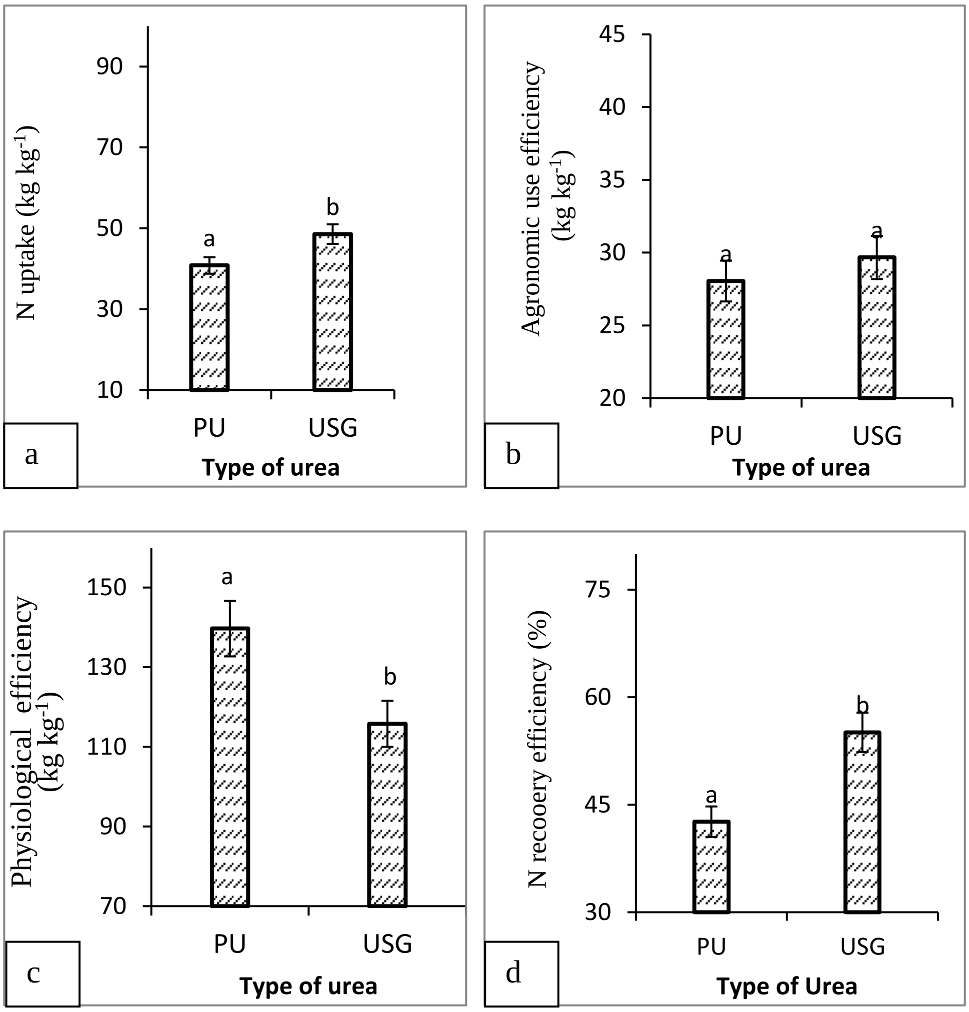


Figure 4.3.14: Effect of the type of urea on NU (a), AE (b), PE (c) and RE (d) at Kouto site, season 1

The N rate had a significant *($P<0.05$)* effect on the NU and nitrogen efficiency. Increasing N rates increased NU. Subsequently, the highest NU was recorded with N140 (Figure 4.3.15.). The results indicated similar and higher AE (32 kg kg^{-1}) for N78 and N104 as compared for N52 that recorded the lowest AE (22 kg kg^{-1}) (Figure 4.3.6.b). The RE decreased with increased rates of nitrogen. N rate of 52 showed the highest RE (58%) as compared with N78 and N104 that recorded respectively 49 and 45%

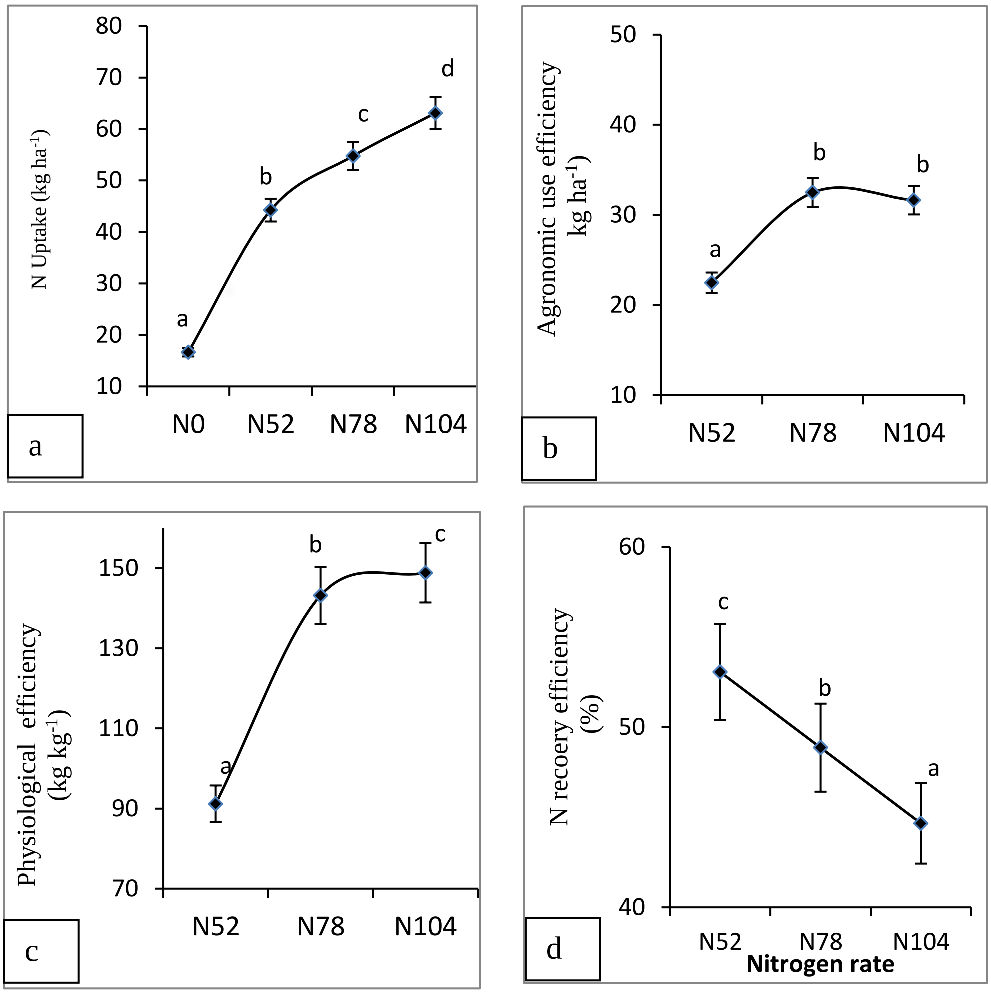


Figure 4.3.15: Effect of rice N rate on NU (a), AE (b), PE (c) and RE (d) at at Kouto site, season 1

- ***Interaction effect of rice variety, urea type and nitrogen rate on rice nitrogen uptake and nitrogen use efficiency. Kouto site season 1***

Table 4.3.19 summarizes the interaction effects of the different treatments on the rice nitrogen uptake and use efficiency. Results showed significant *(P<0.05)* effects of the interaction between rice variety and the type of urea on the nitrogen uptake (NU). TG-405*PU had the lowest NU but not significantly different from IR841*PU while the interaction between the TG-405 with the USG gave the highest NU (50 kg kg^{-1}).

The combination of the TG-405 with the USG increased the AE by 3.3% over the PU combined with the same variety while the combination of IR-841 with the USG increased the AE only by 7% over the combination of the same variety with PU.

Even though the interaction effects of the variety and the urea mode of application were significant on the NU, this interaction did not significantly *(P>0.05)* affect the nitrogen use efficiency parameters (Table 4.3.19). Likewise, the interaction between the rice variety and the nitrogen rate did not show any significant difference on the NU, AE, PE and RE. This implies that, at Kouto site in the first season, the effect of the nitrogen rate on the nitrogen uptake and nitrogen use efficiency did not depend on the rice variety and vice versa (Table 4.3.19).

Regarding the interaction between the urea type of urea and the nitrogen rate did not significantly *(P>0.05)* affect AE, PE and RE. However, the interaction significantly affected the nitrogen uptake. The USG*N104 produced the highest NU (69 kg ha^{-1}) followed by USG*N78 and PU*N104 that were similar. The lowest NU was recorded with the PU applied at N rate of 0 kg ha^{-1} (Table 4.3.19).

The interaction between the rice variety, the type of urea and the nitrogen rate was not significant. The results are presented in appendix 8

Table 4.3.19: The interaction effects of treatments on the NU, AE, PE and RE; *Kouto Season 1*

Treatments	Nitrogen uptake (kg ha^{-1})	Agronomic efficiency (kg kg^{-1})	Physiology efficiency (kg kg^{-1})	Nitrogen Recovery (%)
Variety*Type of urea				
IR-841*PU	42 a	27	134	43
IR-841*USG	47 b	29	121	52
TG-405*PU	40 a	29	146	42
TG-405*USG	50 c	30	111	58
Fpr	*0.008*	*0.655*	*0.050*	*0.055*
LSD	*3.114*	*NS*	*NS*	*NS*
Variety*Nitrogen rate				
IR-841* N0	17	-	-	-
IR-841*N52	44	21	86	52
IR-841* N78	54	33	146	48
IR-841* N104	62	30	150	43
TG-405* N0	16	-	-	-
TG-405 * N52	44	24	96	54
TG-405 * N78	55	32	140	50
TG-405 * N104	64	33	148	46
Fpr	*0.730*	*0.420*	*0.450*	*0.916*
LSD	*NS*	*NS*	*NS*	*NS*
Type of urea* Nitrogen rate				
PU*N0	16 a	-	-	-
PU*N52	40 b	21	99	46
PU*N78	50 c	33	162	43
PU*N104	57 d	31	158	39
USG*N0	17 a	-	-	-
USG*N52	48 c	24	83	60
USG*N78	60 d	32	125	55
USG*N104	69 e	33	140	50
Fpr	*0.006*	*0.317*	*0.218*	*0.672*
LSD	4.403	*NS*	*NS*	*NS*
CV	*8.4*	*11.3*	*12.6*	*11.3*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

4.3.1.3.2. Results at Kouto site; season 2

- ***Rice growth, yield components and yield as affected by variety, urea type and nitrogen rate. Kouto site, Season 2***

Table 4.3.20 shows the effects of the treatments on rice growth, yield components and yield at Kouto site in the first season. The results indicated no significant *(P>0.05)* effects of the rice variety on the number of tillers, weight of 1000 grains, grain and straw yields and harvest index. But, the rice variety significantly *(P<0.05)* affected the plant height, and the length of panicles. The TG-405 induced higher height (94 cm) and longer panicle (23 cm) IR-841.

The type of urea did not significantly *(P>0.05)* affect the length of panicles, the weight of 1000 grains and the straw and grain yields. However; it affected the height of rice, the number of tillers and the harvest index. The USG produced significantly higher height (94cm), number of tillers (13), and the harvest index (47) than PU which produced lower height (92 cm), number of tillers (12) and harvest index (46) (Table 4.3.20).

Nitrogen rate had similar trends for rice height, length of panicles and harvest index. On these parameters, N78 and N104 produced similar and highest parameters while the lower performances were recorded with the N0. However, significant *(P<0.05)* increases in the number of tillers, straw and grain yields were observed with increased rates of nitrogen applied. Especially on the weight of 1000 grains, no significant difference was observed between the effect obtained with N52, N78 and N104 (Table 4.3.20).

Table 4.3.20: Effects of rice variety, type of urea and nitrogen rate on rice growth, yield components and yield. *Kouto site, Season 2*

Treatments	Height (cm)	Number of tillers per hill	Length of panicles (cm)	Weight of 1000 grains (g)	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index
Rice Variety							
IR-841	92 a	12	21 a	25	2855	3245	46
TG-405	94 b	13	23 b	26	2899	3291	46
Fpr	*0.040*	*0.628*	*<0.001*	*0.262*	*0.509*	*0.549*	*0.671*
LSD	*1.995*	*NS*	*0.872*	*NS*	*NS*	*NS*	*NS*
Type of Urea							
PU	92 a	12 a	22	25	2866	3314	46 a
USG	94 b	13 b	22	26	2889	3222	47 b
Fpr	*0.021*	*<0.001*	*0.167*	*0.093*	*0.728*	*0.235*	*0.001*
LSD	*1.995*	*0.707*	*NS*	*NS*	*NS*	*NS*	*0.420*
Nitrogen rate							
N0	70 a	7 a	16 a	21 a	1094 a	1340 a	45 a
N52	90 b	12 b	23 b	26 b	2242 b	2646 b	46 b
N78	106 c	14 c	24 bc	27 b	3702 c	4162 c	47 c
N104	106 c	16 d	25 c	27 b	4471 d	4923 d	48 c
Fpr	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*	*<0.001*
LSD	*2.821*	*1.000*	*1.233*	*1.271*	*188.8*	*218.5*	*0.593*
CV	*3.6*	*9.6*	*6.8*	*6.0*	*7.9*	*8.0*	*1.5*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

- ***Interaction effects of rice variety, type of urea and rate of urea on Rice growth, yield components and yield. Kouto site, Season 2***

The Table 4.3.21 presents the interaction effects among the various factors studied. The result shows that no significant *($P>0.05$)* effect was observed for the interaction between the rice variety and the type of urea on the rice height, panicles length, weight of 1000 grains, straw and grain yield and the harvest index. However, the interaction affected the number of tillers per hill. The interaction between the TG-405 and USG produced the highest number of tillers (14) followed by the IR-841*USG and IR-841*PU that showed similar *($P>0.05$)* values (12-13). The lowest number of tillers was recorded with TG-405*PU.

Besides, the interactions among the variety and the nitrogen rate, type of urea and urea nitrogen rate did not significantly *($P>0.05$)* affect the rice growth, the yield components and yield at Kouto site during the second season (Table 4.3.21). Furthermore, the interaction among the three factors (variety, type of urea and nitrogen rate) did not affected the parameters studied (Appendix 10)

Table 4.3.21. The interaction effects of variety, type of urea and nitrogen rate on rice growth, yield components and yield. *Kouto site, Season 2*

Treatments	Height (cm)	Number of tillers per hill	Length of panicles (cm)	Weight of 1000 grains (g)	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index
Variety*Type of urea							
IR-841*PU	91	12 ab	20	25	2796	3217	46
IR-841*USG	93	13 b	21	26	2915	3273	47
TG-405*PU	93	11 a	23	26	2935	3410	46
TG-405*USG	95	14 c	23	26	2863	3171	47
Fpr	*0.779*	*0.02*	*0.656*	*0.312*	*0.153*	*0.06*	*0.069*
LSD	-	*0.982*	*NS*	*NS*	*NS*	*NS*	*NS*
Variety*Nitrogen rate							
IR-841*N0	69	8	15	21	1113	1346	45
IR-841*N52	88	12	22	26	2250	2654	46
IR-841*N78	106	14	22	27	3671	4125	47
IR-841*N104	105	16	24	27	4388	4854	47
TG-405*N0	72	7	17	21	1075	1333	45
TG-405*N52	92	12	23	27	2233	2638	46
TG-405*N78	107	15	26	27	3733	4200	47
TG-405*N104	107	16	26	28	4554	4992	48
Fpr	*0.73*	*0.464*	*0.185*	*0.973*	*0.684*	*0.867*	*0.554*
LSD	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
Type of urea* Nitrogen rate							
PU * N0	71	7	16	21	1104	1354	45
PU *N52	88	11	22	26	2254	2721	45
PU * N78	104	14	24	27	3746	4279	47
PU * N104	105	16	24	27	4358	4900	47
USG * N0	70	8	16	21	1083	1325	45
USG *N52	92	13	23	27	2229	2571	46
USG * N78	109	16	24	28	3658	4046	47
USG * N104	108	16	25	27	4583	4946	48
Fpr	*0.138*	*0.082*	*0.832*	*0.957*	*0.358*	*0.575*	*0.304*
LSD	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
CV	*3.6*	*9.5*	*6.6*	*6.1*	*7.9*	*8.0*	*1.5*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

- ***Rice nitrogen uptake and nitrogen use efficiency as affected by the variety, urea type and nitrogen rate. Kouto site, Season 2***

The Figure 4.3.16 shows the effect of the rice variety on the nitrogen uptake of rice (NU), agronomic efficiency (AE), physiological efficiency (PE) and the nitrogen recovery efficiency (RE). Results indicate no significant *($P<0.05$)* effect of the rice variety on the NU and use efficiency parameters. On the average, the NU, AE, PE and RE with both varieties were respectively 43 kg ha^{-1}, 29 kg kg^{-1}, 138 kg kg^{-1} and 44%.

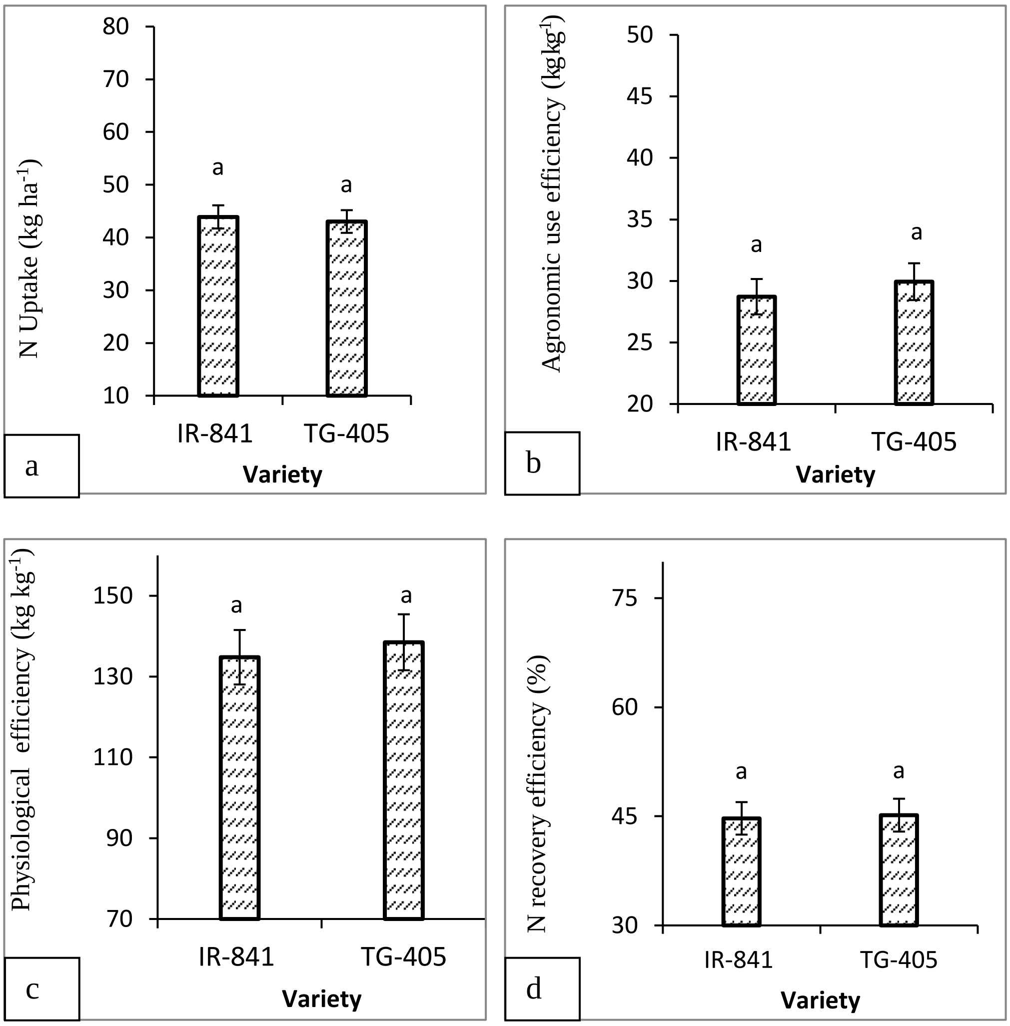


Figure 4.3.16: Effect of rice variety on NU (a), AE (b), PE (c) and RE (d) at Kouto site season 2

Similarly, the type of urea did not significantly *(P<0.05)* affect the nitrogen uptake and use efficiency parameters. Both PU and USG induced average NU, AE, PE and RE of 43 kg ha^{-1}, 29 kg kg^{-1}, 157 kg kg^{-1} and 45% respectively. (Figure 4.3.17)

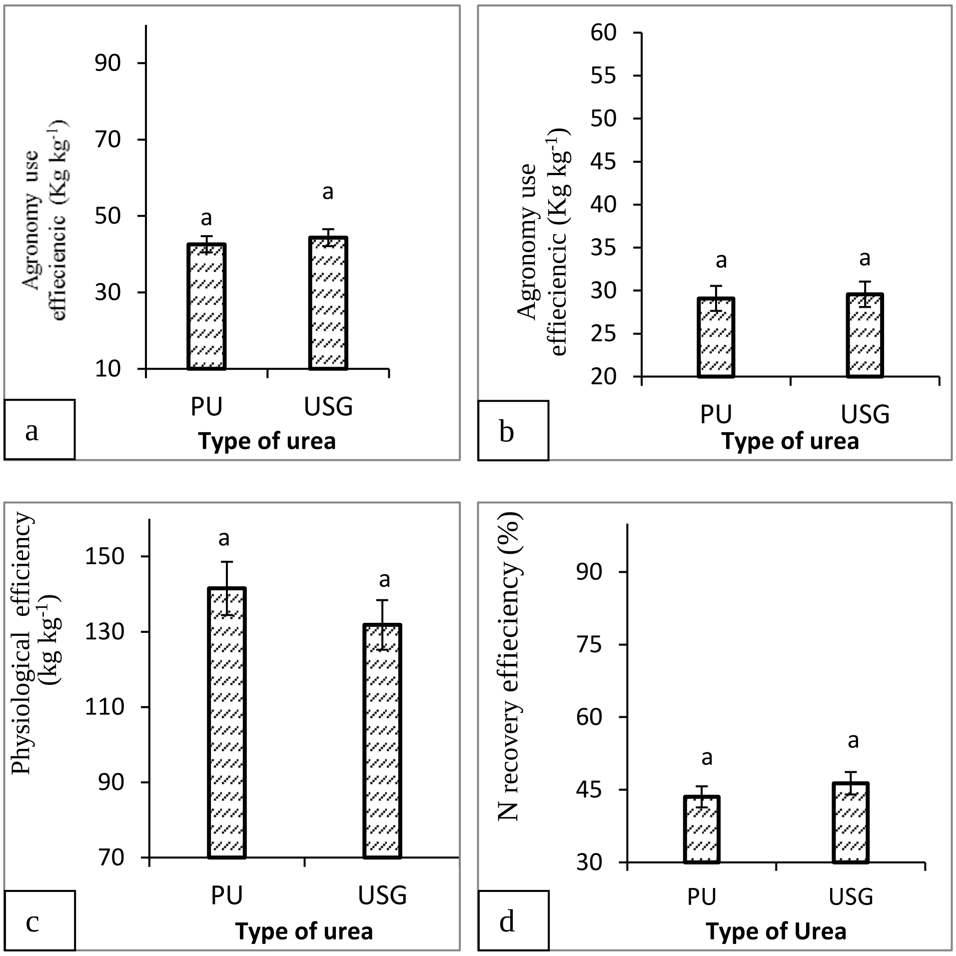


Figure 4.3.17: Effect the type of urea on NU (a), AE (b), PE (c) and RE (d) at Kouto site season 2

On the contrary to the rice variety and type of urea, the rate of nitrogen significantly *(P<0.05)* affected the nitrogen uptake and use efficiency parameters. The NU increased significantly with increase in nitrogen rate (Figure 4.3.18). Thus N104 showed the highest value of NU (59 kg ha^{-1}) while the lowest (17 kg ha^{-1}) was recorded with the control. The agronomic efficiency and physiology efficiency, N78 and N104 showed statistically similar and highest effects. On the Recovery efficiency, no significant effect of the different rates on nitrogen was observed. An average nitrogen recovery efficiency of 45% was recorded for N52, N78 and N104 (Figure 4.3.18).

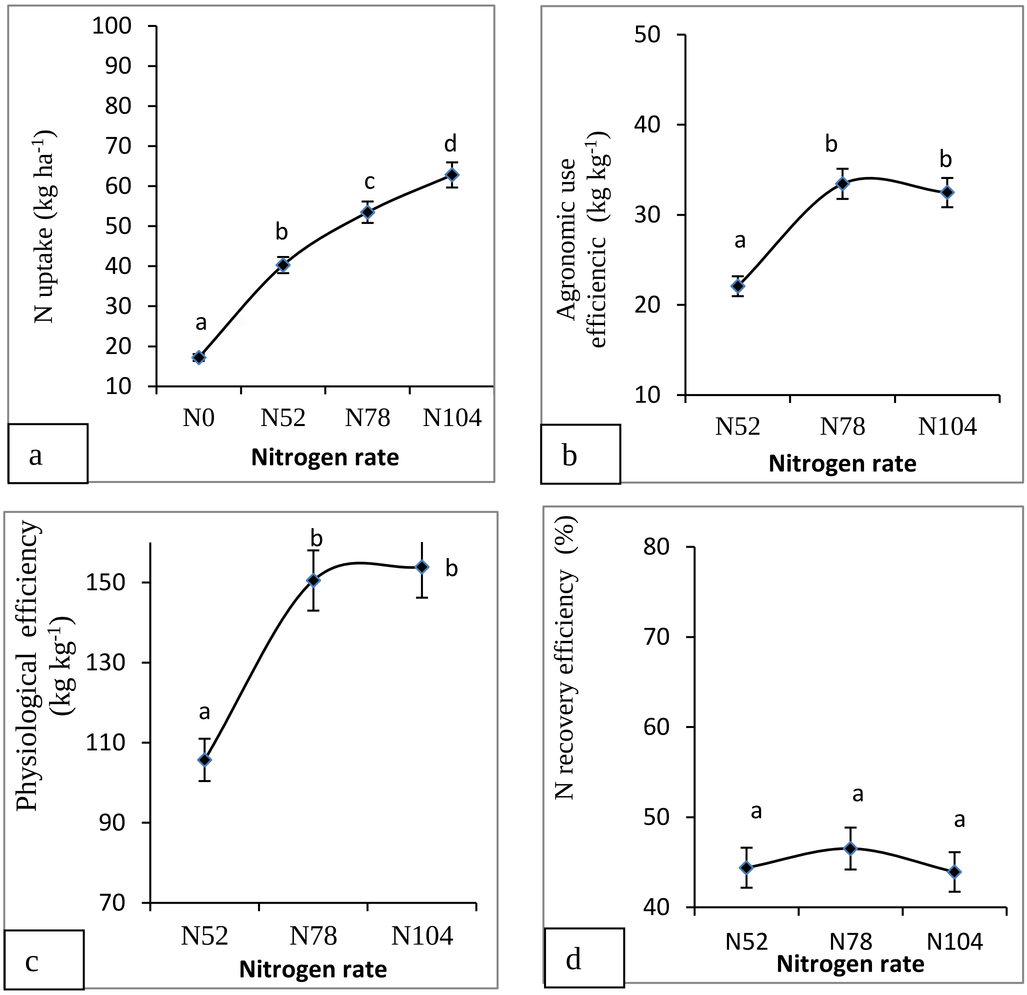


Figure 4.3.18: Effect of nitrogen rate on NU (a), AE (b), PE (c) and RE (d) at Kouto site season 2

- ***Interaction effect of rice variety, urea type and nitrogen rate on rice nitrogen uptake and nitrogen use efficiency. Kouto site season 2***

The results of the interactions between the rice variety and the type of urea, the variety and nitrogen rate and the type of urea and nitrogen rate on rice nitrogen uptake and nitrogen use efficiency parameters at Kouto site in season 2 are presented in Table 4.3.22. There was significant ($P<0.05$) effect of the interaction between the variety and the type of urea on the nitrogen uptake (NU), agronomic efficiency (AE) and recovery efficiency (RE). The IR-841*USG and TG-405*PU were not significantly different but produced higher NU as compared with IR-841*PU and TG-405*USG that were also no significantly different from each other. For AE and RE, the IR-841*PU produced the lowest effect as compared with the other interactions that showed statistically similar performances (Table 4.3.22).

The results showed no significant ($P>0.05$) effect of the interaction between the rice variety and the applied nitrogen rate on the nitrogen uptake and use efficiency parameters. Similar results were obtained for the interactions between the type of urea and the nitrogen rate (Table 4.3.22). The interaction between the rice variety, the type of urea and the nitrogen rate also did not significantly affected the NU and the nitrogen use efficiency parameters (Appendix 11)

Table 4.3.22: The interaction effects of treatments on the NU, AE, PE and RE. *Kouto site season 2*

Treatments	Nitrogen uptake (kg ha^{-1})	Agronomic efficiency (kg kg^{-1})	Physiology efficiency (kg kg^{-1})	Recovery Efficiency (%)
Variety*Type of urea				
IR-841 *PU	41 a	26.8 a	136	42 a
IR-841 *USG	46 b	31 ab	133	48 b
TG-405*PU	43.4 ab	32 ab	147	46 ab
TG-405*USG	42.6 a	29 ab	130	45 ab
Fpr	*0.031*	*0.031*	*0.268*	*0.035*
LSD	*3.220*	*4.400*	*NS*	*4.475*
Variety*Nitrogen rate				
IR-841 * N0	18	-	-	-
IR-841*N52	41	21.9	103.0	44.9
IR-841* N78	53	32.8	151.0	45.6
IR-841* N104	63	31.5	150.5	43.8
TG-405* N0	17	-	-	-
TG-405 *N52	39	22.3	108.3	43.9
TG-405 * N78	54	34.1	150.0	47.5
TG-405 * N104	62	33.5	157.3	44.1
Fpr	*0.932*	*0.851*	*0.268*	*0.747*
LSD	*NS*	*NS*	*NS*	*NS*
Type of urea* Nitrogen rate				
PU * N0	17	-	-	-
PU *N52	39	22	116	41.4
PU * N78	53	34	155	46.4
PU * N104	62	31	154	42.9
USG * N0	17	-	-	-
USG *N52	42	22	96	47.4
USG * N78	54	33	146	46.7
USG * N104	64	34	154	45.0
Fpr	*0.711*	*0.416*	*0.416*	*0.324*
LSD	*NS*	*NS*	*NS*	*NS*
CV	*8.9*	*15.3*	*13.0*	*10.5*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

4.3.1.3.3 Rice yield, nitrogen uptake and nitrogen use efficiency parameters as affected by the season at Kouto site

Rice growth, yield components and yield were statistically not different (P>0.05) for the two seasons at Kouto site. This has led to the conclusion that with the same variety and fertilization management, the two seasons produced identical effects on the rice growth and yield (Table 4.3.23).

Table 4.3.23: Rice growth and yield parameters as affected by the season at Kouto site.

Treatments	Height (cm)	Number of tillers per hill	Length of panicles (cm)	Weight of 1000 grains (g)	Grain Yield (kgha^{-1})	Straw Yield (kgha^{-1})	Harvest Index
Season 1	93.89	12.29	21.87	25.79	2888	3277	46.465
Season 2	93.17	12.46	21.82	25.42	2877	3268	46.379
Fpr	0.209	0.556	0.811	0.207	0.804	0.857	0.542
LSD	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
CV	*3.0*	*11.1*	*5.4*	*5.5*	*7.1-*	*7.3*	*1.5*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

At Kouto site, even though the nitrogen uptake, the agronomic efficiency and the physiological efficiency were similar for both seasons, significant *($P<0.05$)* effects of the season were observed on the nitrogen recovery efficiency of rice. The recovery was higher (49%) in the first season than in the second (45%) (Table 4.3.24).

Table 4.3.24: Rice nitrogen uptake and nitrogen use efficiency parameters as affected by season at Kouto site.

Season	Nitrogen uptake (kg ha^{-1})	Agronomic efficiency (kg kg^{-1})	Physiology efficiency (kg kg^{-1})	Recovery efficiency (%)
Season 1	45	29	128	49 b
Season 2	43	29	137	45 a
Fpr	*0.124*	*0.626*	*0.063*	*0.004*
LSD	*NS*	*NS*	*NS*	*2.604*
CV	*8.7*	*13.9*	*15.0*	*11.7*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

4.3.1.4. General effect of the treatments on the rice growth, yield components and yield across the sites and seasons.

The data on the effect of the rice variety, application mode of urea and nitrogen rate, regardless of the specific sites and seasons are presented in Table 4.3.25. The result indicated that the rice variety had no significant *($P>0.05$)* effect on the number of tillers and length of panicles. However, the variety significantly *($P<0.05$)* affected rice growth in term of height. TG-405 was taller (95 cm) than the IR-841 (93 cm). Similarly, TG-405 significantly increased the weight of 1000 grains, grain yield and straw over IR-841.

The type of urea significantly affected the rice growth, yield and yield parameters. Across the season, the USG induced significantly higher plant height (95 cm) and number of tillers (14 cm) than the PU that recorded respectively 92 and 13 cm. Likewise, higher performances of USG over PU were observed on the weight of 1000 (22 and 21 g), grains yield 4199 and 3670 kg ha^{-1}) and straw yield (3693 and 3225 kg ha^{-1}).

Table 4.3.25: Effects of the treatments on the rice growth, yield components and yield across sites and seasons.

Treatment	Height (cm)	Number of tillers per hill	Length of panicles (cm)	Weight of 1000 grains (g)	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index
Variety							
IR-841	93 a	13.7	26	21 a	3882 a	3379 a	46.320
TG-405	95 b	14.0	26	22 b	3988 b	3540 b	46.702
Fpr	*<.001*	*0.123*	*0.122*	*<.001*	*<.001*	*<.001*	*0.453*
LSD	*0.503*	*C*	*NS*	*0.2393*	*62.3*	*46.3*	*NS*
Type of Urea							
PU	93 a	13 a	26.7 a	21.4 a	3670 a	3225 a	46.468
USG	95 b	14 b	27.1 b	22.4 b	4199 b	3693 b	46.554
Fpr	*<.001*	*<.001*	*0.001*	*<.001*	*<.001*	*<.001*	*0.025*
LSD	*0.503*	*0.3357*	*0.2978*	*0.2393*	*62.3*	*46.3*	*NS*
Nitrogen rate							
N0	71 a	8 a	23 a	17 a	1655 a	1397 a	45.70 a
N52	91 b	13 b	26 b	22 b	3483 b	2909 b	45.69 a
N78	106 c	16.7 c	27 c	23.9 c	5052 c	4460 c	46.89 b
N104	107 d	17.3 d	27 c	24.4 d	5549 d	5071 d	47.75 c
Fpr	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*<.0.469*
LSD	*0.711*	*0.4747*	*0.4211*	*0.3384*	*88.1*	*65.5*	*NS*
CV	*2.3*	*10.4*	*4.9*	*4.7*	*6.8*	*5.8*	*2.1*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

The effect of the nitrogen rate on the various growth and yield parameters were statistically different *(P<0.05)* regardless of variety and type of urea. The plant height at maturity increased with increasing rate of nitrogen from 71 cm with the control without nitrogen application to 104 cm with 104 kg N ha^{-1}. Similar significant increasing values of rice growth and yield parameters with nitrogen rates were observed. Grain yields were respectively 1397, 2909, 4460, and 5071 kg ha^{-1} for N0, N52, N78, and N104 (Table 4.3.25).

4.3.1.5. General effect of the treatments on the nitrogen uptake and nitrogen use efficiency across the sites and seasons.

Generally, the results indicate significant *($P<0.05$)* effects of the treatments on rice N uptake (NU), agronomic efficiency (AE) and recovery efficiency (RE). TG-405 had higher NU (55 kg ha^{-1}), AE (36 kg kg^{-1}) and RE (60% kgha^{-1}) than IR-841 that recorded 53 kg ha^{-1}, 33 kg kg^{-1} and 58% for NU, AE and RE respectively. The rice variety did not affect *($P>0.05$)* the physiological efficiency (PE) (Table 4.3.26).

Across the sites and seasons, the NU, AE and RE values were significantly ($P<0.05$) higher for USG than PU. However, the PE was higher for the PU (137 kg kg^{-1}) than the USG (119 kg kg^{-1}). It was observed significant increase of NU with increasing rates of nitrogen (Table 4.3.26). The NU increased from 47 kg ha^{-1} for the control to 78 kg ha^{-1} for N104. However, the pattern was different for the AE which increased from 29 kg kg^{-1} with N52 to 39 with N78 and decreased later to 35 kg kg^{-1} with N104. Comparable trend was observed for the PE. The RE decreased significantly ($P<0.5$) with increasing doses of nitrogen applied. It dropped from 62 to 59 and 55% with N52, N78 and N104 (Table 4.3.26).

Table 4.3.26: Effect of the treatments on nitrogen uptake and nitrogen use efficiency across the sites and seasons.

Treatment	Nitrogen uptake (kg ha^{-1})	Agronomy efficiency (kg kg^{-1})	Physiology efficiency (kg kg^{-1})	Nitrogen Recovery (%)
Variety				
IR-841	53.81 a	33.41 a	127.1	57.83 a
TG-405	55.40 b	35.71 b	128.3	59.91 b
Fpr	*<.001*	*<.001*	*0.570*	*<.001*
LSD	*0.764*	*0.965*		*1.032*
Type of Urea				
PU	46.92 a	29.54 a	136.8 a	46.10 a
USG	62.29 b	39.58 b	118.6 b	71.64 b
Fpr	*<.001*	*<.001*	*<.001*	*<.001*
LSD	*0.764*	*0.965*	*4.20*	*1.032*
Nitrogen rate				
N0	20.64 a	-	-	-
N52	52.98 b	29.09 a	98.7 a	62.18 c
N78	67.13 c	39.27 c	144.8 c	59.60 b
N104	77.67 d	35.33 b	139.7 b	54.83 a
Fpr	*<.001*	*<.001*	*<.001*	*<.001*
LSD	*1.081*	*1.182*	*5.14*	*1.264*
CV	*6.0*	*10.4*	*12.2*	*6.5*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

4.3.1.6. Rice yield, nitrogen uptake and nitrogen use efficiency as affected by the different sites.

The grain yield, the nitrogen uptake and the nitrogen use efficiency parameters were significantly different *(P<0.05)* at the three sites. Ablotsri site had the highest performance followed by Hahome site. Kouto site showed the lowest performance for the yield and other parameters studies (Table 4.3.27).

Table 4.3.27: Rice yield, nitrogen uptake and nitrogen use efficiency at the different sites.

Site	Grain yield (kg ha^{-1})	Nitrogen uptake (kg ha^{-1})	Agronomy efficiency (kg kg^{-1})	Physiology efficiency (kg kg^{-1})	Recovery (%)
Ablotsri	4062 c	63 c	40 c	130 b	68 c
Hahome	3433 b	56 b	34 b	121 a	62 b
Kouto	2882 a	44 a	29 a	132 b	47 a
Fpr	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*
LSD	*64.7*	*1.033*	*1.18*	*5.14*	*1.264*
CV	*5.8*	*6.0*	*10.4*	*12.2*	*6.5*

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

4.3.1.7. Economic evaluation of N mode of application of rice.

The economic analysis indicated high value-cost ratio for the two modes of urea application, nitrogen rate and their interactions in all seasons and sites. This led to the conclusion that the two modes of urea application at the different rates tested were all profitable for rice production at all sites and seasons.

The deep placement of USG showed higher VCR in the two seasons at the sites of Ablotsri and Hahome. However, at Kouto site, the superiority of PU over USG was observed in the two seasons (Figure 4.3.19).

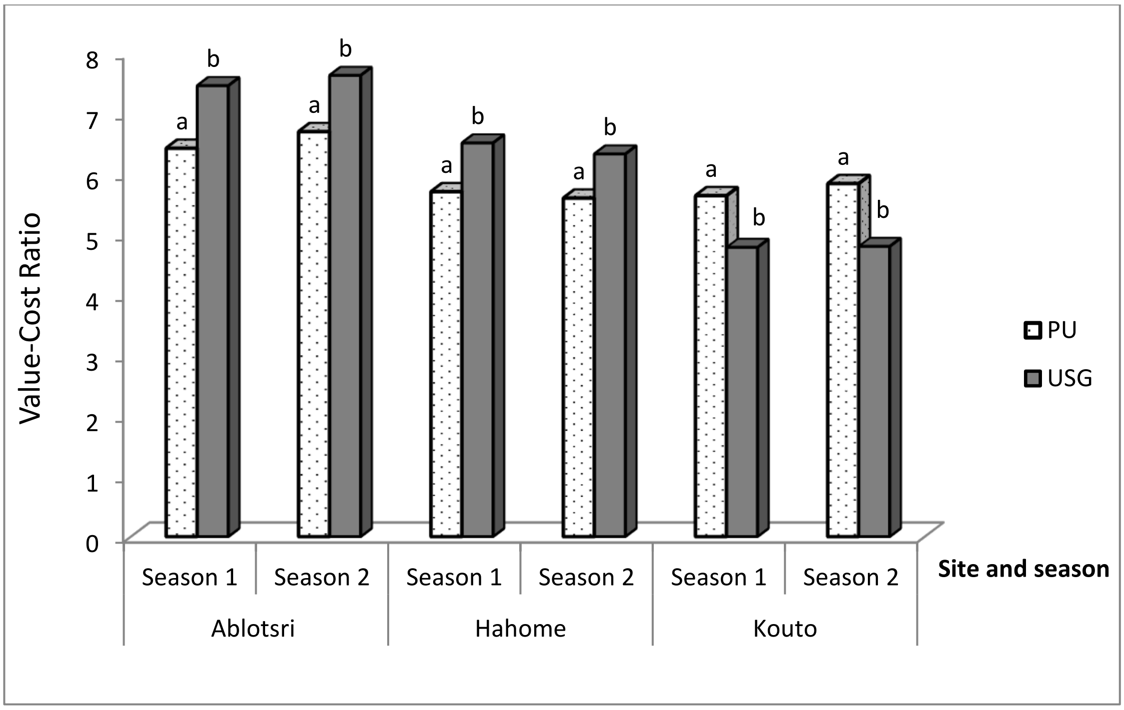


Figure 4.3.19: VCR of the USG and PU application mode with the seasons and sites

Regardless of the urea application mode, the highest VCR was observed for 78 kg ha^{-1} at Ablotsri site while at Hahome and Kouto sites, 104 kg ha^{-1} gave the highest VCR. Across the sites and seasons the lowest VCR was obtained with 52 kg ha^{-1} N.

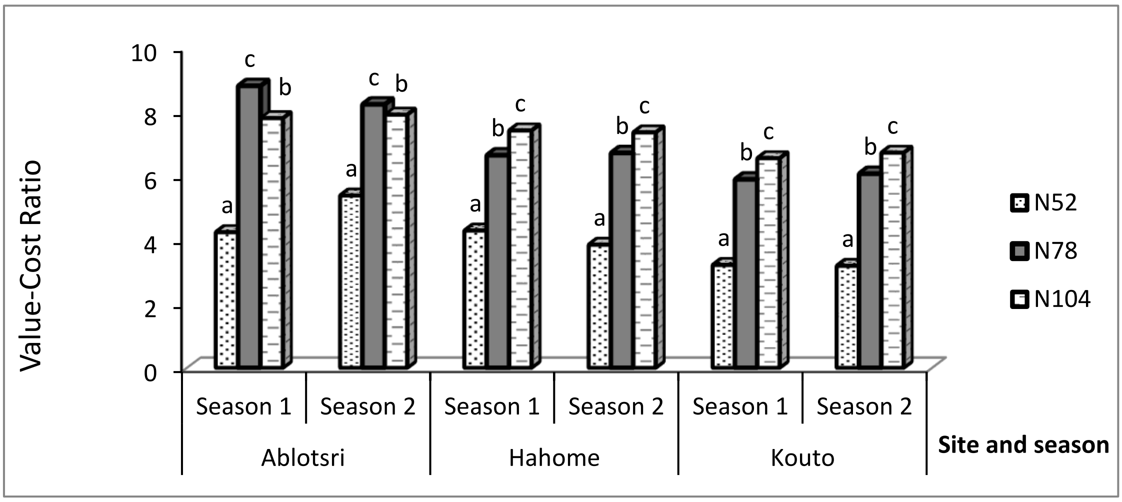


Figure 4.3.20: VCR of the N application rate with seasons and sites

With regards to the interaction between the type of urea and the nitrogen rate, both USG and the PU applied at 78 recorded statistically similar *(P>0.05)* VCR and were the higher than other treatments. In the second season of Ablotsri site, PU*N52, PU*N78 and USG*N78 gave the highest VCR. At Hahome site and in the two seasons, the VCR was the highest when nitrogen was applied at 104 kg ha^{-1} either as USG or PU. At Kouto site, the VCR was similar for all interaction between the urea mode of application and nitrogen rate (Figure 4.3.21).

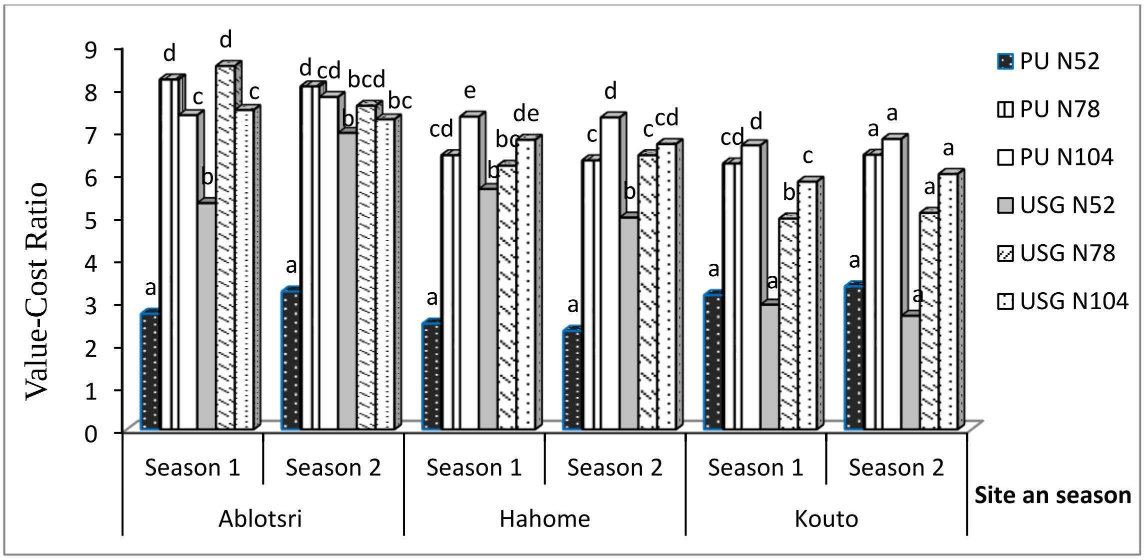


Figure 4.3.21: The VCR of USG and PU modes of application at different nitrogen rates in the seasons and sites

4.3.2. Discussion

4.3.2.1. Rice growth, yield components and yield as affected by rice variety

At Ablotsri and Hahome sites the variety TG-405 gave higher plant height than the variety IR-841, while at Hahome site, the two varieties had similar plant heights. The number of tillers followed similar trend with plant height across the seasons and sites. The panicle length was also higher for the TG-405 than IR-841 except in the second season on Ablotsri site. This result was consistent with those of Khisha (2002) and Rahman (2003) who reported differences in rice growth among rice varieties.

The difference in rice height observed between the two varieties could be attributed to the difference in their genotypes that expressed specific phenotype and reproduction characteristics. As indicated in Table 3.3 in section 3.3.2.1, TG-405 has phenotypycal higher average height than IR-841.

Mohammad *et al*. (2002) explained differences in plant height among various rice varieties by their genetic differences under similar environmental conditions. Similar results on plant height were obtained by Hossain *et al*. (2008) and Jahan *et al*. (2014) who found differences in the height of two varieties. Hussain *et al*. (2014) and Khatun (2001) also reported differences in rice height among varieties. Idris and Matin (1990) reported differences in panicle length among rice varieties and attributed this result to the difference among the rice genotypes.

The 1000 grain weight was similar for both varieties across the seasons and sites. This result is in agreement with Islam (2007) who reported that weight of 1000 grain was similar for different varieties. This result can be explained by the fact that weight of 1000 grain is usually a stable varietal character (Yoshida, 1981). However, Mannan *et al*. (2010) found difference in 1000-grain weight due to genetic variability.

The differences in the genotypic characteristics might also be the reason for the higher yield of TG-405 over IR-841 across the seasons and sites. Comparable results were earlier reported by researchers (Khisna, 2002; Tyeb *et al.* 2013; Islam *et al*., 2014 and Bony *et al*, 2015). Anwar *et al.* (1999) reported variations in grain yield and straw yield to be due to different rice varieties across sites and seasons. Islam (2007) also mentioned variation of grain yield among six aromatic rice varieties. Hasan *et al*. (2002) also studied the effect of two rice varieties on the yield and observed significant effect of the variety on the straw and grain yields. Hossain *et al*. (2008) and Hussain *et al*. (2014) reported variation in the yield amount among rice varieties.

The rice varieties did not show any difference in their growth and yield characteristics when combined with USG or PU. Similar results were obtained by Jahan *et al*. (2014). They reported that all the yield attributes of aromatic rice varieties were not significantly influenced by combined effect of variety and nitrogen mode of application. Hossain *et al.* (2008) also observed that effective tillers/hill did not vary significantly by the interactive effect of variety and nitrogen source. However, Bandaogo *et al*. (2015) observed higher interactive effect of USG on FKR62N variety than on FKR 19 variety in Burkina Faso.

4.3.2.2. Rice growth, yield components and yield as affected by the type of urea

Generally, deep placement of USG increased plant growth, yield contributing characters and yield more than the surface broadcasting of prilled urea (PU). Across the seasons and sites, except the second season at Kouto site, USG showed higher rice growth and yield performances than the PU. This can be attributed to the fact that, the deep placement of USG favoured better fertilizer-root contact for high absorption of N. Also, the deep placement of USG in the reduced zone of paddy soil reduces various N losses pathways and optimises its uptake in plant. The application of USG is also considered as a slow N release fertilizer that continuously makes N available to rice plant (Eriksen and Nilsen, 1982a). Gaudin (1988) observed a synchrony of N supply with USG to rice plant demand.

Xiang *et al*., (2013) reported that the incorporation of N at 5 to 10 cm depth increased rice vegetative growth parameters over the surface application or prilled urea. The continuous availability of N with USG can increase root development and favour higher nutrient uptake and higher growth (Xiang *et al*., 2013). One of the reasons of the higher performances of the deep placement of USG on rice growth and yield is that root growth is significantly sensitive to high ammonia emissions following the surface application of PU (Xiang *et al*., 2013).

The higher growth performances of USG over PU obtained in this experiment confirms the results obtained by many authors. Naznin *et al*. (2013) reported superiority of USG deep application over the broadcasting of PU in rice growth. Islam *et al*. (2011) and Bandaogo *et al*. (2015) also observed increased plant height and panicle length, as well as higher number of effective tillers in rice due to deep application of USG. Kabir *et al*. (2009) and Miah and Masum (2004) reported taller rice plant with USG application than PU broadcasting. Naznin *et al*. (2013) and Khatun *et al*. (2015) reported higher number of tillers of urea deep placement than PU at various locations.

Across the sites and seasons, the deep placement of USG showed significant superiority in rice straw yield over the surface broadcasting of PU. This result is in perfect agreement with the findings of Bowen (2005); Kabir *et al*. (2009); Azam *et al*. (2012); and Bandaogo *et al*. (2015) who reported significant increases of rice straw and grain yield with USG over PU.

The grain yield was significantly superior for the deep application of USG than the surface application of PU at all the sites and seasons. Similar results were reported by

Xiang *et al*. (2013), Debnath (2013), Mohammad *et al*. (2014), Das *et al*. (2014) and Bony *et al*. (2015).

Rice grain yield and straw yield varied with different rates of USG and PU. These results are in agreement with the findings of Phongpan *et al*. (1988) who reported that, with respect to the method of application, the surface broadcasting of urea, at comparable rates gave lower grain and straw yields than the incorporation in the reduced zone of paddy soil . The results also confirmed those of Bony *et al*. (2015) who observed significant differences in grain yield with different rates of USG. Similarly, BRRI (2000) and Hasan (2007) reported increased rice yield parameters with increasing rates of USG. Islam *et al*. (2014) also reported responses in rice yield to increasing rates of USG. The improvement of rice yield with increasing rate of USG can be attributed to the availability of higher amount of nitrogen with USG that enhanced rice growth.

In general, the increase effect of the type of urea in rice grain yield was influenced by the nitrogen rate. At the Ablotsri site in the second season for instance, the USG applied at 52 kg ha^{-1} produced similar rice yield with PU applied at 78 kg ha^{-1}. At 78 kg N ha^{-1}, USG produced similar rice yield with PU applied at 104 kg N ha^{-1}. This suggests that 26 to 52 kg N ha^{-1} can be saved on the site while applying USG instead of PU. Kapoor *et al*. (2008) also reported possibility of saving 25 kg N ha^{-1} by farmers while using USG instead of PU.

At the Kouto site, the broadcasting of PU and the deep placement of USG showed identical grain and straw yield. Yaosse (2009) also reported no significant yield increasing effect of USG over PU. This result can be attributed to the soils properties of the site. Compared to those of Ablotsri and Hahome, Kouto soil is of lower CEC and relatively high sand and low clay content that reduces nitrogen stability in the soil and increases its leaching above roots zone. The USG is not recommended for such type of soil because of the danger of leaching (Savant and Stangel, 1990). Mohantyet al. (1999) stated that the placement technology suits conditions where ammonia volatilization rather than leaching or denitrification is the predominant N loss mechanism. Thus, the benefit of deep placement of USG is greater than surface application of PU on soils with moderate to heavy texture, low permeability and percolation rate, high cation exchange capacity and pH. Field works suggested a possible improvement of rice yield with urea deep placement by varying the amount of clay in the soil (Misra *et al*., 1995). Mohanty *et al*. (1999) observed no rice yield increase of USG deep placement over PU broadcasting in sandy loam soils with less than 20% clay. With regards to the results in the present experiment, the deep placement of USG cannot be recommended for rice farmers at Kouto site.

4.3.2.3. Rice growth, yield components and yield as affected by nitrogen rate

Across the seasons and sites and regardless of the type of urea, nitrogen rate significantly influenced rice growth parameters, yield attributing parameters and yields. Generally, rice parameters increased with increasing rates of nitrogen applied. This result is in conformity with the finding of Zhilin *et al*. (1997), Abou-Khalifa (2007), Singh *et al.* (2008), and Jana (2012).

Across the sites and seasons, plant height increased with increasing rates of N. This can be ascribed to higher N uptake and its high availability in soil at high application levels. Nitrogen induces maximum vegetative growth at higher application rates. Nitrogen is known to be the main nutrient that boosts biomass development. It plays prominent role in enhancing cell elongation, building up of new meristematic cells, enhancing and increasing photosynthetic activities of the plant (Salem *et al*., 2011). Eriksen and Nilsen (1982a) also explained the increase in plant growth in response to increasing N fertilizers application as enhancement of availability of nitrogen that consequently leads to more leaf area resulting in higher photoassimilates and thereby results in more dry matter accumulation. Similar results to those of the present experiment were also reported by Mandal *et al*. (1992). The role of nitrogen is well known in the various physiological processes including cell division and cell elongation of the plant (Zhilin *et al*., 1997). However, excess supply of nitrogen results in succulent growth leading to susceptibility to pests and diseases (Imran and Gurmani, 2011) and enhancement of lodging during grain filling stage (Sidhue *et al*., 2004).

Across the sites and seasons, plant number of tillers per hill increased with increasing application of urea. These results corroborated the findings of Singh *et al.* (1996), Surekha *et al.* (1999), Debnath (2013) and Eriksen and Nilsen (1982b). They reported increased number of tillers due to increasing application rates of N. According to Yoshida *et al*. (1972), as the amount of nitrogen applied increases, there is an increase in the number of tillers per hill. Similar results have been reported by Eriksen and Nilsen (1982b).

Regardless of the mode of urea and the seasons, the plant height and number of tillers increased with increasing N rate and reached their maximum with 78 kg ha^{-1}. Except for the first season at Ablotsri site, the N rate of 104 kg ha^{-1} produced similar rice growth as 78 kg N ha^{-1}. A similar result was obtained by Saha *et al*. (2017) who reported a maximum rice height at 90 kg N ha^{-1}. Tunio *et al.* (2002) and Rahman *et al.*, (2007) also reported similar results. The maximum growth obtained at N rate of 78 kg ha^{-1} in the present study is probably due to a higher uptake of N at that level.

Across the locations and seasons, the straw yield and grain yield increased with increased N rates. The increase of straw and grain production could be due to the increment of leaf area index with N supply, leaf chlorophyll content (Salem, 2006) and nutrients uptake (Hussaini *et al*., 2008). Eriksen and Nilsen (1982b) attributed the increase in yield with increasing rate of N applied to the importance of this nutrient in the synthesis of nucleotides, proteins, chlorophyll and enzymes that are involved in various metabolic processes that impacts directly on the vegetative and reproduction phases. The increase of grain yield with the increase of N rate can also be explained by the increase effect of N on the number and size of meristematic in new shoot formation (Lawlor, 2002).

In general, rice grain yield increased with N uptake to the highest rate of 104 kg ha. However, there was less increase in grain yield between 78 and 104 kg ha^{-1} which suggests that the availability of other nutrients or genetic potential of rice became more important in determining the yield than N supply (Marschner, 1995).

At Ablotsri site, N78 and N104 produced similar grain yield. The result suggests no need to exceed the rate 78 kg N ha^{-1} at Ablotsri site.

4.3.2.4. NU, AE, PE and RE as affected by rice variety

Rice variety TG-405 showed significant higher nitrogen uptake than IR-841 at Ablotsri site in the two seasons and at Hahome site in the first season. This result is in accordance with Coelho *et al*. (2016) who reported significant effect of cultivars on rice uptake of N. Prasad and Prasad (1980) also found different nitrogen uptake with different rice varieties.

This high uptake of nitrogen of TG-405 over IR-841 can be attributed to the difference in their genotypes that lead to different vegetative growth and yield patterns between the two varieties. Regardless of the seasons, the TG-405 showed higher growth, yield components and yield than IR-841 as a consequence of higher uptake of nitrogen by TG-405 than IR-841.

Even though TG-405 showed superiority in NU over IR-841 in the first season at Hahome site and in both seasons at Ablotsri site, the differences were insignificant at Kouto site. This can be explained by specific soil and climatic factors that can reduce the effect of nitrogen uptake by rice varieties.

Inconsistent significant differences in AE, PE and RE were observed between the two varieties. The variety TG-405 recorded systematically higher values of nitrogen use efficiency than IR-841 where differences exist. These results are in accordance with de Vries *et al*. (2010), Djaman *et al*. (2016) and Naveen and Uma (2016) who reported differences in nitrogen use efficiency due to rice varieties.

4.3.2.5. NU, AE, PE and RE as affected by the type of urea

In all soils and seasons, the nitrogen uptake (NU), Agronomy use Efficiency (AE), Physiological Efficiency and the Recovery efficiency (RE) were higher for the deep application of USG than the surface broadcasting of PU. This result corroborates the findings of Hussain *et al*. (2015) who reported higher NU and AE with the deep application of USG than the surface broadcasting of PU. Earlier on, Broadbent and Mikkelsen (1968); de Datta *et al. (*1968) and Koyama (1971) recorded considerably lower yields as well as lower N uptake with the broadcasting method than with incorporation or deep placement of fertilizers.

4.3.2.6. NU, AE, PE and RE as affected by nitrogen rate

Across the seasons and locations, increased nitrogen rate consistently showed increased nitrogen uptake by the rice. This result is similar to those of Qiao *et al*. (2012), Eriksen and Nilsen (1982a) and Khande *et al*. (2017). This can be explained by the fact that, application of high rates of nitrogen implies its high concentration in soil and its high availability for plant uptake. Eriksen and Nilsen (1982b) observed that nitrogen uptake by rice is markedly influenced by the N fertilizer rate.

Across the seasons and sites, the agronomic efficiency (AE) and the physiological efficiency (PE) increased first when N rate increased from 52 to 78 kg ha^{-1} and declined further when N rate was increased to 104 kg ha^{-1}. These result is in accordance with Dobermann (2005) who indicated that the AE and PE varied widely depending on the level of N rate and the N management system. The decline of AE and PE observed at higher N rate suggested that the rice plant cannot absorb or utilize nitrogen at higher doses or N losses surpassed uptake by rice plant (Fageria, 2005). Xie *et al*. (2007) and Djaman *et al.* (2016) also reported a decreasing NUE with increased N fertilizer. The result on the increase of AE and PE when N rate was raised from 52 to 78 was in accordance with Pan *et al.*, (2012) and Sui *et al.*, (2013) who reported that for reasonable N application rates, nitrogen use efficiency was improved as well as grain yield.

The PE was defined as the ratio of biomass yield increase with applied N to total N uptake. The AE of applied N represents the grain yield increasing effect of applied N (Dobermann, 2007). Therefore the AE and PE vary with various factors that affect rice growth and yield. Differences in AE and PE observed on the different sites can be explained by the differences existing in their soil properties. As in the present experiment, Cantarella *et al*., (2008) reported significant differences in AE and PE between two different soils.

The apparent recovery efficiency of N (RE) reflects the percentage of fertilizer N recovered in aboveground plant biomass (Dobermann, 2007). Across the sites and seasons in the present experiment, the RE was negatively correlated with N rate. Thus with higher N rate, a lower RE was obtained. Hirzel and Rodríguez (2013) reported similar results. Huang *et al.* (2008) pointed out a decrease in RE with increased N rate for two rice cultivars. Zhu *and* Chen *(*2002) and Zhang *et al. (*2012) linked this result to the fact that excessive application of N fertilizer causes higher N surplus in the soil system enhancing losses by gaseous emission, denitrification, leaching and runoff. Other previous researchers confirm this fact (Jiang *et al*., 2004; Peng *et al*., 2006; Mae *et al*., 2006; and Xie, *et al*., 2007). According to Fageria (2013), decline in NUE indicates that rice could not utilize or absorb N at higher rate because their absorption mechanisms might have been saturated or N losses exceed the N absorption.

The results of the present experiment showed that RE ranged from 46-72% with averages of 69% at Ablotsri, 62% at Hahome and 47% at Kouto site. These values are in agreement with the findings of Dobermann (2005) who indicated 30 to 50% as common values of RE and 50-80% in case of low levels of N or proper N management systems. The N management in this study has been the split application of PU and deep placement of USG.

While comparing the NU, the AE, PE and RE with regards to the locations, the Ablotsri site showed the highest performances followed by the Hahome site while the lowest performances were obtained at Kouto site. These differences in the NU and NUE of the different locations can be attributed to the soil specific properties. In fact, the soils have different physico-chemical characteristics that affect N transformations, movement and availability for plant. As compared to this field experiment, Dong *et al*., (2015); Ye *et al*., (2007); Matsunami *et al*., (2009); Rahman *et al*., (2009) reported differences in NU and NUE between different locations. The lowest NU and NUE parameters obtained at Kouto site suggests that this soil is more vulnerable to N loss and proper N fertilizer management should be adopted to improve rice N use efficiency and yield.

4.4. Results and discussion experiment 3

4.4.1. Results

4.4.1.1. Effect of seedling age and time of USG application on some rice characteristics

- ***Rice plant height***

The effect of the seedling age on rice plant height at 45, 75 DAT and at harvest is illustrated by Figure 4.4.1. The result showed a significant *(P<0.05)* decrease of rice plant height with increasing age of the seedling age at 45 DAT, 75 DAT and maturity stage.

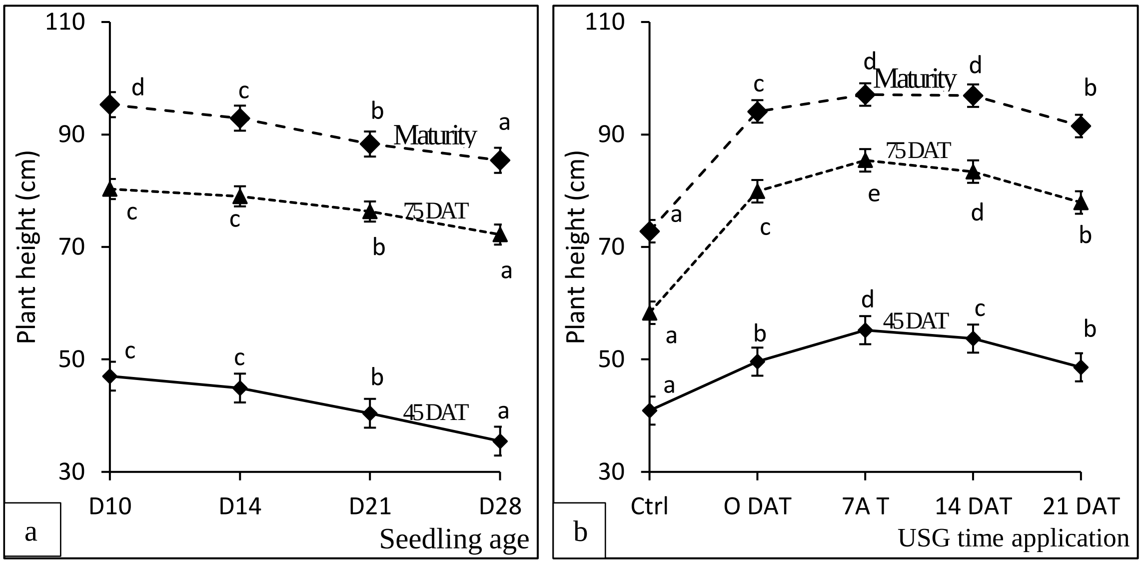


Figure 4.4.1: Rice plant height as affected by seedling age (a) and time of USG application (b).

At 45 and 75 DAT, the highest rice plant was observed with both 10 and 14-day old seedlings but at maturity stage, the highest rice plant rice was obtained with only 10-day old seedlings. At all growing stages the lowest rice plant height was observed with the 28-day old seedlings (Figure 4.4.1 a).

The USG application time significantly affected the plant height. At the 45, 75 DAT and at maturity, the lowest rice height was recorded with the control treatment (without N application). With the USG treatments, at 45 and 75 DAT, the highest rice height was observed when USG was applied at 7 DAT, followed by14 DAT treatment. The 0 and 21 DAT treatments showed similar height at 45 DAT while at 75 DAT, 0 DAT treatments showed higher rice height compared to the 21 DAT treatment. At maturity, 7 and 14 DAT treatments showed similar plant heights which were the highest followed by the 0 DAT treatments (Figure 4.4.1 b)

- ***Number of tillers***

Tillers are side shoot development from the base of rice plant and play major role in the yield of a crop. The total number of tillers was significantly *($P<0.05$)* affected by the seedlings age (Figure 4.4.2). The highest number of tillers was recorded both with 21 and 28-day old seedlings while the lowest number of tillers was observed with 10-day old seedlings. However, similar number of tillers was observed between 14 and 21-day old seedlings (Figure 4.4.2 a). The general trend observed was a slight increase in the number of tillers with increasing seedling age. The date of USG application did not affect the number of tillers (Figure 4.4.2 b).

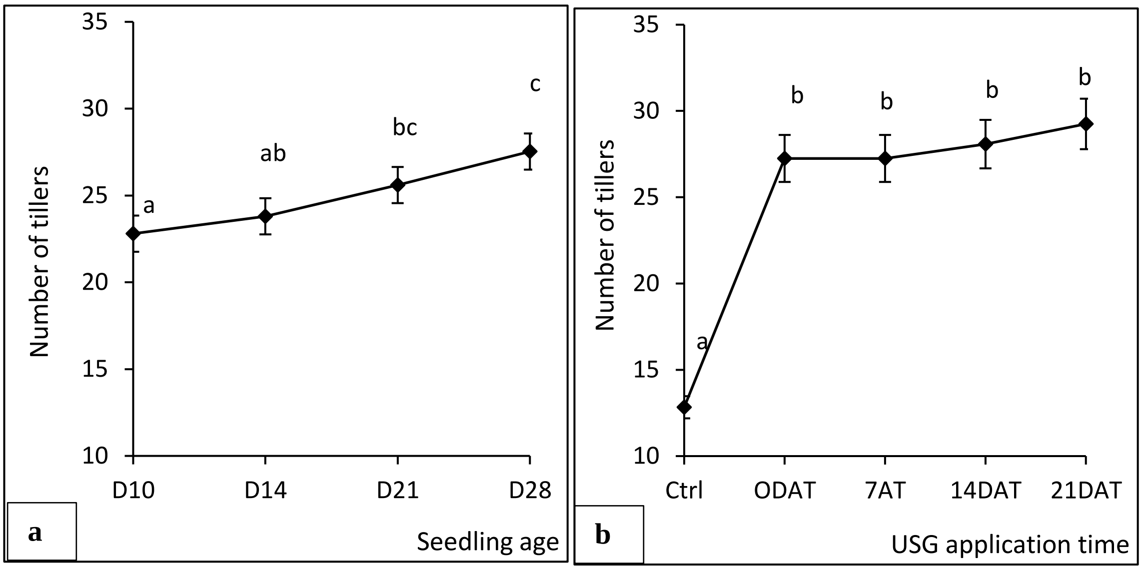


Figure 4.4.2: Number of tillers as affected by seedling age (a) and time of USG application (b).

- ***Interaction effect on plant height and number of tillers***

The effect of the interaction between the age of rice seedlings and the time of USG application on the height was significant *($P<0.05$)* at 45 DAT and not significant at maturity. However, at 75 DAT, the interaction showed significant *($P<0.05$)* effect on the plant height (Table 4.4.1). At this stage, the highest plant height (85-87 cm) was obtained for both 10 and 14-day old seedlings on which USG was applied at 7 or 14 DAT. The lowest height was obtained for the 28-day old seedlings on the control (53.5 cm). At maturity, the 10 and 14-day old seedlings each combined with USG applied at 0, 7 and 14 DAT showed the high height (99-101 cm); however, the differences were not statistically significant among the interactions at that stage. The total number of tillers was not affected by the interaction between the seedling age and the time of USG application (Table 4.4.1).

Table 4.4.1: Interaction effect of seedling age and time of USG application on rice plant height

Treatments	Height at 45DAT (cm)	Height at 75 DAT (cm)	Height at maturity (cm)	Number of tillers per pot
10DAT*Ctl	42.3	62.9 c	76.7	13
10DAT*0	47.4	84.2 ij	99.7	30
10DAT*7	49.3	80.80 fgh	101.1	30
10DAT*14	50.1	86.7 jk	101.2	29
10DAT*21	46.0	80.8 fgh	98	25
14DAT*Ctl	38.8	59.3 b	75	15
14DAT*0	43.6	80.9 gh	96	29
14DAT*7	48.9	87.5 k	98.9	32
14DAT*14	48.2	85.2 ijk	100.6	31
14DAT*21	45.0	82.8 hi	94	31
21DAT*Ctl	34.7	57.3 b	72	12
21DAT*0	40.1	78.8 efg	91.8	27
21DAT*7	44.2	84.3 ij	95.2	28
21DAT*14	43.2	83.13 hi	93.7	28
21DAT*21	40.0	77.9 ef	88.7	24
28DAT*Ctl	29.6	53.5 a	67.3	11
28DAT*0	36.1	75.8 e	89	23
28DAT*7	40.5	82.7 hi	93.3	26
28DAT*14	37.7	78.8 efg	92	25
28DAT*21	33.4	70.1 d	85.5	29
Fpr	0.035	0.031	0.291	0.291
LSD	2.319	3.04	*NS*	*NS*
CV	2.8	2.4	2.7	12

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

4.4.1.2. Effect of the seedling age and USG application time on the yield components, yield and harvest index

- ***Length of panicles***

The seedling age significantly affected the length of panicle *(P<0.05)*. The panicle length was statistically similar (22 cm on average) but highest for 10 and 14-day old seedlings. Above 14-day old, the length of panicle decreased with seedling age. The lowest (20 cm on average) was obtained with 21 and 28-day old seedlings which recorded statistically similar performances (Figure 4.4.3 a). Except the control (without any N application) statistical similar panicle lengths were obtained for the different time of USG application (Figure 4.4.3 b).

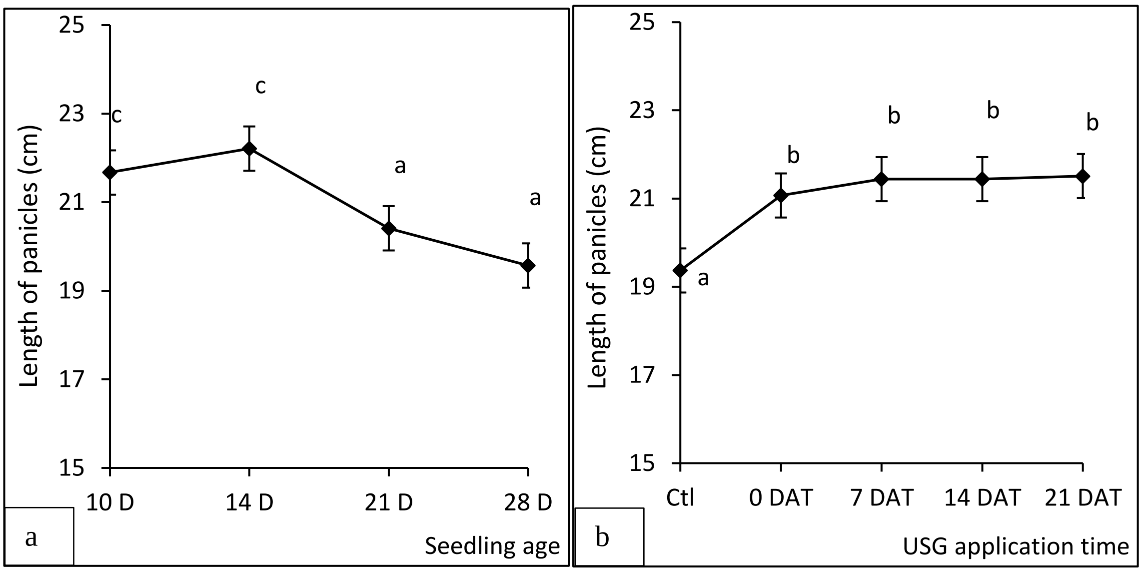


Figure 4.4.3: Length of panicles as affected by seedling age (a) and time of USG application (b).

- ***Weight of 1000 grains***

The seedling age did not affect the weight of 1000 grains (Figure 4.4.4 a). However, the weight of 1000 grains was significantly affected by the time of USG application. The highest 1000 grain weight (26 g) was obtained when USG was applied at both 7 and 14

DAT. However, application of USG at 0, 14 and 21 DAT produced statistically ($P > 0.05$) similar 1000 grains weight (25 g) (Figure 4.4.4 b).

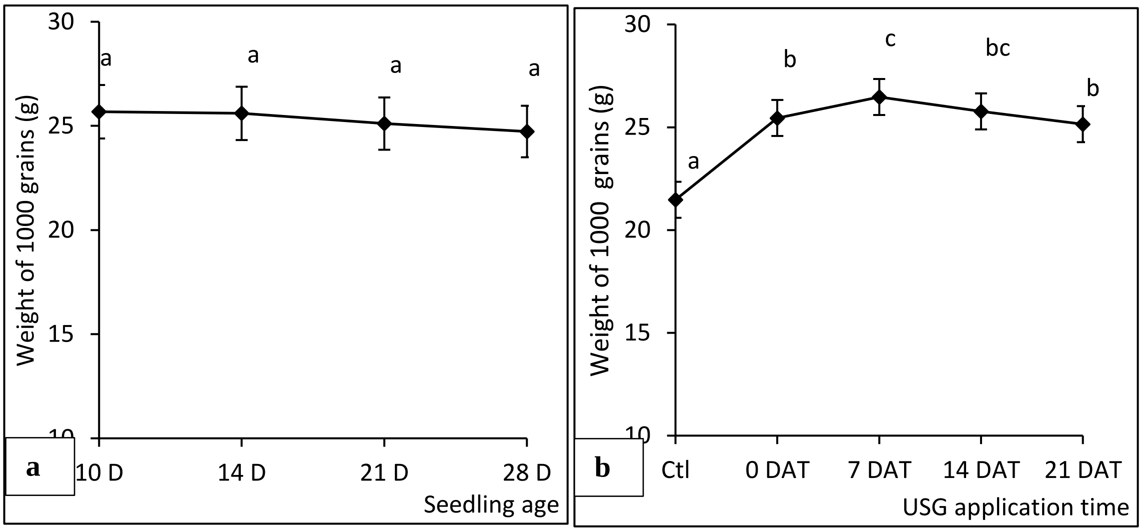


Figure 4.4.4: Weight of 1000 grains as affected by seedling age (a) and time of USG application (b).

- ***Grain yield***

The grain yield significantly ($P<0.05$) decreased with seedling age. The highest grain yield (86 g pot^{-1} on average) was obtained at both with 10 and 14-day old seedlings followed by the 21 days seedlings. The 28 days seedlings had the lowest grain yield (72 g pot^{-1}) (Figure 4.4.5.a).

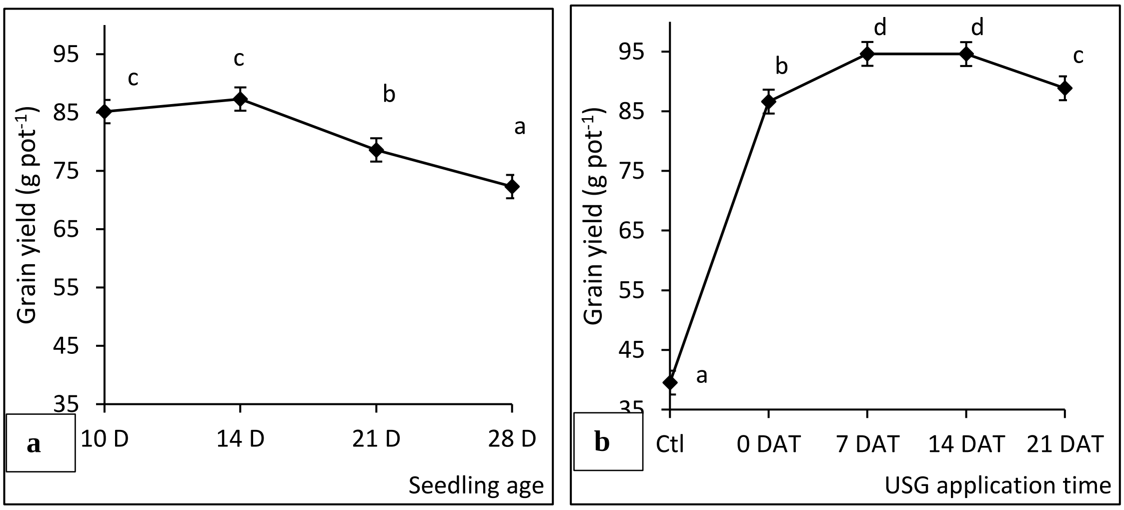


Figure 4.4.5: Grain yield as affected by increasing age of seedlings (a) and time of USG application (b)

The grain yield was significantly *($P<0.05$)* affected by the time of USG application. Rice yield increased with increasing time of USG application from 0 to 14 DAT. Thereafter, it decreased when USG application time increased from 14 to 21 DAT. Similar grain yield (95 g pot^{-1}) was obtained when USG was applied at both 7 and 14 DAT. Application of USG at 0 DAT gave the lowest grain yield (87 g pot^{-1}) as compared with other USG treatments (Figure 4.4.5 b).

- ***Relationship between the rice grain yield and the seedling age, and the grain yield and USG application time***

The equations in terms of rice yield as a function of the seedling age and time of USG application are illustrated in Figure 4.4.6.

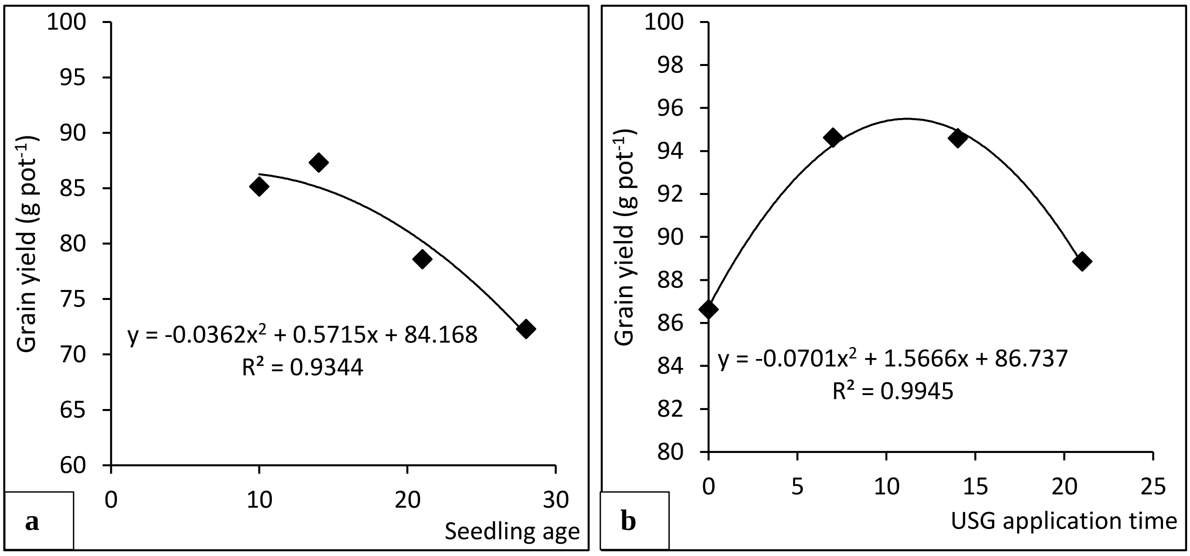


Figure 4.4.6: Relationship between the grain yield and the seedling age (a) and rice yield and time of USG application (b)

Knowing the age of seedling (in days) and the number of days after transplanting (in day), the rice grain yield can be predicated with the following equations:

$$GY_{(Grain\ yield)} = -0.036\,D^2 \times 0.5715 \times D + 84.168 \qquad R^2 = 0.930 \qquad [4.3.1]$$

$$GY_{(Grain\ yield)} = -0.0701\,DAT^2 + 1.5666\,DAT + 86.737 \qquad R^2 = 0.993 \qquad [4.3.2]$$

Where: GY = grain yield

D = Age (in days) of the seedling

DAT= Number of days after transplanting

- ***Straw yield***

The straw yield significantly *($P<0.05$)* decreased with the age of the seedlings. The highest performance (94 g pot^{-1} on average) was obtained at 10 and 14 days seedlings. The 21 and 28-day old seedlings produced statistically similar and lower straw yields. (Figure 4.4.7.a).

The time of USG application affected the straw yield. Application of USG at 0 DAT produced the lowest straw yield (97 g pot^{-1}) as compared with other USG treatments. The highest straw yield was recorded for USG applied at 7 and 14 DAT (Figure 4.4.7b).

- ***Harvest Index***

No significant *($P>0.05$)* effects of the seedling age and time of USG application were observed for harvest index. All treatments recorded statistically similar HI (47 on average) (Figure 4.4.8)

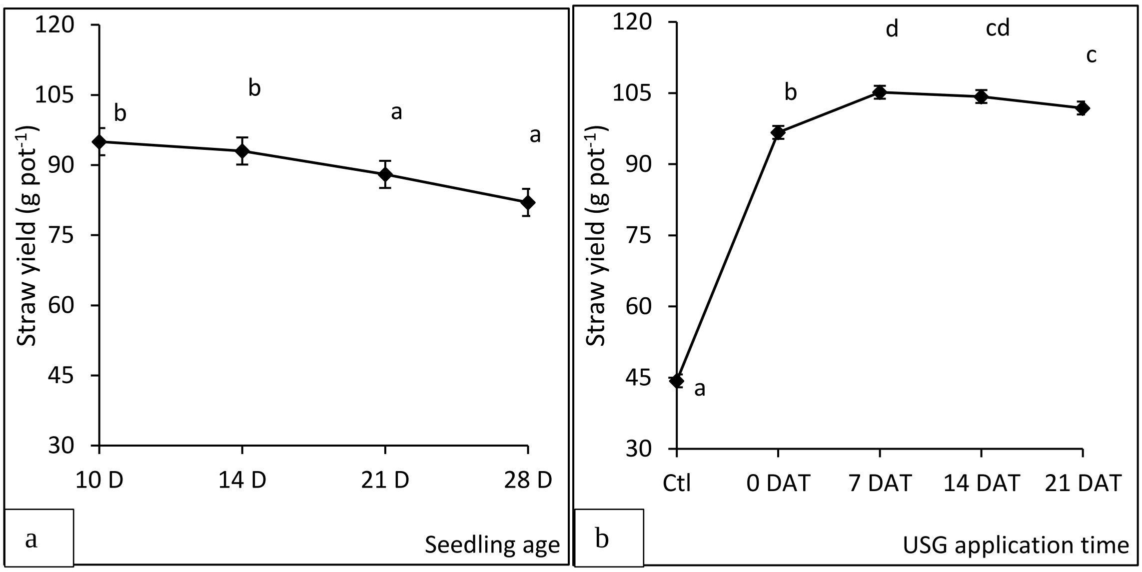


Figure 4.4.7: Straw yield as affected by increasing age of seedling (a) and time of USG application (b)

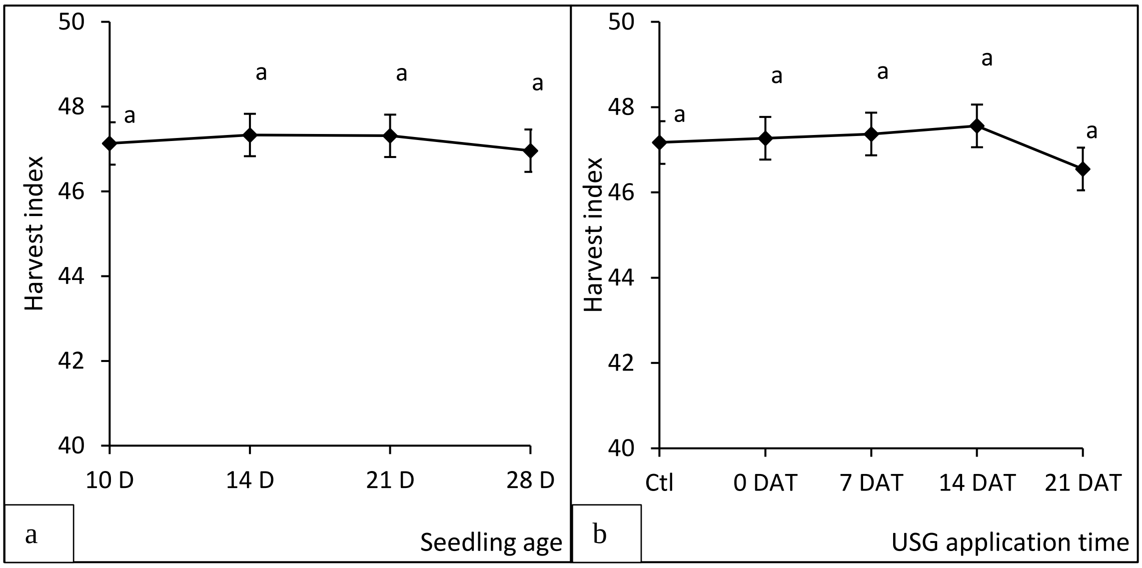


Figure 4.4.8: Harvest Index as affected by increasing age of seedling (a) and time of USG application (b)

- ***Interaction effects of the seedling age and time of USG application on rice yield parameters and yield.***

The interaction between the seedling age and the time of USG application affected the grain yield. The highest grain yield was obtained with the 14 days seedling age on which USG was applied either at 7 or 14 DAT and with the 10 days seedling age when USG was applied at 14 DAT. The lowest grain yield was observed with the 28-day old seedlings when the USG was applied at 21 DAT. No significant interaction between the seedling age and the time of USG deep placement was observed on the length of panicles, weight of 1000 grains, straw yield and harvest index (Table 4.4.2).

4.4.1.3. Effect of seedling age on NU and NUE

The nitrogen uptake (NU) decreased with increasing ages of the seedlings. The NU was the lowest (1 g pot^{-1}) with the oldest seedlings (28-day old) while the highest NU (1.2 g pot^{-1}) was observed both with 10 and 14-day old seedlings (Figure 4.4.9 a).

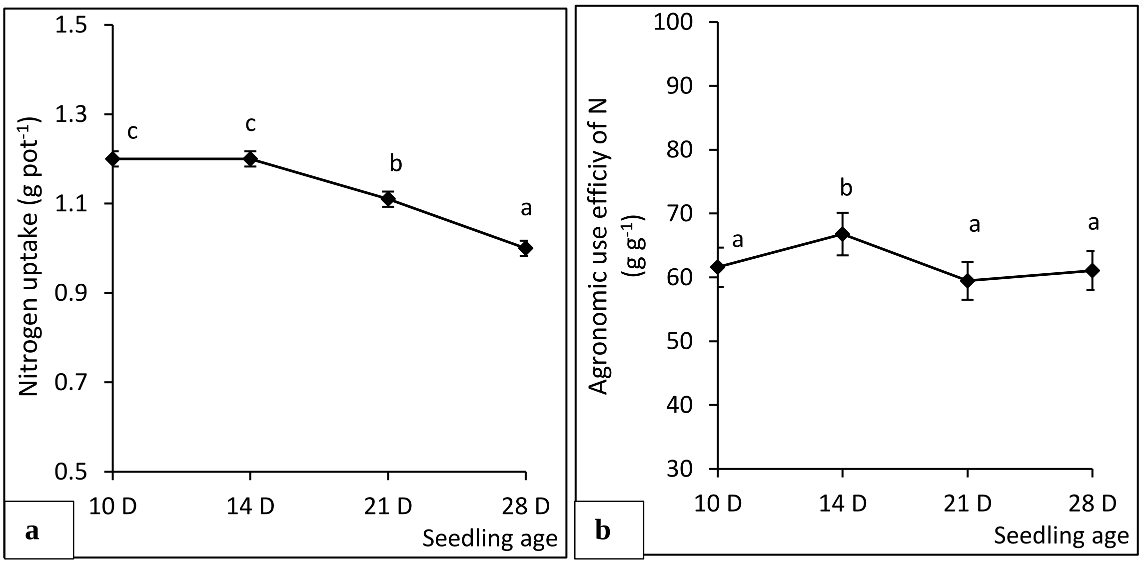


Figure 4.4.9: Effect of seedling age on NU (a) and AE (b)

Table 4.4.2: Interaction effect of seedling age and time of USG application on rice growth and yield parameters

Interaction	Length of panicles (cm)	Weight of 1000 grains (g)	Grain Yield (g pot^{-1})	Straw Yield (g pot^{-1})	Harvest Index
10D*Ctl	19.9	22.6	44.27 c	51	46
10D*0 DAT	21.67	25.4	89.80 ghi	99	48
10D*7DAT	22.03	26.2	96.97 k	108	47
10D*14DAT	22.1	25.6	99.23 klm	108	48
10D*21DAT	22.67	25.1	95.53 jk	108	47
14D*Ctl	20.17	20.0	42.97 c	48	47
14D*0DAT	21.77	26.0	93.00 ij	98	47
14D*7DAT	23.5	27.4	102.10 m	107	48
14D*14DAT	23.43	27.4	100.73 lm	107	48
14D*1 DAT	22.2	26.7	97.77 kl	105	47
21D*Ctl	19.03	21.9	39.10 b	44	47
21D*0DAT	20.97	25.6	84.03 f	92	48
21D*7DAT	20.37	26.3	91.67 i	101	48
21D*14DAT	20.67	25.2	90.97 hi	102	47
21D*21DAT	21.03	24.8	87.20 fg	99	47
28D*Ctl	18.37	21.4	31.75 a	35	48
28D*0	19.9	24.8	79.63 e	88	47
28D*7DAT	19.87	26.0	87.73 fgh	97	47
28D*14DAT	19.57	24.9	87.43 fgh	97	47
28D*21DAT	20.13	24.0	74.93 d	91	45
Fpr	0.853	0.119	0.626	0.365	0.288
LSD	*NS*	*NS*	3.76	*NS*	*NS*
CV	5.8	4.7	2.8	3.6	1.8

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

The agronomic efficiency (AE) increased with the seedling age from 10-day old seedlings to get a peak (67 kg kg^{-1}) with 14-day old seedlings (Figure 4.4.9 b). Thereafter it decreased when the seedlings age increased to 21 and 28-day old that recorded statistically *(P>0.05)* similar performances (60 kg kg^{-1} on average). On the contrary the physiological efficiency (PE) increased with increasing seedling age. The highest PE was obtained with the oldest seedlings (28 D) while the lowest was observed with the youngest seedling (10 D) (Figure 4.4.9 c).

The recovery efficiency was statistically similar (P > 0.05) for 10 and 14-day old seedlings but higher than the RE obtained with 21 and 28 days seedlings that were also similar (Figure 4.4.9 d).

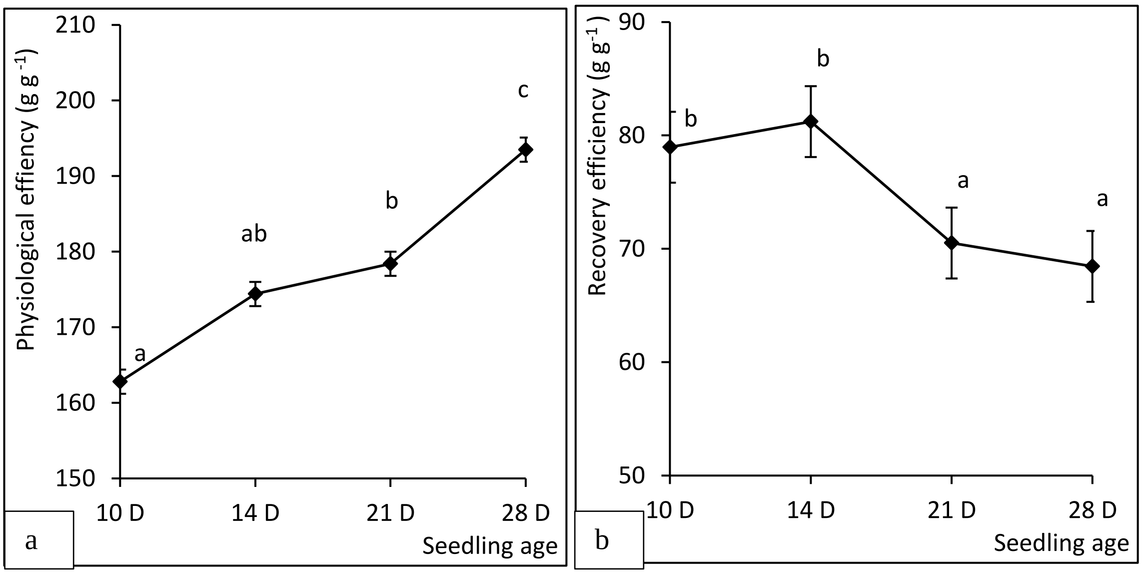


Figure 4.4.10: Effect of seedling age on PE (a) and RE (b)

4.4.1.4. Effect of USG application time on the NU and NUE.

Statistical differences *($P<0.05$)* were obtained with the nitrogen uptake (NU). Figure 4.4.11.a shows an increase in NU from the 0 DAT to 14 DAT where it reached a maximum value (1.29 kg ha^{-1}) and decreased when the application time of USG increased to 21 DAT.

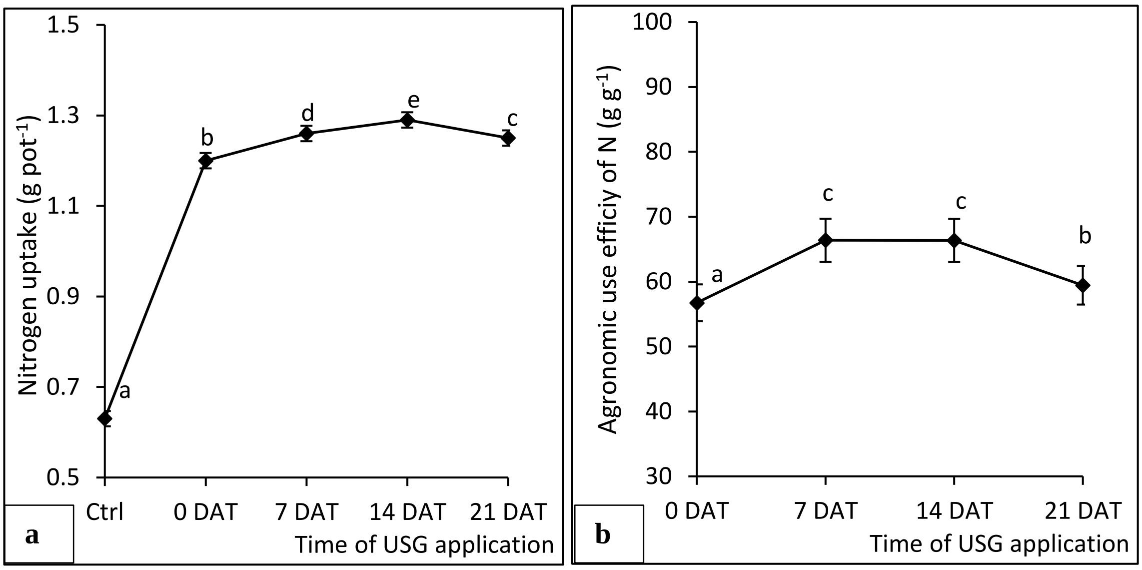


Figure 4.4.11: Effect of time of USG application on NU (a) and AE (b)

The highest AE was obtained when the USG was applied at 7 or 14 DAT. The 0 DAT treatment recorded the lowest AE (Figure 4.4.11.b). The highest PE (184 g g^{-1}) was obtained when USG was applied at 7 DAT. Statistically, the PE obtained for USG applied at 0, 14 and 21 DAT were similar but lower as compared with the 7 DAT (Figure 4.4.12.a). The RE significantly ($P < 0.05$) increased with increasing time of USG application up to 14 DAT by which the maximum value (79%) was obtained. The RE decreased thereafter when the USG application time was delayed from 14 to 21 DAT (Figure 4.4.12.b).

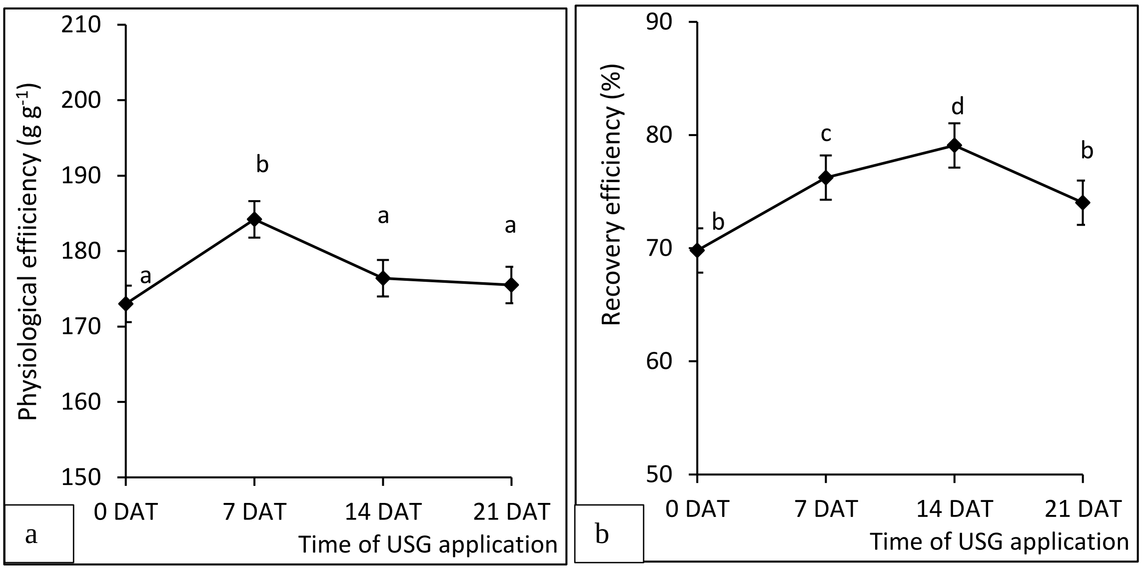


Figure 4.4.12: Effect of Time of USG application on PE (a) and RE (b)

- ***The interaction effects between the seedling age and the time of USG application on the NU and NUE.***

The interaction between the seedling age and the date of USG application showed significant effects on the NU and AE (Table 4.4.3). The highest NU (1.3 g pot^{-1}) was obtained with 10 and 14-day old seedlings when the USG was applied either at 7, 14 or 21 DAT. The lowest NU was observed with the 28-day old seedlings when USG was applied at 0 DAT or 21 DAT.

The AE was highest with the 14-day old seedlings when USG was applied at the 7 and 14 DAT. The interaction was the lowest with the 28 day seedlings combined with USG application at 21 DAT. Statistically, the interaction between the seedling age and the time of urea application did not affect the PE and RE (Table 4.4.3).

Table 4.4.3: Interaction effect of the seedling age and time of USG application on the NU an NUE

Interaction	Nitrogen Uptake (g g pot^{-1})	Agronomic Use efficiency (g g pot^{-1})	Physiological Efficiency (g g pot^{-1})	Recovery efficiency %
10DAT*Ctl	0.681 b			
10DAT*0	1.270 ghi	54 ab	159	71
10DAT*7	1.340 jk	63 def	170	80
10DAT*14	1.373 k	66 efg	162	84
10DAT*21	1.357 jk	61 cd	160	82
14DAT*Ctl	0.658 b	-	-	-
14DAT*0	1.300 hij	60 cd	168	78
14DAT*7	1.325 ijk	71 h	185	81
14DAT*14	1.365 k	69 gh	170	85
14DAT*21	1.331 jk	66 efg	174	81
21DAT*Ctl	0.640 b			
21DAT*0	1.191 def	54 ab	170	67
21DAT*7	1.248 fgh	63 def	181	73
21DAT*14	1.236 fg	62 de	184	72
21DAT*21	1.221 efg	57 bc	178	70
28DAT*Ctl	0.550 a			
28DAT*0	1.080 c	57 bc	194	64
28DAT*7	1.142 d	67 fgh	200	71
28DAT*14	1.173 de	67 fgh	189	75
28DAT*21	1.071 c	52 a	190	63
Fpr	<.001	<.001	0.380	0.054
LSD	0.061	4.2	NS	NS
CV	3.3	3.1	3.8	3.2

Fpr= Fisher probability, NS = Not Significant, LSD = Least Significant Difference CV = Coefficient of Variation

- ***Multiple regressions of rice yield and the nitrogen NU, AE, PE and RE***

The results of the multiple regressions are presented in Table 4.4.4. The Table indicates that the rice yield was significantly correlated with NU and AE *($P<0.05$)* while it wasn't with the RE and PE. The Estimated constant was also not significant.

Table 4.4.4: Regression analysis between grain yield and NU and NUE

Parameter	Estimate	SE	t pr.
Constant	1.7	10.8	0.879
AE	0.725	0.127	<.001
PE	-0.0533	0.0455	0.248
RE	-0.236	0.13	0.077
NU	57.13	5.55	<.001
R^2		93.7	
Pr		<.001	

The regression analysis was repeated without the non-statistically different parameters (PE and RE) and the result presented in Table 4.4.5 and followed by the regression model (equation 4.3.1).

Table 4.4.5: Result of regression analysis between grain yield and NU and AE

Parameter	Estimate	SE	t pr.
Constant	-7.8	3.82	0.047
AE	0.532	0.0529	<.001
NU	52.62	3.02	<.001
R^2	93.5		
Pr	<.001		

$$GY_{(Grain\ yield)} = 52.62\ NU + 0.532\ AE - 7.8 \qquad [4.3.1]$$

4.4.2. Discussion

4.4.2.1. Rice growth as affected by the seedling age

In general, rice plant height decreased with increasing age of seedlings at all growing stages. This result is in agreement with many researchers (Salem *et al*., 2011; Hossain *et al*., 2011; Sarwar, *et al*', 2011, Rahman *et al*., 2013; Kirttania *et al*., 2013; Mobasser, *et al*.,2007**;** and Mishra and Salokhe, 2008).

Plant height is an important yield factor that is controlled by the genetic makeup of the plant. The generally higher plant height observed with younger seedlings over the aged ones can be explained by the ability of younger seedlings to produce more phyllochrons before entering the reproductive phase as compared with older seedlings. Also, transplanting of young rice seedlings reduces the transplanting shock (Mishra and Salokhe, 2008), favour early plant root establishment and growth in the soil environment. Mishra and Salokhe (2008) observed greater root growth and establishment with younger seedlings transplanted than old ones. Himeda (1994) and Sasaki (2004) explained that the above and below-ground characteristics of rice plants, before and after transplanting, vary with seedling age. Vishwakarma *et al*. (2016) stated that younger seedlings exploit the initial vigour of the genotype and provide initial conditions for better establishment. Rahman *et al*. (2013) recorded a similar result to that of the present experiment and linked the decreasing of the rice plant height with the seedling age to the availability of short vegetative growth period of aged seedlings in comparison to young ones. Rasool *et al*. (2016) also obtained similar results and concluded that transplanting aged seedlings led to a poor crop performance. Early transplanting of seedlings shifts the high rice density in the nursery bed to a very low density on the field and thus reduces nutrient competition and improves aeration for faster growth.

The number of tillers increased in general with increasing age of seedlings. The effect of seedling age on tiller production had been reported by Himeda (1994), Sarwar *et al*. (2011), Anwar and Begum (2004), Sasaki, (2004), Mishra and Salokhe (2008) and Kirttania *et al*. 2013). The lower tillers number observed with the young seedlings as compared with aged ones might be due to the continuous tillering at maturity as observed for the plots that received old seedlings. This is in agreement with Chandra and Manna (1988), Kewat *et al*. (2002), NARC (2004) and Rasool *et al*. (2016) who reported lower rice tillering with young seedlings than old ones. Sarkar *et al*. (2011) tested among other factors two levels of seedling age and found that transplanting 35-day old seedlings produced significant greater tillers as compared with 25-day old seedlings. Contrarily to the results of the present experiment, many findings supported the superiority of younger transplanted seedlings over old ones with regards to the number of tillers (Mobasser *et al*., 2007**;** Alam *et al*., 2002; Mishra and Salokhe, 2008). In the System of Rice Intensification (SRI), Patra and Haque (2011) investigated pattern of rice tillering as influenced by age of seedlings and reported higher number of tillers with 10-day old seedlings compared to 12, 14 and 16-day old seedlings.

The length of panicles was significantly affected by the seedling age. It decreased with increasing seedling age. The result is in conformity with Mobasser *et al.* (2007)**,** Sarkar *et al.* (2011), Prabha *et al.* (2011), Patra and Haque (2011), Kirttania *et al*., (2013) and Rahimpour *et al.* (2013) who reported that the age of rice seedlings at transplanting significantly influences the length of panicles. This can be a consequence of greater growth rate observed with younger transplanted seedlings as compared with old ones.

The seedling age did not affect the weight of 1000 grains. This may be due to the fact that 1000 grain weight varies hardly with cultural managements. Ashraf *et al*. (1999) recorded similar result and indicated that weight of 1000 grains is the least affected by growing conditions and depended on genetic makeup. However, the present finding are contrary to those of Rao and Raju (1987), Sasaki (2004), Abou-Khalifa (2007) and Sarwar *et al*. (2011) who reported that transplanting of younger seedlings yielded higher 1000 grain weight than old seedlings.

The grain yield was affected by the age of seedling at transplanting. This result confirmed the finding of Ashraf *et al*. (1999); Nandini and Singh, (2000); Thanunathan and Sivasubramanian (2002), Salem *et al*. (2011), Sarwar *et al*. (2011), who reported significant differences in grain yield due to the age of seedling.

In the present experiment, rice yield decreased with increasing age of seedling age. The highest yield was observed for younger seedlings of 10 and 14-day old. This can be attributed to the higher rice growth observed with younger tillers. Young transplanted seedlings may not have suffered from irreparable damage of the roots during transplanting (Ros *et al.*, 2003) and as result, the root establish fast and induce good vegetative growth. Mishra and Salokhe (2008) observed greater root length density with young rice seedlings than older ones. They explained that transplanting young seedlings led to full utilisation of the root structure for uptake of nutrients and their upward flow produced vigorous plants at later growth stages. Shukla *et al*. (2014) explained similar result that, use of 10-day old seedlings utilized phyllochronic potential to produce significant higher grain yield. Uphoff (2002) indicated that the transplanting of younger seedlings along with soil, keep the roots intact resulting in their early adaptation to soil and climatic condition, thereby inducing better growth and yield.

Among the factors that affect rice yield, Ali *et al.* (1995) indicated that, seedling age is rated high because it has tremendous effect on rice growth and yield characters such as plant height, tiller production, panicle length, and grain formation. Many other authors obtained higher rice yield in transplanting young seedlings than aged seedlings (Himeda, 1994; Rao and Raju, 1987; Wagh *et al*., 1988; Ashraf *et al*., 1999; Nandini and Singh, 2000; Sarwar *et al*., 2011; Thanunathan and Sivasubramanian, 2002, and Mobasser *et al*., 2007). Studies on System of Rice Intensification (SRI) also shows that rice yield components and yield might be increased by transplanting seedlings as young as 14 days instead of older seedlings of 21-23 days (Makarim *et al. 2002)*.

Results of the present experiment indicated lowest rice yield recorded with oldest seedlings of 28 days. Liu *et al.* (2017) also observed similar result and indicated that, decrease of rice tiller number, pre-anthesis dry matter accumulation, remobilization efficiency and contribution to grain yield, as well as post-anthesis photosynthesis were associated with transplanting of older seedlings, causing reductions in the number of effective panicles, the total number of grains per panicle, the sink capacity per tiller, and grain yield. The increase of the number of tillers observed in the present experiment with aged seedlings did not contribute to increase grain yield because late production of many tillers near the maturity stage did not produce panicles. Hanada (1979) indicated that many of the late tillers do not produce panicles due to higher population and nutrients competition.

The straw yield decreased generally with increasing age of seedling. The straw yield was similar for seedlings of 10 and 14-day old but higher than those of 21 and 28 days which were also similar. The decrease in rice straw yield with the age of seedlings is a consequence of the general decrease of rice plant growth recorded at all stage in the present experiment. This may be due to greater root shock received by the aged seedlings during the uprooting and transplanting which have hindered growth rate (Rasool *et al*., 2016). Ros *et al*. (2003) stated that, the older the seedling, the greater is its depressing vigour after transplanting due to the impairment of root growth in the nursery. In fact, seedling of less than four leaves pollychrons has greater biomass production potential (Katayama, 1951). It has been also observed that transplanting of seedlings that stayed on nursery bed for long period result in deterioration of primary tiller buds on the lower node of the main column and that leads to reduced growth and yield parameters (Mobasser *et al.*, 2007). The result on rice straw in the present experiment is in conformity with many researchers works. Mandal *et al*. (1984) observed that successive delay of rice seedling transplanting resulted in concomitant reduction in dry matter production. Sahoo and Rout (2004) transplanted four weeks old seedlings and recorded greater shoot dry matter than six week old seedlings. Rahman *et al*. (2013) obtained higher total dry matter production with 25-day old seedlings than 35-day old ones. Vishwakarma *et al*. (2016) indicated that 10 days seedlings increased rice straw by 3.6 and 6.9% over 14 and 18-day old seedlings respectively. Horie *et al. (*2005) and Mishra and Salokhe (2008), Sarwar *et al*., (2011) reported maximum straw yield by transplanting younger seedlings than older seedlings. Rasool *et al*, (2016) indicated that 35 days and 25-day old seedlings showed similar quantities of dry matter but were significantly higher than that obtained with 45-day old seedlings. Maximum dry matter was obtained by younger seedlings than older ones, all grown on a dry nursery bed (Mishra and Salokhe, 2008)

The harvest (HI) is the grain yield expressed as a decimal fraction of total biomass yield. In this experiment, although the grain and straw yields were significantly affected by the seedling age, the harvest index was not. This can be due to the various levels of significance in grain and straw yields that can affect the difference in HI between the treatments. However, Sarwar *et al*. (2011) observed higher HI with 10 days seedlings than those obtained with more aged seedlings of 20, 30, and 40 days.

The nitrogen uptake (NU) markedly decreased with seedling age. Younger seedlings of 10 and 14-day old showed similar NU but higher than those recorded with 21 and 28-day old seedlings. This result confirms the finding of Rasool *et al*. (2016) who reported higher NU obtained when younger seedlings are transplanted than older seedlings. As result of increased NU with young seedlings over old ones, the PE (being inverse function of NU) was higher for aged seedlings as compared to young ones. The recovery efficiency (RE) (as the portion of the applied N that is taken up) was higher with the young seedlings than with old ones. Salem *et al*. (2011) also reported significantly higher NU and RE of young seedlings than old seedlings. Rasool *et al*. (2016) also obtained higher NU for 35 days seedlings than those of 45-day old seedlings.

4.4.2.2. Effect of USG application time on rice growth, yield, NU and AUE of N.

The highest performances on rice plant height, weight of 1000 grains, grain and straw yields were recorded when USG was applied at 7 or 14 DAT. This result can be a consequence of good synchrony of N availability to rice's need during its growing cycle under the two treatments. In fact, N synchrony to rice plant need is the main objective targeted by USG technology and is a very important strategy for plant growth and yield improvement. With USG deep placement just after rice transplanting, the NH_4^+ released following urea hydrolysis is adsorbed on soil particles and released slowly for rice root uptake throughout the growing season. Savant and Stangel (1990) explained that, typically steep concentration gradient of ammonium exist in the placement point and controls the rate and duration of USG-N available to the rice plant as result of diffusive transport mechanism and soil CEC. This makes the USG considered as a slow release N-fertilizer although it dissolves some few hours after placement.

Application of USG at 0 DAT (transplanting day) showed lower rice growth, yield NU and NUE performances as compared with 7 and 14 DAT treatments. The lower rice performances obtained with the application of USG at 0 DAT can be due to a lag period of the USG-N diffuse and become available to young rice plants. The lag period might have irreversibly impacted on rice growth rate and therefore on their yield, N uptake and use efficiency. Gaudin (1987) stated that the transport of ammonium from the placement site was slowed because it is mainly a diffusion mechanism that is influenced by ion-exchange. And as a result, a concentration gradient of USG ammonium tend to exist around the placement site where the young transplanted roots cannot reach because rice plant takes one to two weeks lag period for establishment and root development (Savant and Stangel, 1990).

The lower rice growth, yield, NU and AE and RE observed with the 0 DAT treatment can also be due to the toxicity effect of earlier ammonium-N fertilizers application on transplanted plants. In fact, application of USG is followed by high ammonium release around the placement site in the soil system which becomes toxic to young tillers establishment and root elongation. The tendency of young rice roots to avoid toxicity of high ammonium concentration near the USG placement site can negatively affect rice nutrients uptake and physiological processes and furthermore impact on its growth and yield. Gaudin (1988) observed in a root-box study with 1 g USG, an ammonium concentration of 0.45 mM as a threshold below which rice root uptake became highly efficient. Britto and Kronzucker (2002); Balkos *et al*. (2010); and Li *et al*. (2011) reported negative effects on root growth, yield depression, and chlorosis of leaves associated with high levels of NH_4^+ in soil. Bremner (1995) and Fan and MacKenzie (1995) observed ammonia toxicity on rice plant when urea fertilizer was placed close to young rice plants.

As compared with the 7 and 14 DAT treatments, the rice yield, NU and NUE performances were lower when USG was applied at 21 DAT and sometimes similar to 0 DAT treatment. The lower performances of the 21 DAT treatment might be due to late supply of N to the rice plant. The late USG application enhanced by the lag period of diffusion of the released NH_4^+-N outside the placement site can seriously delay N availability to transplanted seedlings and therefore induce irreversible impacts on its growth rate. Nitrogen being a predominant nutrient for plants in tropical soils, its synchrony with vegetative growth is very important because delays in N supply can irreversibly impact the plant growth and reproduction. The importance of earlier rice N fertilization was proven in many studies (Keisers, 1987; Sahoo *et al*, 1990; and Mahabari *et al*., 1996).

The delay in USG application can be the reason why the difference in the total number of tillers at maturity was reduced to insignificant level among the treatments. In fact, the application of USG at 21 DAT induced continuous tillering at the maturity stage and thus, increased the total number of tillers to a similar amount of that obtained with USG applied at 0, 7 and 14 DAT. This result is in accordance with the findings of Abedin *et al*. (2015) who also found higher number of tillers with USG application at 25 DAT. The delay in N supply can also be the cause of the lower 1000 grain weight, grain and straw yield recorded for the application of USG at 21 DAT as compared with the 7 and 14 DAT treatments.

The NU and RE significantly increased with increasing time of USG application from 0 to 14 DAT above which, the parameters decreased. This led to the conclusion that 14 DAT is the optimum time of USG application for optimal N uptake and recovery efficiency and therefore, the application of USG at 14 DAT can be recommended among other treatments to reduce environmental pollution associated with urea fertilizer use in paddy fields. The high NU and RE observed with the 14 DAT treatment contributed to high AE as a consequence of the high rice growth and grain yield obtained. However, the PE that is the total biomass harvested by unit of N uptake was higher for 7 DAT than 14 DAT treatment because of the low NU associated with high grain and straw yields obtained with the 7 DAT treatment.

4.5. Summary of the results and General discussion

The present study aimed at managing urea supergranule (USG) to improve growth and yield of rice in some paddy soils of Togo and Ghana. Generally, the results confirmed the importance of nitrogen fertilization in paddy fields. Application of urea, the predominant N-fertilizer used over the world was confirmed to be highly vulnerable to ammonia loss. Cumulative ammonia loss varied greatly depending on the type of paddy soil and the type of urea. Among the modes of urea application and across the types of paddy soils, USG applied at soil surface showed the highest ammonia loss (up to 44% of N applied) followed by the surface application of the prilled urea. The deep application of USG significantly reduced ammonia loss more than the split application of prilled urea (PU), and the optimum depth of USG application for minimizing ammonia loss and improving rice growth yield and nitrogen use efficiency depended on the type of paddy soil. The results of the first experiment enabled to determine specific application depth of USG in the selected paddy soils.

In the field, the results confirmed the increase in of rice growth, yield parameters and nitrogen use efficiency for the deep placement of USG over the split application of prilled urea. However, this increment was not significant at Kouto site where the soil is a sandy loam with low CEC when compared to Ablotsri and Hahome soils. This justifies the recommendation not to apply USG in drained soils. The efficiency and the profitability of USG application in the different paddy fields depended greatly on the nitrogen rate and fairly on the rice variety and the planting season. These results confirm the statement of Savant and Stangel (1990) that introduction of the technology into a new area should be preceded by adaptation tests for site-specific recommendations.

Through the third experiment it was found that, the efficiency of USG on rice growth, yield and nitrogen use efficiency depend greatly on its time of application and the age of rice seedling at transplanting. Result showed that, up to 16 % increment of rice yield can be made by a good management of seedling age. A good management of USG application time can also increase rice yield by more than 10%. Very earlier or too late application of USG and aged seedling can considerably reduce USG efficiency in rice production. These results remind the principle of young seedling transplanting to improve rice yield in the System of Rice Intensification (SRI).

The study has generated detailed data and knowledge to improve upon the use of USG management and its application in some paddy soils of Togo and Ghana. However, the study has some limitations which are discussed in the following chapter.

CHAPTER FIVE

5.0. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The study aimed at improving rice production with urea deep placement (UDP) technology. Firstly, the study assessed in a greenhouse experiment ammonia loss following urea supergranule (USG) application at different depths and determined the appropriate depths that minimized ammonia volatilization and improved rice nitrogen use efficiency (NUE) and yield in different paddy soils. Secondly, the study evaluated in a field experiment the efficiency of USG compared to prilled urea (PU) in order to identify the optimum rates for the best yield, NUE and profitability at different location during two consecutive seasons. Finally, the effects of seedling age and USG application time on rice growth, yield and NUE were evaluated in a pot experiment. The study enabled the generation of data and contribution to knowledge on the use of USG and to make specific recommendations to improve rice production in some paddy soils in Togo and Ghana. The major findings are as follows:

(i) USG deep placement reduced ammonia volatilization in paddy soils more than the split application of prilled urea. The greater the depth of USG placement, the lower the amount of ammonia loss. Ammonia loss was affected by the type of paddy soil. The results suggested that specific application depths of USG in paddy soils are required to enhance rice growth, increase yield and NUE. The optimum application depths were 8-12 cm for Canne series (clay, acid and high CEC), 8 cm for Akuse series (clay, high CEC and alkaline) and 4 cm for both Voudou series soil (sandy-loam, low CEC and slightly acid) and Bumbi series (sandy-clay-loam, low CEC and alkaline). Beyong the above indicated optimum depths, low nitrogen use efficiencies were recorded.

(ii) In the field, performance of the UDP technology varied significantly depending on the sites and seasons. Regardless of the varieties, UDP increased rice growth, yield, NUE over PU but was more profitable for 78 kg N ha^{-1} at Ablotsri site (clay soil) and for 104 kg N ha^{-1} at Hahome site (sandy-clay-loam). Therefore USG merits to be recommended at the rates indicated above on such soils to improve irrigated rice production. However, at Kouto site (sandy-loam), no differences were obtained on the agronomic performances between USG and PU, but PU was economically more lucrative than USG and got the best profitability at the rate of 104 kg N ha^{-1} and thus can be recommended to farmers on paddy soils comparable to this site. Therefore, results suggested low efficiency of USG as compared with PU at Kouto site.

(iii) Rice agronomic characteristics varied with the seedling age and the application time of USG. The younger the seedlings, the better was rice performances. Deep application of USG at 10 or 14 days after transplanting of 10 or 14-day old seedlings were the best combinations that can improve rice growth, yield and NUE.

5.2. Recommendations

The present research generated data, enabled understanding the urea supergranule deep placement technology in some paddy soils of Togo and Ghana. Out of the study, the following recommendations are made:

1. To reduce ammonia loss and improve upon nitrogen use efficiency and yield of rice, farmers should apply USG at the following depths in the different soils:
    - Canne series (Kovié in Togo) 8-12 cm
    - Voudou series (Misson-Tové in Togo) 4 cm
    - Akusse Series (Kpong in Ghana): 8 cm
    - Bumbi Series (Ashiaman in Ghana): 4 cm

2. The UDP technology is recommend to:
    - Farmers at Abrotsri site at 78 kg / ha (as USG of 1.8 g size)
    - Farmers at Hahome sites at 104 kg / ha (as USG of 3.8 g size)

3. At Kouto site, the split application of PU is recommended over USG. The optimum rate of PU for higher rice yield and profitability is 104 kg / ha.

4. With regard to the seedling age and time of USG application, rice farmers are recommended to use young seedlings or 10 to 14 days old and apply USG at 7 to 14 days after rice transplanting.

The study however has some limitations and some aspects need further investigation:

(i) Some of the investigations were done in the greenhouse or opened field pot experiments, and the results were not sufficient to draw full conclusions and make substantial recommendations on some of the studied aspects such as ammonia volatilization monitoring and depth of USG application with regards to paddy soil types. Therefore, field work which takes environmental conditions into consideration need to be designed and implemented in order to confirm the present results and make substantial recommendations for irrigated rice cropping.

(ii) The field work focused on rice cropping under irrigated system where rice was transplanted in line with regular transplanting dimension of 20 cm x 20 cm under water control. However in Togo, rainfed lowland rice is the dominant system that occupies more than 60% of rice cultivated areas in which, most of the time, rice is randomly transplanted or sown, and water is not controlled. Thus, further research on USG deep placement efficiency and its adaptation should target rainfed lowland rice with its various aspects for significant improvement of rice production level of the country.

(iii) Also, the efficiency of USG was soil and season specific. Therefore, research needs to be extended to the major agro-ecological zones for specific recommendations.

(iv) Moreover, despite the advantage of USG over PU in terms of rice yield increase, its hand application requires heavy and expensive labour that significantly reduces the overall monetary profitability. Local research into machinery and simple tools to make the USG application fast as well as cheap is imperative to enhance its adoption. UDP technology is still in the research phase in Africa, and briquette machines are not easily available for farmer organizations. The adoption of the technology will strictly depend on government's policy of making the briquette machines available in rice production areas.

REFERENCES

Abdel-Bary, E. A., and Metwally, S. M. (2001). Potentiality of 1, 4-phenylendiamine for retardation of urea transformations in flooded rice soils. *Egyptian Journal of Soil Science 41: 165–185.*

Abedin, S. M. S., Mannan, M. A., Mamun, M. A. A., Rahman, G. K. M. M., and Mridha, A. J. (2015). Growth and yield performance of tidal local aman rice as influenced by USG application at non tidal condition. Bangladesh Agronomy Journal, 18(1), 71–80.

Aboa, K.; Dantsey-Barry, H. ; Kpemou, K. (2007). Le riz (Oriza spp.) In Agbobli, C.A. ; Adomefa, K. ; and Labare, K. Situation de référence sur les principales céréales cultivées aux Togo : Maïs, Riz, Sorgho, Mil. *ITRA-Lome, pp 39-28.*

Abou-Khalifa, A.A. (2007). Performance of two hybrid rice and Sakha 101 rice cultivars to three nitrogen levels and three sowing dates. *Egyptian Journal of Plant Breed., 11(2): 681-691. Special Issue.*

Africa Rice Center (AfricaRice). 2015. Lessons from the rice crisis: Policies for food security in Africa. *Cotonou, Benin*

Ahn, S.W., Nonman J.M., Brandon, D.M., Groth, D.E., Gunnell, P.S, Hibino, H., Hollier, C.A., Lee, F.N., Webster, R.K. and Whitney, G. (1992). Compendium of rice diseases. Webster RK, Gunnel PS (eds.).APS Press.

Alam, M. Z., Ahmed, M., Alam, M. S., Haque, M. E., and Hossin, M. S. (2002). Performance of seedling ages and seedling raising techniques on yield and yield components of transplant Aman rice. *Pakistan Journal of Biological Sciences, 5(11), 1214-1216*

Alberda, T. (1953). Growth and root development of lowland rice and its relation to oxygen supply. *Plant and soil, 5(1), 1-28.*

Alfa-Toga, A. T. (2011). Etude de l'efficacité de la technologie de placement profond de l'urée briquette 5PPU sur le rendement du maïs au Togo, Cas du sud-Togo. *IPR/IFRA Mali. 56 p*

Ali M.Y, Rahman, M.M., Haq, M.F. (1995). Effect of time of transplanting and age of seedling on the performance of late planted aman rice. Bangladesh J Sci Ind Res 30(1): 45-58.

Al-Kanani, T., MacKenzie, A. F., and Barthakur, N. N. (1991). Soil water and ammonia volatilization relationships with surface-applied nitrogen fertilizer solutions. Soil *Science Society of America Journal, 55(6), 1761-1766.*

Aly, S. S. M., Soliman, S., Ismail, M. M., Awad, E., and El-Sherbieny, A. E. (2001). The efficiency of modified urea labelled with N-15 by rice plant. Egyptian *Journal of Soil Science 41:15–26.*

Amatekpor, J. K., Oteng, J. W. and Agyiri, P. 1993. Field tour Guide: Technical Center for Agricultural and Rural Co-operation (CTA) *Seminar on Sustaining Soil Productivity in Intensive African Agriculture. 14-19 Nov. 1993.*

Anwar. M.P. Begum, M. (2004). Tolerance of hybrid rice variety sonarbangla1 to tiller separation. Bangladeshj. *Crop science 13 (2): 39-44.*

Anwar, M.P., Hossain S.M.A. and Islam M.A. (1999). Response of Hybride and inbred varieties to different levels of nitrogen fertilizer. *Progress in Agriculture. 10: 111-116.*

Appel, T. (1994). Relevance of soil N mineralization, total N demand of crops and efficiency of applied N for fertilizer recommendations for cereals—Theory and application. *Journal of Plant Nutrition and Soil Science, 157(6), 407-414.*

Ashraf, M., A. Khalid, and K. Ali. 1999. Effect of seedling age and density on growth and yield of rice in saline soil. *Pakistan Journal of Biology Science 2:860-862.*

Asiamah, R. D. (1995). Soils of the Ho-Keta plains Volta Region, Ghana. *Advent Press. Accra: CSIR. 76-80*

Azam, F., Müller, C., Weiske, A., Benckiser, G., and Ottow, J. (2002). Nitrification and denitrification as sources of atmospheric nitrous oxide–role of oxidizable carbon and applied nitrogen. *Biology and Fertility of Soils, 35(1), 54-61.*

Azam, M. T., Ali, M. H., Karim, M. F., Rahman, A., Jalal, M. J., and Mamun, A. F. M. (2012). Growth and Yield of Boro Rice as Affected by Different Urea Fertilizer Application Methods. International *Journal of Sustainable Agriculture, 4(3), 45-51.*

Baggs, E. M., Cadisch, G., Verchot, L. V., Millar, N., and Ndufa, J. K. (2002). Environmental impacts of tropical agricultural systems: N_2O emissions and organic matter management. In 17. *World Congress of Soil Science, Bangkok (Thailand), 14-21 Aug 2002.*

Baligar, V. C., and Bennett, O. L. (1986). Outlook on fertilizer use efficiency in the tropics. *Fertilizer Research, 10(1), 83-96.*

Baligar, V. C., Fageria, N. K., and He, Z. L. (2001). Nutrient use efficiency in plants. *Communications in Soil Science and Plant Analysis, 32(7-8), 921-950.*

Balkos, K. D., Britto, D. T., and Kronzucker, H. J. (2010). Optimization of ammonium acquisition and metabolism by potassium in rice (*Oryza sativa L. cv. IR-72*). *Plant, Cell and Environment, 33(1), 23-34.*

Bandaogo, A. A. (2014). Nitrogen Use Efficiency of Rice As Affected By the Type of Urea Fertilizers and Soil Properties in Burkina Faso. PhD Thesis. *University of Science and Technology, Kumasi, Ghana.180pp*

Bandaogo, A., Bidjokazo, F., Youl, S., Safo, E., Abaidoo, R., and Andrews, O. (2015). Effect of fertilizer deep placement with urea supergranule on nitrogen use efficiency of irrigated rice in Sourou Valley (Burkina Faso). *Nutrient Cycling in Agroecosystems, 102(1), 79-89.*

Banning N.C., Maccarone L.D., Fisk L.M., Murphy D.V. (2015). Ammonia-oxidising bacteria not archaea dominate nitrification activity in semi-arid agricultural soil. *Scientific Reports 5: 11146*.

Bautista EU, Koike M, Suministrado DC (2001) Mechanical deep placement of nitrogen in wetland rice. *J Agric Eng Res 78(4):333–346*

Bayrakli, F. (1990). Ammonia volatilization losses from different fertilizers and effect of several urease inhibitors, CaCl2 and phosphogypsum on losses from urea. *Fertilizer research, 23(3), 147-150.*

Bianco, M. S., Filho, A. B. C., and De Carvalho, L. B. (2015). Nutritional status of the cauliflower cultivar "Verona" grown with omission of out added macronutrients. *PLoS ONE, 10(4), 1–17.*

Black, C.A. (1986). Methods of soil analysis. Part I. Physical and mineralogical properties including statistics of measurement and samplings Part II. Chemical and Microbiological properties. *Agronomy series. ASA. Madison. Wis. USA*

Blaise, D., Amberger, A., and Von Tucher, S. (1997). Influence of iron pyrites and dicyandiamide on nitrification and ammonia volatilization from urea applied to loess brown earths (luvisols). *Biology and fertility of soils, 24(2), 179-182.*

Bloom, A.J., (2015). The increasing importance of distinguishing among plant nitrogen sources. *Current opinion in plant biology, 25: 10-16.*

Bohlool, B. B., Ladha, J. K., Garrity, D. P., and George, T. (1992). Biological nitrogen fixation for sustainable agriculture: A perspective. *Plant and soil, 141(1-2), 1-11.*

Bony, M. H., Paul, S. K., Kaderand, M. A., and Sarkar, M. A. R. (2015). Yield performance of Boro rice in response to urea super granular. Journal of the *Bangladesh Agricultural University, 13(1), 13–17.*

Botanical on line (2019) available on https://www.botanical-online.com/en/botany/rice

Bowen, W. (2005). Urea Deep Placement as an Option for Increasing Nitrogen Use Efficiency Rice Production in Bangladesh (million t). *In Rice-wheat Consortium Meeting. Dhaka, Bangladesh.*

Bowen, W.T., Diamond, R.B., Singh, U. and Thompson, T.P. (2005). Urea deep placement increases yield and saves nitrogen fertilizer in farmers' field in Bangladesh. *IFDC, Asia Division. Dhaka-1212, Bangladesh.*

Brady, N.C. and Weil, R.R. (1996). The Nature and Properties of soil (11th ed.). Prentice-Hall, Inc. *United States of America*.

Brammer, H. (1960). Memoir N° 3, Soils of Accra Plains. CSRI. *The State Publishing Corporation Kumasi 73-80.*

Brammer, H. (1967). Soils of the Accra Plains. Soil Science Research Institute (SRI) of Ghana, *Memoir No.3. Kumasi, Ghana.*

Bray, R. H., and Kurtz, L. T. (1945). Determination of total, organic, and available forms of phosphorus in soils. *Soil science, 59(1), 39-46.*

Bremner JM (1995). Recent research on problems in the use of urea as a nitrogen fertilizer. *Fertilizer Research. 42:321-329.*

Britto DT, Kronzucker HJ (2002) NH_4^+ toxicity in higher plants: a critical review. *Journal Plant Physiology, 159:567–584.*

Broadbent, F.E. and Viikkelsen, D.S. (1968). Influence of placement on uptake of tagged nitrogen by rice. *Agronomy Journal., 60, 674-677.*

BRRI. (2008). Adhunik Dhaner Chas (In Bengali). Bangladesh Rice Research Institute. Joydebpur, Gazipur, Bangladesh. *pp. 38-39. 38-39.*

BRRI (2000). Bangladesh Rice Research Institute, *Joydebpur, Gazipur, Bangladesh. pp.*

Buresh, R. J., and De Datta, S. K. (1990). Denitrification losses from puddled rice soils in the tropics. *Biology and Fertility of Soils, 9(1), 1-13.*

Byrnes, B. H., and Freney, J. R. (1995). Recent developments on the use of urease inhibitors in the tropics. *In Nitrogen Economy in Tropical Soils (pp. 251-259). Springer, Dordrecht.*

Cai, G. X. (1992). Evaluation of gaseous nitrogen losses from fertilizers applied to flooded rice fields in China. Proc. *Inter. Symp. on Paddy Soils. pp. 99-106. Science Press, Beijing.*

Cai, G. X. (1997). Ammonia volatilization. *In Nitrogen in soils of China (pp. 193-213). Springer, Dordrecht.*

Cai, G. X., Chen, D. L., Ding, H., Pacholski, A., Fan, X. H. and Zhu, Z. L. (2002). Nitrogen losses from fertilizers applied to maize, wheat and rice in north China plain. *Nutrient cycling in Agroecosystems 63: 187 – 195.*

Cai, G. X., Yang, N. C., Lu, W. F., Chen, W., Xia, B. Q., Wang, X. Z., and Zhu, Z. L. (1992). Gaseous loss of nitrogen from fertilizers applied to a paddy soil in southeastern China. *Pedosphere, 2(3), 209-217.*

Cai, G.-X. (1997). Ammonia volatilization. In Nitrogen in Soils of China, 193–213.. *Kluwer Academic Publishers,. Malaysia*

Camberato, J. J. (2001). Nitrogen in soil and fertilizers. SC Turfgrass Foundation News, 6–10. *Retrieved from http://www.scstma.org/upkeep/resources/files/Nitrogen in Soil and Fertilizers*

Cantarella, H., Trivelin, P. C. O., Contin, T. L. M., Dias, F. L. F., Rossetto, R., Marcelino, R. Quaggio, J. A. (2008). Ammonia volatilisation from urease inhibitor-treated urea applied to sugarcane trash blankets. *Scientia Agricola, 65(4), 397–401.*

Cao, Y., Tian, Y., Yin, B., Zhu, Z. (2013). Assessment of ammonia volatilization from paddy fields under crop management practices aimed to increase grain yield and N efficiency. *Field Crops Res. 147, 23–31.*

Cao ZH, De Datta SK and Fillery IRP (1984). Nitrogen-15 balance and residual effects of urea-N in wetland rice fields as affected by deep placement techniques. Soil Sci Soc Am J 48: 203–208

Carney, Judith Ann (2001). Black rice: the African origins of rice cultivation in the Americas. Cambridge: Harvard University Press. ISBN 978-0-674-00452-8

Carrasco, D., Fernandez Valiente, Y., Ariosa, Y., and Quesada, A. (2004) Measurement of coupled nitrification denitrification in paddy fields affected by Terrazole, a nitrification inhibitor. *Biology and Fertility of. Soils, 39: 186–192.*

Cassman, K. G., Dobermann, A., and Walters, D. T. (2002). Agroecosystems, nitrogen-use efficiency, and nitrogen management. AMBIO: *A Journal of the Human Environment, 31(2), 132-140.*

Cerrato, M. E., and A. M. Blackmer. 1990. Effects of nitrapyrin on corn yields and recovery of ammonium-N at 18 site-years in Iowa. *J. Prod. Agric. 3:513–521*

Chameides, W. L., Kasibhatla, P. S., Yienger, J., and Levy, H. (1994). Growth of continental-scale metroagroplexes, regional ozone pollution, and world food production. *Science, 264(5155), 74-77.*

Chandra, D., and G.B. Manna. (1988). Effect of planting date, seedling age, and planting density in late planted wet season rice. *International Rice Research Notes (IRRN) 13(6):30.*

Chen D, Suter H, Islam A, Edis R, Freney JR, Walker CN. (2008). Prospects of improving efficiency of fertiliser nitrogen in Australian agriculture: a review of enhanced efficiency fertilisers. *Australian Journal of Soil Research, 46, 289-301.*

Chen, A., Lei, B., Hu, W., Lu, Y., Mao, Y., Duan, Z., and Shi, Z. (2015). Characteristics of ammonia volatilization on rice grown under different nitrogen application rates and its quantitative predictions in Erhai Lake Watershed, China. *Nutrient Cycling in Agroecosystems, 101(1), 139–152.*

Chen, H. K., Li, F. D., Chen, W. X., and Cao, Y. Z. (1981). Soil microbiology. *Shanghai Science Technology Press, Shanghai (in Chinese).*

Cheng, L. L., Wen, Q. X., and Li, H. (1989). Transformation of 15N labeled fertilizer N in soils under greenhouse and field conditions. *Acta Pedologica Sinica, 26(2), 124-130.*

Chien, S. H., Prochnow, L. I., and Cantarella, H. (2009). Recent developments of fertilizer production and use to improve nutrient efficiency and minimize environmental impacts. *Advances in Agronomy, 102, 267-322.*

Chopra, N.K. and Chopra, N. (2000). Effect of row spacing and N level on growth, yield and seed quality of scented rice under transplanted conditions. *Indian. J. Agron. 45(2): 304-308.*

Choudhury, A. T. M. A., and Kennedy, I. R. (2005). Nitrogen fertilizer losses from rice soils and control of environmental pollution problems. Communications in Soil *Science and Plant Analysis, 36(11-12), 1625-1639.*

Christianson, C. B., Carter, M. F., and Holt, L. S. (1988). Mineralization and nitrification of urea form fertilizers. *Fertilizer research, 17(1), 85-95.*

Cisse, D. (2011). Evaluation des performances agronomiques du placement profond de l'uree en riziculture irriguee dans la vallee du sourou au burkina faso. Universite polytechnique de bobo-dioulasso.

Coelho, C. P., Santos, L. A., Rangel, R. P., Sperandio, M. V. L., Bucher, C. A., De Souza, S. R., and Fernandes, M. S. (2016). Rice varieties exhibit different mechanisms for Nitrogen Use Efficiency (NUE). *Australian Journal of Crop Science, 10(3), 342–352.*

Cong, R. H., Zhang, Z., Lu, J. W., Li, X. K., Ren, T., and Wang, W. N. (2015). Evaluation of nitrogen requirement and efficiency of rice in the region of Yangtze River Valley based on large-scale field experiments. *Journal of Integrative Agriculture, 14(10), 2090–2098.*

Cu R.M., Mew,T.W., Cassman, K.G., Teng, P.S. (1996). Effect of sheath blight on yield in tropical, intensive rice production system, Plant Disease 80, 1103–1108.

Dancer, W., Peterson, L. and Chesters, G. (1973). Ammonification and nitrification of N as influenced by soil pH and previous N treatments. *Soil Science Society of America Proceedings 37: 67-69.*

Das, S., Chaki, A. K., Sobhan, N., Hossain, M. M., and Arshad, H. M. (2014). Effect of Plant Spacing and Depth of USG Placement on Yield of Boro Rice, *Bangladesh Agronomy Journal,17(1), 103–105.*

Day, P. R. (1965). Particle fractionation and particle-size analysis. p. 545–567. CA Black (ed.) Methods of soil analysis. Part 1. Agron. Monogr. 9. ASA, Madison, WI. Particle fractionation and particle-size analysis. p. 545–567. In CA Black (ed.) Methods of soil analysis. Part 1. *Agronomy Monographs. 9. ASA, Madison, WI.*

De Datta SK, and Craswell ET (1982) Nitrogen fertility and fertilizer management in wetland rice soils. In Rice Research Strategies for the Future. Pp 283-316. International Rice Research Institute, Los Banos, Philippines

De Datta, S. K. (1978). Fertilizer management for efficient use in wetland rice soils. *Soils and Rice, 671-701.*

De Datta, S. K. (1987). Advances in soil fertility research and nitrogen fertilizer management for lowland rice. *Efficiency of nitrogen fertilizers for rice, 27-41.*

De Datta, S. K., Gomez, K. A., and Descalsota, J. P. (1988). Changes in yield response to major nutrients and in soil fertility under intensive rice cropping. *Soil Science, 146(5), 350-358.*

De Datta, S.K. (1978) Fertilizer management for efficient use in wetland rice soils. In Soils and Rice; Ponnamperuma, F.N., ed.; International Rice Research Institute: *Los Banos, Philippines, 671–701.*

De Datta, S.K. (1985) Availability and management of nitrogen in lowland rice in relation to soil characteristics. In Wetland Soils: Characterization, Classification, and Utilization; Banta, S.J., ed.; *International Rice Research Institute: Los Banos,Philippines, 247–267.*

De Datta, S.K., and E.T. Creswell. (1982). Nitrogen fertility and management in wetland rice soils. p. 283-316. In Rice Research Strategies for the Future. *International Rice Research Institute, Los Baños, Philippines.*

De Datta, S.K., C.P. Magnaye, and J.C. Moomaw. (1968). Efficiency of fertilizer nitrogen (15N-labelled) for flooded rice. *p. 67–76. In Trans. Int. Soil Sci. Congr., 9th, Adelaide, Australia. Vol. 4.*

De Souza, K.H. (2000) Etude sur le Périmètre Irrigué du Zio. ARDI/PPLM.

de Vries, E. M., Rodenburg, J., Bado, B. V., Sow, A., Leffelaar, P. A., and Giller, K. E. (2010). Rice production with less irrigation water is possible in a Sahelian environment. *Field Crops Research. 116: 154-164.*

Debnath, M. (2013). An Effect of Fertilizer Management Practices on the Yield of T. Aman Rice under Tidal Ecosystem. *American Journal of Agriculture and Forestry, 1(4), 74.*

Denmead, O. T., Freney, J. R., and Simpson, J. R. (1982). Dynamics of Ammonia Volatilization during Furrow Irrigation of Maize 1. *Soil Science Society of America Journal, 46(1), 149-155.*

Dillon, K. A., Walker, T. W., Harrell, D. L., Krutz, L. J., Varco, J. J., Koger, C. H., and Cox, M. S. (2012). Nitrogen sources and timing effects on nitrogen loss and uptake in delayed flood rice. *Agronomy journal, 104(2), 466-472.*

Ding, H., Cai, G. X., Wang, Y. S., and Chen, D. L. (2002). Nitrification-denitrification loss and N2O emission from urea applied to crop-soil systems in North China Plain. *Agricultural Sciences in China, 1(2), 184-188.*

Djaman, K., Vincent, B., and Valere, M. (2016). Yield and nitrogen use efficiency of aromatic rice varieties in response to nitrogen fertilizer. Emirates Journal of Food and Agriculture, 28(2), 126.

Dobermann, A. R. (2005). Nitrogen Use Efficiency – State of the Art. University of Nebraska, *Agronomy and Horticulture - Faculty Publications, 6, 1–16*.

Dobermann, A., and Fairhurst, T. H. (2000). Nutrient disorders and nutrient management. Potash and Phosphate Institute, Potash and Phosphate Institute of Canada and International *Rice Research Institute, Singapore*.

Dobermann, A.R. (2007). Nutrient use efficiency – measurement and management. In "IFA International Workshop on Fertilizer Best Management Practices", Brussels, Belgium, p1-28.

Dong, Z., Wu, L., Chai, J., Zhu, Y., Chen, Y., and Zhu, Y. (2015). Effects of Nitrogen Application Rates on Rice Grain Yield, Nitrogen-Use Efficiency, and Water Quality in Paddy Field. *Communications in Soil Science and Plant Analysis, 46(12), 1579–1594.*

Dongarwar, U. R., Patankar, M. N., and Pawar, W. S. (2003). Response of rice to different fertility levels. *Journal of Soils and Crops, 13(1), 120-122.*

DSID (2017). Togo National Data Base. Available on *http://countrystat.org/home.aspx?c=TGOandtr=8*

Duhan, B. S., and Singh, M. (2002). Effect of green manuring and nitrogen on yield and uptake of micronutrient by rice. *Journal of the Indian Society of Soil Science (India) 50(2): 178-180.*

Duy, P. Q., Abe, A., Hirano, M., Sagawa, S., and Kuroda, E. (2004). Analysis of lodging-resistant characteristics of different rice genotypes grown under the standard and nitrogen-free basal dressing accompanied with sparse planting density practices. *Plant production science, 7(3), 243-251.*

Eagle, A. J., Bird, J. A., Horwath, W. R., Linquist, B. A. Brouder, S. M. Hill, J. E. and Kesse, C. V. l. (2000). Rice yield and nitrogen utilization efficiency under alternate straw Management practices. *Agronomy Journal. 92:1096–1103.*

Eriksen, A. B., and Nilsen, S. (1982a). The effect of deep placement and surface application of nitrogen fertilizers at different light intensities on growth and yield of wetland rice. *Plant and Soil 68(3), 341–351.*

Eriksen, A. B., and Nilsen, S. (1982b). Effects of deep placement and surface application of urea on the yield of wetland rice in pot trials. *Plant and Soil, 66(1), 29-36.*

Ernst, J. W., and Massey, H. F. (1960). The Effects of Several Factors on Volatilization of Ammonia Formed from Urea in the Soil 1. *Soil Science Society of America Journal, 24(2), 87-90.*

Fageria N. K. (2009). The Use of Nutrients in Crop Plants. *Boca Raton, FL: CRC Press Boca Raton, USA.*

Fageria, N. K. 2001. Nutrient management for improving upland rice productivity and sustainability. Commun. Soil Sci. Plant Anal. 32:2603‑2629

Fageria, N. K and Baligar, V.C. (2005) Enhancing Nitrogen Use Efficiency in Crop Plants. *Advances in Agronomy, 88, 97-185.*

Fageria, N. K. (2013). Mineral nutrition of rice. *CRC Press. Taylor and Francis Group. Boca Raton, USA*

Fageria, N. K. and Baligar, V.C. (1996). Response of lowland rice and common bean grown in rotation to soil fertility levels on a Varzea soil. Fert. Res. 45:13-2

Fageria, N. K., Baligar, V. C. and Jone s C. A. (2011). Growth and Mineral Nutrition of Field Crops, 3rd edition. Boca Raton, FL: CRC Press.

Fageria, N. K., and Baligar, V. C. (1999). Growth and Nutrient Concentrations of Common Bean , Lowland Rice , Corn , Soybean , and Wheat at Different Soil pH on an Inceptisol. *Journal of Plant Nutrition, 22(9), 1495–1507.*

Fageria, N. K., and Baligar V. C,. (2005). Nutrient availability. In Encyclopedia of Soils in the Environment, ed. D. Hillel, pp. 63–71. San Diego, CA: Elsevier.

Fageria, N. K., Baligar, V. C., and Jones, C. A. (2010). Growth and Mineral Nutrition of Field Crops , Third Edition, (October), 2010.

Fageria, N. K., and A. S. Prabhu. 2004. Blast control and nitrogen management in lowland rice cultivation. Pesq. Agropec. Bras. 39:123‑129.

Fageria, N. K., Slaton, N. A. and Baligar, V. C. (2003). Nutrient management for improving lowland rice productivity and sustainability. Adv. Agron. 80:63‑152.

Fan MX and MacKenzie AF (1995) The toxicity of banded urea to corn growth and yield as influenced by triple superphosphate. *Canadian journal of soil science, 75(1), 117-122.*

Fan, X. H., Song, Y. S., Lin, D. X., Yang, L. Z., and Luo, J. F. (2006). Ammonia volatilization losses and N-15 balance from urea applied to rice on a paddy soil. *Journal of Environnemental Sciences-China, 1:2 299-303*

FAO. (1981). Crop production levels and fertilizer use. (Food And Agriculture Organization Of The United Nations (Fao), Ed.). Rome.

FAO. (2015). World fertilizer trends and outlook to 2018. Food and Agriculture Organization of United Nations (FAO). Rome.

Faqir, H., and Malik, K. A. (1983). Ammonia volatilization losses from a flooded rice soil system. *Pakistan Journal of Agricultural Research, 4(2), 126-130.*

Fenn, L.B., and Kissel D.E. (1976). The influence of cation exchange capacity and depth of incorporation on ammonia volatilization from ammonium compounds applied to calcareous soils. *Soil Sci. Soc. Am. J. 40, 394 - 398.*

Ferguson, R. B., and Kissel, D. E. (1986). Effects of Soil Drying on Ammonia Volatilization from Surface-applied Urea 1. *Soil Science Society of America Journal, 50(2), 485-490.*

Ferguson, R. B., Lark, R. M., and Slater, G. P. (2003). Approaches to management zone definition for use of nitrification inhibitors. *Soil Science Society of America Journal, 67(3), 937-947.*

Fillery, I. R. P., and Vlek, P. L. G. (1982). The significance of denitrification of applied nitrogen in fallow and cropped rice soils under different flooding regimes I. Greenhouse experiments. *Plant and Soil, 65(2), 153-169.*

Fixen, P. E., and West, F. B. (2002). Nitrogen Fertilizers: Meeting Contemporary Challenges. AMBIO: *A Journal of the Human Environment, 31(2), 169–176.*

Fixen, P., Brentrup, F., Bruulsema, T., F, G., Norton, R., and Zingore, S. (2012). Nutrient/fertilizer use efficiency (N/FUE); Measurement, *Current Situation and Trends. pp. 1–29.*

Freney, J.R., D.G. Keerthisinghe, S. Phongpan, P. Chaiwanakupt, and K.J. Harrington. (1995). Effect of urease, nitrification and algal inhibitors on ammonia loss and grain yield of flooded rice in Thailand. Fert. Res. 40:225–233.

Gaudin, R. (1987). L'effet supergranule d'urée (SGU) en sols de rizières: un problème de diffusion avec échange d'ions. Essai de modélisation. Thèse de doctorat sciences agronomiques, *Institut polytechnique de Lorraine, Nancy-Vandoeuvre, 147 p*

Gaudin, R. (1988). L'ammoniac NH3, une clé pour comprendre l'efficacité des supergranules d'urée en riziculture irriguée. *L'Agronomie Tropicale 43(1):30–36.*

Gaudin, R. (1991). Le rôle de l'ammoniac NH3 dans l'alimentation azotée des plantes: un problème remis à jour par l'étude de la fertilisation super granule d'urée du riz irrigué. *Bull Acad. Malg. Tome 66/1-2. Pages 180-186.*

Gay, S. W., and Knowlton, K. F. (2009). Ammonia emissions and animal agriculture. *Virginia Cooperative Extension, 442(110), 1–5.*

Glibert, P. M., Harrison, J., Heil, C., and Seitzinger, S. (2006). Escalating Worldwide Use of Urea: A Global Change Contributing to Coastal Eutrophication. *Biochemistry, 77(3), 441–463.*

Google (2018) Google mape, available on https://www.google.tg/maps/@7.063784,-0.5274438,535927m/data=!3m1!1e3?hl=en&authuser=0

Griggs, B.R., R.J. Norman, C.E. Wilson Jr., and N.A. Slaton. 2007. Ammonia volatilization and nitrogen uptake for conventional and conservation tilled dry-seeded, delayed-flood rice. *Soil Sci. Soc. Am. J. 71:745–751*

Gui-xin, L. (1997). Ammonia Volatilization. In Zhu, Z., Qi-xiao, W., and Freney, J. R. (1997). Nitrogen in soils of china. *Kluwer Academic Publishers,. Malaysia. 193-214*

Haden, V.R., Xiang, J., Peng, S.B., Bouman, B.A.M., Visperas, R.M., Ketterings, Q.M., Hobbs, P., Duxbury, M.J., 2011. Relative effects of ammonia and nitrite on the germination and early growth of aerobic rice. *J. Plant Nutri. Soil Sci. 174, 292–300*

Hanada, K. (1979). Differentiation and development of tiller buds in rice plants. *Japan Agricultural Research Quarterly . 16:79-86.*

Hasan, M. S. A., Hossain, S. M. A., Salim, M., Answar, M. P., and Azad, A. K. M. (2002). Response of hybrid and Inbred rice varieties to the application methods of urea supergranules and prilled urea. *Pakistan Journal of Biological Sciences, 5(7), 746–748.*

Hasan, S. M. (2007). Effect of level of urea super granules on the performance of T. aman rice. M. Sc. Ag. *Thesis in Agronomy, BAU, Mymensingh.*

Hasanuzzaman, M., Nahar, K., and Alam, M. (2009). Response of transplanted rice to different application methods of urea fertilizer. *International Journal of Sustainable Agriculture, 1(1), 1–5.*

Hasebe, A., and Iimura, K. (1982). Influence of soil moisture contents before flooding on the differentiation of the oxidized and reduced soil layers. *Japanese Journal of Soil Science and Plant Nutrition. 53:497-502.*

Hasebe, A., Koike, I., Ohmori, M., and Hattori, A. (1987). Variations in the process of nitrification and nitrate reduction in submerged paddy soils as measured by 15N isotope dilution technique. *Soil science and plant nutrition, 33(2), 201-211*.

Hayashi K, Nishimura S, Yagi K (2006) Ammonia volatilization from the surface of a Japanese paddy field during rice cultivation. *Soil Sci Plant Nutr 52(4):545–555*

Hayashi, K., Nishimura, S., and Yagi, K. (2008). Ammonia volatilization from the surface of a Japanese paddy field during rice cultivation. *Soil Science and Plant Nutrition, 52(4), 545–555.*

Hemerly, A. (2016). Genetic controls of biomass increase in sugarcane by association with beneficial nitrogen-fixing bacteria'', In Plant and Animal Genome XXIV Conference. Plant and Animal Genome, during month of January 2016

Himeda, M. (1994) Cultivation Technique of Rice Nursling Seedlings: Review of Research Papers and its Future Implementation. *Agriculture and Horticulture, 69, 679-683.*

Hirzel, J., and Rodríguez, F. (2013). Increasing nitrogen rates in rice and its effect on plant nutrient composition and nitrogen apparent recovery. *Chilean Journal of Agricultural Research, 73(4), 385–390.*

Hopkins, W. G., and Huner, N. P. A. (2009). Acclimation to environmental stress. Introduction to plant physiology. Wiley, USA, 241-260.

Horie, T., Shiraiwa, T., Homma, K., Katsura, K., Maeda, S., and Yoshida, H. (2005). Can yields of lowland rice resume the increases that they showed in the 1980s? Plant Prod. *Sci. 8, 259–274. doi: 10.1626/pps.8.259*

Hossain, M. A.; Sarkar, M. A. R. and Paul, S. K. (2011). Growth analysis of late transplant aman rice (cv. BR 23) raised from tiller seedlings. *Libyan Aric. Res. Cen. J. Intl., 2 (6): 265-273.*

Hossain, M. B., Islam, M. O. and Hasanuzzaman, M. (2008). Influence of different nitrogen levels on the performance of four aromatic rice varieties. International *Journal of Agriculture and Biology. 10: 693-696.*

Huang, J.L., He, F., Cui, K. H., Buresh, R. J., Xu, B., Gong, W. H., Peng, S. B. (2008). Determination of optimal nitrogen rate for rice varieties using a chlorophyll meter. *Field Crops Res, 105: 70–80.*

Hussain, F., and Malik, K. A. (1983). Ammonia Volatilization Loss from a Flooded Rice Soil System. *Pakistan Journal of Agriculture Research. 4(2) 126-130*

Hussain, J., Salim, M., Siddique, M. A., Khatun, M., and Islam, S. (2015). Evaluation of N Efficiency Using Prilled Urea and Urea Super Granules in T. Aman Rice. *Bangladesh Agronomy Journal*, *18*(1), 59-63.

Hussain, S., Fujii, T., McGoey, S., Yamada, M., Ramzan, M., and Akmal, M. (2014). Evaluation of different rice varieties for growth and yield characteristics. *J Anim Plant Sci*, *24*(5), 1504-1510.

Hussaini, M.A., Ogunlela, B., Ramalan, A.A. (2008). Mineral composition of dry season maize (Zea mays L.) in response to varying levels of nitrogen, phosphorus and irrigation at Kadawa, Nigeria. *World Journal of Agricultural science, 4: 775-780.*

Idris, M., Matin, M.A. (1990). Response of four exotic strains of aman rice to urea. Bangladesh *Journal of Agricultural Sciences 17: 271-275.*

IFDC 2013. Fertilizer-Deep-Placement technology. Available @ http://www.ifdc.org/getattachment/1c7e9b2e-37b3-4ea4-93c1-318013dc3ce9/FDP.pdf/ [November 02, 2014].

Imran, M., and Gurmani, Z. A. (2011). Role of Macro and Micro Nutrients in the Plant Growth and Development, Pakistan journal of Science *Technology and Development 30 (3), 36–40.*

IRRI. (2010). International Rice Research Institute Reporter. (IRRI, Ed.). *Los Banos: IRRI.*

Islam, M. S., Rahman, F., and Hossain, A. T. M. S. (2011). Effects of NPK briquette on rice (Oryza sativa) in tidal flooded ecosystem. *The Agriculturists, 9(1-2), 37-43.*

Islam, M.S., Paul, S.K. and Sarkar, M.A.R. (2014). Varietal performance of modern transplant Aman rice subjected to level of nitrogen application. *Journal of Bangladesh Agricultural. Univ. 12(1): 55-60.*

Islam, N. (2007) Yield and quality characters of six local aromatic rice cultivars. M.S. Thesis, Agrotechnology Discipline, Khulna *University, Khulna-9208, Bangladesh.*.

ITRA. (2007). Situation de référence sur les principales céréales cultivées au Togo (pp. 39–68). Lome: ITRA.

Jahan, M. S., Sultana, S., and Ali, M. Y. (2014). Effect of different nitrogen levels on the yield performance of aromatic rice varieties. Bull. Inst. Trop. Agr., Kyushu Univ. 37: 37, 47–56

Jana, K. (2012). Effect of nitrogen levels and weed management practices on grain yield of aerobic rice cultivation system. *Green Farming International Journal of Applied Agricultural and Horticultural Sciences. 3:670-673.*

Jantalia, C. P., Halvorson, A. D., Follett, R. F., Alves, B. J. R., Polidoro, J. C., and Urquiaga, S. (2012). Nitrogen source effects on ammonia volatilization as measured with semi-static chambers. *Agronomy Journal, 104(6), 1595–1603.*

Jiang, L.G., Dai, T.B., Jiang, D., Cao, W.X., Gan, X.Q., Wei, S.Q. (2004). Characterizing physiological N-use efficiency as influenced by nitrogen management in three rice cultivars. *Field Crops Research., 88(2-3):239-250.*

Jaiswal, V.P. and G.R. Singh. (2001). Performance of urea supergranule and prilled urea under different planting methods in irrigated rice (Oryza sativa). Indian J. of Agric. Sci. 71 (3):187-189.

Jones, C. A., Koenig, R. T., Ellsworth, J. W., Brown, B. D., and Jackson, G. D. (2007). Management of urea fertilizer to minimize volatilization. *Montana State University Extension Service. Bozeman, Montana 1-12.*

Jones, C., Brown, B. D., Engel, R., Horneck, D., and Olson-Rutz, K. (2013). Factors Affecting Nitrogen Fertilizer Volatilization. M. S. University, Ed. 1st ed.. Montana: *Montana State University Extension. pp 1-6*

Kabir, M. H., Sarkar, M. A. R. and Chowdhury, A. K. M. S. H. (2009). Effect of urea super granules, prilled urea and poultry manure on the yield of transplant Aman rice varieties. *Journal of Bangladesh Agricultural. University. 7(2): 155–159.*

Kabir, M.H., Quddus, K.G., Alli, M.Y. and Hossain, S.M.I. (2009). Effect of urea super granule deep placement on rice cultivation in the tidal coastal area of Khulna region, Khulna. *Journal of Bangladesh Agricultural University. 7(2): 1027-1032.*

Kadiyala, D. M. (2012). *Optimizing Cultural Practices for Saving Water and Nitrogen for Rice-Maize Cropping System in Semi-Arid Tropics* (Doctoral dissertation, University of Florida).

Katayama, T. (1951). Studies on tillering of rice and barley plant. *Ine mugi no bungetsu kenkyu). Yokendo, Tokyo.*

Kapoor, V., Singh, U., Patil, S. K., Magre, H., Shrivastava, L. K., Mishra, V. N. (2008). Rice Growth, Grain Yield, and Floodwater Nutrient Dynamics as Affected by Nutrient Placement Method and Rate. *Agronomy Journal, 100(3), 516–536.*

Keeney, D. R., and Sahrawat, K. L. (1986). 2. Nitrogen transformations in flooded rice soils. *Fertilizer Research, 9(1-2), 15-38.*

Keeney, D.R., 1982. Nitrogen-availability indices. In: Page, Miller, A.L., Keeney, R.HD.R. (Eds.), Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties, 2nd Edition. *Agronomy Monograph No. 9,* American Society of Agronomy and Soil Science Society of America, Madison, WI, pp. 711–733.

Keeney, D.R. (1982) Nitrogen availability indexes. In: Page, A.L. *et al*. (eds) Methods of Soil Analysis. Part 2, 2nd edn. Agronomy Monograph 9, Soil Science Society of America, *Madison, Wisconsin, pp. 711–733.*

Keeney, D.R. (1982). Nitrogen management for maximum efficiency and minimum pollution. In Nitrogen in Agricultural Soils; Stevenson, F.J., ed.; American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America: Madison, Wisconsin, 605–649.

Keisers, J. T. (1987). Effect of timing of nitrogen top-dressing on yield and yield components of direct seeded wetland rice. *Surinaasme-Landbrow, 35(1-3), 3-13.*

Keller, G. D., and Mengel, D. B. (1986). Ammonia Volatilization from Nitrogen Fertilizers Surface Applied to No-till Corn1. *Soil Science Society of America Journal, 50(4), 1060-1063.*

Kennedy, I.R. (1992) Acid Soil and Acid Rain, 2 Ed.; *Research Studies Press Ltd.: Taunton, United Kingdom.*

Kewat, M.L., S.B. Agrawal, K.K. Agrawal, and R.S. Sharma. 2002. Effect of divergent plant spacings and age of seedlings on yield and economics of hybrid rice (*Oryza sativa*). *Indian Journal of Agronomy 47:367-371.*

Khande, R. S., Sonboir, H. L., and Sinha, C. (2017). Effect of Nitrogen Levels and Splitting on Nutrient Uptake and Soil Fertility Status in Pre-Monsoon Established Rice (Oryza sativa L .). *Journal of Pharmacognosy and Phytochemistry, 1, 119–122.*

Khatun, A., Sultana, H., Zaman, M. A. U., Pramanik, S., and Rahman, M. A. (2015). Urea Deep Placement in Rice as an Option for Increasing Nitrogen Use Efficiency. *Open Access Library Journal , 2(4), 1–11.*

Khatun, R. (2001) Effect of variety and nitrogen on the performance of fine rice. M.Sc. Thesis, *Department of Agronomy, Bangladesh Agricultural University, Mymensingh, Bangladesh. 93p*.

Kishnah, K. (2002). An Evaluating of Madagascar System of Rice Production in Aman season with three high potential rice varieties. M.S. Thesis, *Department of Agronomy, Bangladesh Agricultural. University., Mymensingh. pp. 36-63.*

Kirttania, B., Sarkar, M. A. R., and Paul, S. K. (2013). Performance of transplant Aman rice as influenced by tiller seedlings and nitrogen management, *J. Bangladesh Agril. Univ. 11(2): 249–256*

Kjeldahl, C. (1883). A new method for the determination of nitrogen in organic matter. *Z Anal Chem, 22, 366.*

Kluvi, K. (2013). Etude de la filière riz au togo. *MAEP Lomé Togo.*

Koyama, T. (1971). Soil-plant nutrition studies on tropical rice Iii. The effect of soil fertility status of nitrogen and its liberation upon the nitrogen utilization by the rice plants in Bangkhen paddy soil. *Soil Science and Plant Nutrition., 17, 210-220.*

Krajewska, B. (2009). Ureases I. Functional, catalytic and kinetic properties: A review. *Journal of Molecular Catalysis B: Enzymatic, 59(1–3), 9–21.*

Kumar N V.M, and Uma, M. . S. (2016). Genetic variability for nitrogen use efficiency and yield related traits in rice under low nitrogen and Available soil nitrogen conditions . *International Journal of Applied and Pure Science and Agriculture*, 83–90.

. Use of urea super granule in rice – IFFCO's experience. In: *Kumar et al. (eds) Soil Fertility and Fertilizer Use, Vol III.*

Kumar, V., Shrotriya, G. C., and Kaore, S. V. (1989). Urea supergranules for increasing nitrogen use efficiency. *Indian Farmers and Fertilizer cooperative (IFFCO), New Delhi, 1-143.*

Kurtz, L. T., Boone, L. V., Peck, T. R., and Hoeft, R. G. (1984). Crop Rotations for Efficient Nitrogen Use1. *Nitrogen in crop production, (nitrogenincropp), 295-306.*

Ladha J.K., Pathak , H.P., Krupnik,T.J., Six, J. and Kessel Chris, V. (2005). Efficiency of fertilizer nitrogen in cereal production: Retrospect and prospects. *Advances in Agronomy 87, 85–156.*

Lawlor, D.W. (2002).carbon and nitrogen assimilation in relation to yield: mechanisms are the key to understand production systems. *Journal of experimental botany 53.370. 773-787*

Leary, M. O., Rehm, G., and Schmitt, M. (2014). Understanding nitrogen in soils. *Nutrient management No. AG-FO-3770-B (Revised), 1–5. Minnesota,US.*

Leuning, R., Denmead, O. T., Simpson, J. R., and Freney, J. R. (1984). Processes of ammonia loss from shallow floodwater. *Atmospheric Environment (1967), 18(8), 1583-1592.*

Li, B., Shi, W., and Su, Y. (2011). The differing responses of two Arabidopsis ecotypes to ammonium are modulated by the photoperiod regime. *Acta physiologiae plantarum, 33(2), 325-334.*

Liang-mo, L. (1997). Denitrification. In Zhu, Z., Qi-xiao, W., and Freney, J. R. (1997). Nitrogen in soils of china. *Kluwer Academic Publishers,. Malaysia. 159-192*

Linquist, B. A., Liu, L., van Kessel, C., and van Groenigen, K. J. (2013). Enhanced efficiency nitrogen fertilizers for rice systems: Meta-analysis of yield and nitrogen uptake. *Field Crops Research, 154, 246-254.*

Liu, Q., Zhou, X., Li, J., and Xin, C. (2017). Effects of seedling age and cultivation density on agronomic characteristics and grain yield of mechanically transplanted rice. *Scientific reports, 7(1), 14072.*

Liu, T. Q., Fan, D. J., Zhang, X. X., Chen, J., Li, C. F., and Cao, C. G. (2015). Deep placement of nitrogen fertilizers reduces ammonia volatilization and increases nitrogen utilization efficiency in no-tillage paddy fields in central China. *Field Crops Research, 184, 80–90.*

Liyanage, L. R. M. C., Jayakody, A. N., and Gunaratne, G. P. (2014). Ammonia Volatilization from Frequently Applied Fertilizers for the Low-Country Tea Growing Soils of Sri Lanka Ammonia volatilization from fertilizers. *Tropical Agricultural Research*, *26*(1), 48–61.

Longo, R. M., and Melo, W. J. De. (2005). Hidrólise da Uréia em Latossolos: Efeito da Concentração deUréia, Temperatura, ph, Trmazenamento e Tempo de Incubação. R. Bras. Ci. *Solo, 29(1), 651–657.*

Mae, T., Inaba, A., Kaneta, Y., Masaki, S., Sasaki, M., Aizawa, M., Okawa, S., Hasegawa, S., Makino, A. (2006). A large-grain rice cultivar, Akita 63, exhibits high yields with high physiological N-use efficiency. *Field Crops Research, 97(2-3):227-237.*

MAEP. (2015).Catalogue National des Espèces et Variétés Végétales Cultivées au Togo. *MAEP-Togo, pp 26-41*

MAEP. (2010). Strategie nationale de developpement de la riziculture (SNDR). *MAEP Lome.*

Mahabari, M. B., Patil, D. S., and Kalke, S. D. (1996). Yield and uptake of nutrients as influenced by the method and time of application of nitrogen fertilizers under flood prone rice (*Oryza sativa L.*). *Journal of Soils And Crops, 6, 27-30.*

Makarim, A.K., V. Balasubramanian, Z. Zaini, I. Syamsiah, I.G.P.A. Diratmadja, A. Handoko, *et al*. (2002). Systems of rice intensification (SRI): evaluation of seedling age and selected components in Indonesia. p. 129-139. In Bouman, B.A.M., A. Hengsdijk, B. Hardy, P.S. Bindraban, T.P. Tuong, and J.K. Ladha (eds.) International Workshop on Water-Wise Rice Production, Los Baños, Phillipines. 8-11 April 2002. *International Rice Research Institute IRRI, Los Baños, Phillipines.*

Mandal, B.K., Sainik, T.R. and Ray, P.K. (1984). Effect of age of seedling and level of nitrogen on the productivity of rice. *Oryza, 21: 225-232.*

Mandal, N.N., Chaudhry, P.P. and Sinha, D. (1992). Nitrogen, phosphorus and potash uptake of wheat (var. Sonalika). Environment. and Ecology. Volume 10: 297

Manickam, T.S. and Ramaswami, P.P. 1985. Influence of N level and source on rice yield. Inter. *Rice Res. Newsl. 10(5): 28.*

Mannan, M.A., Bhuiya, M.S.U., Hossain, H.M.A., Akanda, M.I.M. (2010) Optimization of nitrogen rate for aromatic bas- mati rice (*Oryza sativa L.*). *Bangladesh Journal of Agricultural Research 35: 157-165.*

Marko, J., Vlado, K., Hrvoje, P., Jasna, S., and Mitra, R. (2002). Influences of nitrogen fertilization and irrigation on nitrogen leaching. In Proceedings of the Second International Conference on Sustainable Agriculture for Food, Energy and Industry; Dajue, L., ed.; Institute of Botany, Chinese Academy of Sciences: *Beijing, China. September 8–13; 1641–1647.*

Marschner, H. (1995). Mineral Nutrition of Higher Plants. (2nd Ed.), *Academic Press, San Diego, USA.*

Martin, J. F., and Reddy, K. R. (1997). Interaction and spatial distribution of wetland nitrogen processes, *Ecological Modelling,105, 1–21.*

Matson, P.A., Parton, W.J., Power, A.G., and Swift, M.J. (1997) Agricultural intensification and ecosystem properties. *Science, 277: 504–509.*

Matsunami, M., Matsunami, T., and Kokubun, M. (2009). Growth and Yield of New Rice for Africa (NERICAs) under Different Ecosystems and Nitrogen Levels. Plant Production *Science, 12(3), 381–389.*

Mazumder, M. R., Bhuyia, M. S. U., and Hussain, S. M. A. (2005). Effect of N level and split application on the performance of transplanted aman rice cv. BRRI dhan31. *Bangladesh Journal of Agricultural Science 31(2), 183-188.*

Mc Donald, D.J. (1994). Temperate rice technology for the 21st century, an Australian example. Australian Journal of experimental Agriculture 34: 877 - 888.

McInnes, K.J., Ferguson, R.B., Kissel, D.E. and E.T. Kanemasu. (1986). Ammonia loss for applications of urea-ammonium nitrate solution to straw residue. *Soil Science Society of America Journal. 50:969-974.*

Meertens, B. (2001). La riziculture irriguée dans la vallée de Zio, Région Maritime, Togo. Contraints et Possibilités. *IFDC-Afrique. Lomé.*

Merigout, P. (2006). Étude du métabolisme de la plante en réponse à l'apport de différents fertilisants et adjuvants culturaux. Influence des phytohormones sur le métabolisme azoté. *Thèse doctoral à l'institut national agronomique paris- grignon. pp 110.*

Miah, A. K., and Masum, S. M. (2004). Application of different forms of urea for rice. *Indian Journal of Society of Soil Science, 44, 267-270.*

Miah, M.A.M. and Panaullah, G.M. (1999) Effect of Water Regimes and Nitrogen Levels on Soil Available N, Its Uptake and Use Efficiency by Transplanted Rice. *Bangladesh Agricultural Research, 24, 343-353.*

Mikkelsen, R., Jensen, T. L., Snyder, C., and Bruulsema, T. W. (2012). Chapter 9. Nutrient management planning and accountability. *4R Plant Nutrition: A Manual for Improving the Management of Plant Nutrition (TW Bruulsema, PE Fixen, GD Sulewski, eds.), International Plant Nutrition Institute, Norcross, GA, USA.*

Millette, G., Vieillefon, J., Sant'Anna, R., Koffi, O. et J. de la Tour (1964) Etudes Pedohydrologiques au Togo - Vol II : Les Sols de la Région Maritime et de la Région des Savanes. Projet PNUD/FAO.

Mishra, A., and Salokhe, V. M. (2008). Seedling characteristics and the early growth of transplanted rice under different water regimes. *Experimental Agriculture, 44(3), 365–383.*

Misra C, Mohanty B.C., Das B.S., and Savant N.K. (1995) Relationship between some selected soil properties and yield of transplanted rice fertilized with urea briquettes. *Oryza 32: 178–183.*

Mobasser, H R, Tari D B, Vojdani M, Abadi R S and Eftekhari A. (2007). Effect of seedling age and planting space on yield and yield components of rice (Neda variety). *Asian Journal of Plant Sciences 6 (2): 438–40.*

Mohammad, N., Islam, N., Ziauddin, A. T. M., and Hossain, M. M. (2014). Effect of variety and method of USG placement on the yield performance of transplanted aman rice. *Journal of the Bangladesh Agricultural University, 12(1), 7-12.*

Mohammad, T., Deva, W. and Ahmad, Z. (2002). Genetic variability of different plant and yield characters in rice. *Sarhad Journal of Agriculture. 18: 207-210.*

Mohanty, S. K., Singh, U., Balasubramanian, V., and Jha, K. P. (1999). Nitrogen placement technologies for productivity, profitability, and environmental quality of rainfed lowland rice system. In Resource Management in Rice Systems: Nutrients (pp. 57-77). Springer Netherlands.

Moletti M., Giudici M.L., Villa B., Fiore G. (1992). Quale tecnica colturale per i risi Patna: Performance di sei varietà coltivate con semina in acqua e interrata a dosi diverse di azoto. *L'lnformatore Agrario, 11:83-95.*

Mulvaney, R. L. and Bremner, J. M. (1981). Control of urea transformation in soils. In: Paul, E A and Ladd, J N (eds.), *Soil Biochemistry. 5:153-196. Marcel Dekker, New York.*

Naher, U. A., Saleque, M. A., Panhwar, Q. A., Radziah, O., and Jusop, S. (2011). Techniques of efficient fertilizer management for wetland rice- a review. *Australian Journal of Crop Science, 5(12), 1661–1669.*

Nambiar, K.K.M. and Ghosh, A.B. (1984). Highlights of research of long-term fertilizer experiments in India. p.97. In LTFE Research Bulletin No. 1. *Indian Council of Agricultural Research, New Delhi.*

Nandini, D.K., and A.I. Singh. (2000). Influence of seedling age and plant density on the performance of rice. Central Agricultural University, *College of Agriculture, Imphal, Manipur, India. NARC.*

NARC. (2004). Nepal Annual Report 9900.

Naveen K., V. M., and Uma, M. . S. (2016). Genetic variability for nitrogen use efficiency and yield related traits in rice under low nitrogen and Available soil nitrogen conditions *International Journal of Applied and Pure Science and Agriculture (IJAPSA), 02:07 83–90.*

Naznin, A., Afroz, H., Hoque, T. S., and Mian, M. H. (2013). Effects of PU , USG and NPK briquette on nitrogen use efficiency and yield of BR22 rice under reduced water condition. *Journal of Bangladesh Agricultural University 11(2), 215–220.*

Nazrul, M. I., Rahman, M. A., Chaudhury, D. A., and Quayyum, M. A. (2007). Effect of different times and depths of USG application on the growth and yield of cabbage. *Bangladesh Journal of Agricultural Research, 32*(2), 2007

Norman, R. J., Wilson, C. E., Slaton, N. A., Griggs, B. R., Bushong, J. T., and Gbur, E. E. (2009). Nitrogen fertilizer sources and timing before flooding dry-seeded, delayed-flood rice. Soil Science Society of America *Journal, 73(6), 2184-2190.*

Novoa, R., and R.S. Loomis. 1981. Nitrogen and plant production. *Plant Soil 58:177-204.*

Nwilene F.E., Oikeh S.O., Agunbiade T.A., Oladimeji O., A. O., and Sié M., Gregorio G.B., T. A. and A. D. T. (2008). Growing lowland rice : a production handbook. Africa Rice Center, (WARDA).

Obcemea, W. N., Real, J. G., and De Datta, S. K. (1988). Effect of soil texture and nitrogen management on ammonia volatilization and total nitrogen loss. Philippine. *Journal of Crop Science, 13, 145-153.*

Obiol, T., Gonzalez, L.M. and Akila, J. (2003). Response of new rice varieties with a medium cycle to different doses of nitrogen. *Soil and Fertility. 66(3): 566.*

Olsen, S. R. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *United States Department of Agriculture; Washington.*

Owen, W. T., Diamand, R. B, Singh, U. and Thompson, T. P. (2005). Urea deep placement increases yield and saves nitrogen fertilizer in farmer' fields in Bangladesh. Rice in life: Scientific Perspectives for the 21st Century. In: Proc. World Rice Res. *Conf. held in Tsukuba, Japan, 4-7 Nov. 2004. pp.369.*

Padilla, J. L., Buresh, R. J., De Datta, S. K., and Bautista, E. U. (1990). Incorporation of urea in puddled rice soils as affected by tillage implements. *Fertilizer Research, 26(1–3), 169–178.*

Pan S G, Huang S Q, Zhai J, Wang J P, Cao C G, Cai M L, Zhan M, Tang X R. (2012). Effects of N management on yield and N uptake of rice in central China. *Journal of Integrative Agriculture, 11, 1993–2000.*

Pasandaran E., Gulton, B., Adiringsih, J.S., Aspari H., Rochayati S.R. (1999). Government policy support for technology pro- motion and adoption: a case study of urea tablet technology in Indonesia. *Nutrient Cycling Agroecosystems 53:113–119*

Patra, P.S. and Haque, S. (2011) Effect of Seedling Age on Tillering Pattern and Yield of Rice (Oryza sativa L.) under System of Rice Intensification. *ARPN Journal of Agricultural and Biological Science, 6, 33-35.*

Peng, S.B., Buresh, R.J., Huang, J.L., Yang, J.C., Zou, Y.B., Zhong, X.Y., Wang, G.H., Zhang, F.S. (2006). Strategies for overcoming low agronomic nitrogen use efficiency in irrigated rice systems in China. *Field Crops Res., 96(1): 37-47.*

Phongpan, S. and Byrnes, B.H. (1990). The effect of urease inhibitor N-(n-butyl) thio-phosphoric triamide on the efficiency of urea application in a flooded rice field trial in Thailand. *Fertilizer research, 25(3), 145-151.*

Phongpan, S., Vacharotayan, S., Vacharotayan, S., and Kumazawa, K. (1988). Fate and efficiency of urea fertilizer in wetland rice soil. *Soil Science and Plant Nutrition, 34(1), 117–126.*

Phupaibul, P., Chinoim, N., and Matoh, T. (2002). Nitrate concentration in Chinese kale sold at markets around Bangkok, Thailand. *Thailand Journal of Agricultural Science., 35: 295–302.*

Place, G.A., Sims J.L. and Hall, U.L. (1970). Effects of nitrogen and phosphorous on the growth yield and cooking, characteristics of rice. *Agronomy Journal, 62: 239–41*

Ponnamperuma FN (1965) Dynamic aspects of flooded soils. In: The Mineral Nutrition of the Rice Plant, pp 295-328. *The Johns Hopkins Press, Baltimore, Maryland, USA.*

Prabha, A.C., Thiyagrajan, T.M. and Senthivelu, M. (2011) System of Rice Intensification Principles on Growth Para- meters, Yield Attributes and Yield of Rice (Oryza sativa L.). *Journal of Agronomy, 10, 27-33.*

Prasad, M., and Prasad, R. (1980). Yield and nitrogen uptake by rice as affected by variety, method of planting and new nitrogen fertilizers. *Fertilizer Research, 1(4), 207–213.*

Qi, X., Wu, W., Shah, F., Peng, S., Huang, J., Cui, K., … Nie, L. (2012). Ammonia volatilization from urea-application influenced germination and early seedling growth of dry direct-seeded rice. *The Scientific World Journal, 2012, 857472.*

Qiao, J., Yang,L. Z., Yan, T. M., Xue, F. and Zhao, D. (2012). Nitrogen fertilizer reduction in rice production for two consecutive years in the Taihu Lake area. *Agriculture, Ecosystems and Environment 146: 103–12.*

Qu, Q. X. (1980). Investigation of nitrogen loss from ammonium-form fertilizers applied to calcareous soils. *Soils and Fertilizers. 3:31-35.*

Rahimpour, L., Daliri, M.S. and Mousavi, A.A. (2013) Effect of Seedling Age on Yield and Yield Component of Rice Cultivars (Oryza sativa L.). *Annals of Biological Research, 4, 72-76.*

Rahman, M. M., Amano, T., and Shiraiwa, T. (2009). Nitrogen use efficiency and recovery from N fertilizer under rice-based cropping systems. *Australian Journal of Crop Science, 3(6), 336–351.*

Rahman, K. S., Paul, S. K., Sarkar, M. A. R., and Islam, M. S. (2013). Growth Parameters of Transplant Aman Rice (cv . BRRI dhan 52) as Influenced by Age of Tiller Seedlings , Number of Tiller Seedlings Hill -1 and Level of USG. *J. Environ. Sci. and Natural Resources, 6(2), 101–108.*

Rahman, M.A. (2003). Effect of levels of urea super granules and depth of placement on the growth and yield of transplant Aman rice. M.S. Thesis, *Department of Agronomy, Bangladesh Agricultural Univnviversity., Mymensingh. 100 p.*

Rahman, M.H., Ali, M.H., Ali, M.M.;, Khatun, M.M. (2007). Effect of different level of nitrogen on growth and yield of transplant aman rice CV BRRI dhan32. *International Journal of Sustainable Crop Production. 2(1): 28-34.*

Rahman, M.M., Sarker, M.N.H., Aktar, F.M.F. and Masood, M.M. (2005). Comparative yield performance of two high yielding rice varieties to different nitrogen levels. *Bangladesh Journal of Crop Science 16(1): 73-78.*

Rahman, S., and Barmon, B. K. (2015). Productivity and efficiency impacts of urea deep placement technology in modern rice production: An empirical analysis from Bangladesh. *The Journal of Developing Areas, 49(3), 119–134.*

Rao, C.P., and M.S. Raju. (1987). Effect of age of seedling, nitrogen and spacing on rice. *Indian Journal of Agronomy 32:100-102.*

Rao, E.V.S.P. and Prasad, R. (1980). Nitrogen leaching losses from conventional and new nitrogenous fertilizers in lowland rice culture. *Plant and Soil., 57: 383–392.*

Rasool, R., Singh, P., Akhter, S., and Ramzan, S. (2016). Seedling age and nitrogen application effect on dry matter accumulation, partitioning and nutrient status of rice under temperate conditions. *Journal of Applied and Natural Science, 8(2), 743–746.*

Rawluk, C.D.L., Grant, C.A., and Racz, G.J. (2001). Ammonia volatilization from soils fertilized with urea and varying rates of urease inhibitor NBPT. Canadian *Journal of Soil Science, 81(2), 239-246.*

Reddy, K. R. (1982). Nitrogen cycling in a flooded-soil ecosystem planted to rice (*Oryza sativa L.*). *Plant and Soil, 67(1-3), 209-220.*

Reddy, K. R., and Patrick, W. H. (1986). 5. Denitrification losses in flooded rice fields. *Fertilizer research, 9(1-2), 99-116.*

Reddy, K. R., Patrick, W. H., and Broadbent, F. E. (1984). Nitrogen transformations and loss in flooded soils and sediments. Critical Reviews in Environmental *Science and Technology, 13(4), 273-309.*

Reeves, T.G., Waddington, S.R., Ortiz-Monasterio, I., Ba ¨nziger, M., and Cassaday, K. (2002) . Removing nutritional limits to maize and wheat production: A developing country perspective. In Biofertilisers in Action; Kennedy, I.R. and Choudhury, A.T.M.A., eds.; Rural Industries Research and Development Corporation: Canberra, ACT, Australaia, 11–36.

Roberts, T., and Jarrod Hardke. (2016). Recommended Nitrogen Rates and Distribution for Rice Cultivars in Arkansas. USA Division of Agriculture, Research and Extension, 2016.

Rochette, P., Angers, D. A., Chantigny, M. H., Gasser, M.-O., MacDonald, J. D., Pelster, D. E., and Bertrand, N. (2014). Ammonia Volatilization and Nitrogen Retention: How Deep to Incorporate Urea? *Journal of Environment Quality, 42(6), 1635.*

Rochette, P., Angers, D. A., Chantigny, M. H., Gasser, M., Macdonald, J. D., Pelster, D. E., and Bertrand, N. (2013). NH3 volatilization, soil NH4+ concentration and soil pH following subsurface banding of urea at increasing rates. Canadian Jorunal of Soil Science, 93, 261–26.

Rochette, P., Angers, D.A., Chantigny, M.H., MacDonald, J.D., Bissonnette, N. and Bertrand, N. (2009). Ammonia volatilization following surface application of urea to tilled and no-till soils: A laboratory comparison. Soil and Tillage Research. 103:310-315.

Rochette, P., J.D. MacDonald, D.A. Angers, M.H. Chantigny, M. Gasser, and N. Bertrand. (2009). Banding of urea increased ammonia volatilization in a dry acidic soil. *Journal of Environmental Quality. 38:1383-1390.*

Roger PA., and Watanabe I. (1986). Technologies for utilizing biological nitrogen fixation in wetland rice: Potentialities, current usage and limiting factors. Fertilizer Research 9:39–77

Ros C., Bell, R. W. and White, P. F. (2003). Seedling vigour and the early growth of transplanted rice (Oryza sativa). *Plant and Soil, 252: 325–337.*

Roy, A., Hammond, L., (2004). Challenges and Opportunities for the Fertilizer Industry. In: Mosier, A.R., Syers, J.K., Freney, J.R. (Eds.), Agriculture and the Nitrogen Cycle. *Island Press, Washington, pp. 233–243.*

Roy, R. N., Misra, R. V., and Montanez, A. (2002). Decreasing reliance on mineral nitrogen—yet more food. AMBIO: *A Journal of the Human Environment, 31(2), 177-183.*

Russo S., Raso G., Ferraris G. (1991). Effetti dell’applicazione tardiva di azoto su varietà di riso (Oryza sativa, L.) a differente accrescimento. I. Variazioni biomorfologiche e produttive. *Rivista di Agronomia, 4:45-504*

Ryan, J., Curtin, D. and Safi, (1981). Ammonia volatilization as influenced by calcium carbonate particle size and iron oxides. *Soil Science Society of America Journal. 45:338-341.*

Saha, B., Panda, P., Patra, P. S., Panda, R., Kundu, A., Roy, A. K. S., and Mahato, N. (2017). Effect of Different levels of Nitrogen on Growth and Yield of Rice (*Oryza sativa L.*) Cultivars under Terai-agro Climatic Situation. International *Journal of Current Microbiology and Applied Sciences, 6(7), 2408–2418.*

Sahoo, N. C., Mishra, R. K., and Mohanty, J. P. (1990). Response of aged seedlings of transplanted rice to split application of nitrogen. 2. Effect of single versus split application of nitrogen on partitioning of dry matter and yield of rice. Orissa *Journal of Agricultural Research, 3(1), 13-17.*

Sahoo, N.C. and Rout, L. (2004). Effect of seedling age and plant density on growth, yield and nutrient uptake in high yielding rice varieties and hybrids. *Indian Journal of Agronomy, 49 (1):72-75.*

Salem, A. K. M., Elkhoby, W. M., Abou-Khalifa, A. B., and Ceesay, M. (2011). Effect of nitrogen fertilizer and seedling age on inbred and hybrid Rice Varieties. *American-Eurasian J. Agric. and Environ. Sci., 11(5), 640–646.*

Salem, A.K.M. (2006). Effect of nitrogen levels, plant spacing and time of farmyard manure application on the productivity of rice. *Journal of Applied Science. Res., 2: 980-987.*

Sarkar, M.A.R., Paul, S.K. and Hossain, M.A. (2011) Effect of Row Arrangement, Age of Tiller Seedling and Number of Tiller Seedlings per Hill on Performance of Transplant Aman Rice. *Journal of Agricultural Science, 6, 61-63.*

Sarwar, N., Maqsood, M., Aftab Wajid, S., and Anwar-ul-Haq, M. (2011). Impact of Nursery Seeding Density, Nitrogen, and Seedling Age on Yield and Yield Attributes of Fine Rice. Chilean Journal of Agricultural Research, 71(3), 343–349.

Sasaki, R. (2004) Characteristics and Seedlings Establishment of Rice Nursling Seedlings. *Japan Agricultural Re- search Quarterly, 38, 7-13.*

Savant, N. K., and Stangel, P. J. (1990). Deep placement of urea supergranules in transplanted rice : principles and practices. *Fertilizer Research, 25(1), 1–83*

Schnier, H.F. (1995). Significance of timing and method of N fertilizer application for N-use efficiency in flooded tropical rice. *Fertilizer Research., 42: 129–138.*

Shrestha, R.K. and Ladha, J.K. (1998). Nitrate in groundwater and integration of nitrogen-catch crop in rice-sweet pepper cropping system. *Soil Science Society of America Journal., 62: 1610–1619.*

Shukla U N, Srivastava V K, Singh S, Sen A and Kumar V. 2014. Growth, yield and economic potential of rice (*Oryza sativa*) as influenced by different age of seedlings, cultivars and weed management under system of rice intensification. *Indian Journal of Agricultural Sciences 84 (5): 628–36.*

Sidhue, M.S., Sikka, R., Singh, T. (2004). Performances of transplanted Basmati rice in different cropping systems as affected by N application. *International Rice Research notes 29: 63-65.*

Simpson, J. R. and Freney, J. R. (1988). Interacting processes in gaseous nitrogen loss from urea applied to flooded rice fields. Urea Technology and Utilization. pp. 281-290. *Malaysian Society of Soil Science. Kuala Lumpur, Malaysia*.

Sing, S., Ladha, J.K., Gupta, R.K., Bhushan, L., Rao, A.N. (2008). Weed management in aerobic rice systems under varying establishment methods. *Crop Protection. 27:660-671.*

Singh U (2005) Integrated nitrogen fertilization for intensive and sustainable agriculture. *Journal of Crop Improvement 15, 259-288.*

Singh, G., O.P. Singh, V. Kumar, and T. Kumar. (2008). Effect of methods of establishment and tillage practices on productivity of rice (Oryza sativa) - wheat (Triticum aestivum) cropping system in low lands. Indian J. Agric. Sci. 78: 163-166.

Singh, M.K., Thakur, R., Verma, U.N., Upasani, R.R. and Pal, S.K. (2000). Effect of planting time and nitrogen on production potential of Basmati rice cultivars in Bihar Plateau. *Indian Journal. Of Agronomy. 45(2): 300-303.*

Singh, S. P., Devi, B. S., and Subbiah, S. V. (1996). Effect of nitrogen levels and their time of application

Singh, U., Cassman, K. G., Ladha, J. K., and Bronson, K. F. (1995). Innovative nitrogen management strategies for lowland rice systems. In ‘‘Fragile Lives in Fragile Ecosystems’’, pp. 229–254. *International Rice Research Institute, Manila, Philippines.*

Soil Survey Staff (1996). Keys to Soil Taxonomy. Seventh Edition, USDA Natural Resource Con-servation Service, Washington DC, 644.

Sommer, S.G., Schjoerring, K. and Denmead, O.T. (2004). Ammonia emission from mineral fertilizers and fertilized crops. *Advances in agronomy.82:557–622.*

Son, T. T., and Buresh, R. J. (1993). Incorporation of urea for transplanted rice as affected by floodwater and growing season. *Fertilizer Research, 34(2), 111–120.*

Staff, S. S. (1996). Keys to Soil Taxonomy, *United States Department of Agriculture. Natural Resources Conservation Service, 644.*

Stevens, C. J., Dise, N. B., Mountford, O. and Gowing, D. J. (2004). Impact of nitrogen deposition on the species richness of grasslands. *Science 303: 1876-1879.*

Stewart, W.M. (2008). Fertilizer sources for irrigated corn. In: W.M Stewart and W.B. Gordon, editors, Fertilizing for irrigated corn: Guide to best management practices. IPNI no. 30-3240. *International Plant Nutrition Institute., Norcross, GA. p. 2-1 to 2-6.*

Sullivan, D. G., Wood, C. W., Owsley, W. F., Norfleet, M. L., Wood, B. H., Shaw, J. N., and Adams, J. F. (2003). Ammonia volatilization from a swine waste amended bermudagrass pasture. *Communications in Soil Science and Plant Analysis, 34(11–12), 1499–1510.*

Surekha, M., Reddy, N. and Kumar, R.M. (1999).Yield attributes and yield of rice *Oryza sativa*) hybrid as influenced by nitrogen sources and its split application. *Indian Journal of Agronomy, pp.44 (1): 80-88.*

Sui B, Feng X, Tian G, Hu X, Shen Q, Guo S. (2013). Optimizing nitrogen supply increases rice yield and nitrogen use efficiency by regulating yield formation factors. *Field Crops Research, 150, 99–107.*

Swan, H.S.D. (1971). Relationships between nutrient supply, growth and nutrient concentrations in the foliage of white and red spruce. *Pulp Pap. Res. Inst. Can., Woodlands Pap. WR/34. 27 p.*

Tarfa, B. and Kiger, B. (2013). UDP and Rice production in Nigeria: The experience so far. At the Nigeria launch of 'Guiding Investments in Sustainable Agricultural Intensification in Africa (GISAIA)' . *(PowerPoint Presentation), Abuja. June 17, 2013*

Thanunathan, K., and V. Sivasubramanian. (2002). Age of seedling and crop management practices for high density (HD) grain in rice. *Crop Research 24:421-424.*

Trenkel, M. E. (1997). Controlled-Release and Stabilized Fertilizers in Agriculture. *International Fertilizer Industry Association (IFA), Paris, France.*

Tunio, G. S., Agustin, M.B., Mari, N. and Babar, M.A. (2002). Growth and yield of scented rice varieties under different nitrogen levels. *Sarhad Journal of Agriculture. 18: 3, 303-305.*

Tyeb, A., Paul, S. K. and Samad, M. A. (2013). Performance of variety and spacing on the yield and yield contributing characters of transplant Aman rice. *Journal of Agroforestry and Environment. 7 (1) : 57-60.*

Uphoff N. 2002. System of rice intensification (SRI) for enhancing the productivity of land, labour and water. *Journal of Agricultural Resource Management 1 (1): 43-9.*

USDA (2016). Foreign Agricultural Service, Official USDA Estimates. *Available on* https://www.fas.usda.gov/commodities/rice

Van Keulen, H. van. (1977). Nitrogen Requirements of Rice With Special. *Central Research Institute for Agriculture, Bogor, 30, 1–67.*

Velu, V. and Ramanathan, K.M. (2001) Nitrogen balance in wetland rice ecosystem as influenced by soil type. *Madras Agricultural Journal., 87: 21–25.*

Ventura, W., and Watanabe, I. (1978). Dry season soil conditions and soil nitrogen availability to wet season wetland rice. *Soil Science and Plant Nutrition, 24(4), 535–545*

Vishwakarma, A., Singh, J. K., Sen, A., Bohra, J. S., and Singh, S. (2016). Effect of transplanting date and age of seedlings on growth, yield and quality of hybrids under system of rice (*Oryza sativa*) intensification and their effect on soil fertility. *Indian Journal of Agricultural Sciences, 86(5), 679–685.*

Vlek, P. J. G. and Craswell, .C T. (1979). Effect of nitrogen source and management on ammonia volatilization losses from flooded rice-soil systems. *Soil Science Society of America Journal. 43:352-358.*

Vlek, P. L. G., and Stumpe, J. M. (1978). Effects of Solution Chemistry and Environmental Conditions on Ammonia Volatilization Losses From Aqueous Systems . *Soil Science Society of America Journal, 42(3), 416-421.*

Wagh, R.G., S.A. Khanvilkar, and S.T. Thorat. (1988). Effect of age of seedlings at transplanting, plant densities and nitrogen fertilization on the yield of rice variety R711. *Oryza 25:188-190.*

Walkley, A., and Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science, 37(1), 29-38.*

Wang, C.H. (2004). Response of rice yield to deep placement of fertilizer and nitrogen top-dressing in panicle initiation stage and its diagnosis of fertilizer application. Taiwanese *Journal of Agriculture Chemistry and Food Science. 42(5): 383-395.*

Wang, Z. H., Liu, X. J., Ju, X. T., Zhang, F. S., and Malhi, S. S. (2004). Ammonia volatilization loss from surface-broadcast urea: Comparison of vented and closed chamber methods and loss in winter wheat-summer maize rotation in North China Plain. *Communications in Soil Science and Plant Analysis, 35(19–20), 2917–2939.*

Wani, A.R., Hasan, B. and Bali, A.S. (1999). Relative efficiency of some modified urea materials in transplanted rice under temperate conditions of Kashmir. *Oryza, vol. 36, no. 4, pp. 382-383.*

Ward, M.H., Mark, S.D., Cantor, K.P., Weisenburger, D.D., Correa-Villaseñor, A. and Zahm, S.H. (1996). Drinking water nitrate and the risk of non-Hodgkins lymphoma. *Epidemiology 7, 465–471.*

Watkins, B., Hignight, J. and Wilson, Jr, C.E. (2008). Estimating cost of production, rice, clay soils, eastern Arkansas. AG-1210-11-08. *Univ. of Arkansas, Division of Agriculture., Coop. Ext. Serv., Little Rock.*

Wen, Q. X. and Zhang, X. H. (1986). Fixed ammonium in soils. In: Soil Agricultural Chemistry Committee and Soil Biology and Biochemistry Committee. Soil Science Society of China (eds.), *Advances and Prospects for Soil Nitrogen Research in China. (in Chinese), pp. 34-45. Science Press, Beijing.*

Xiang, J., Haden, V. R., Peng, S., Bouman, B. A. M., Huang, J., Cui, K., … Chen, H. (2013). Effect of deep placement of nitrogen fertilizer on growth, yield, and nitrogen uptake of aerobic rice. *Australian Journal of Crop Science, 7(6), 870–877.*

Xie, L. L., H. X. Weng, C. L. Hong and A. L. Yan. (2007). Uptake of bokchoy and Ipomoea aquatica Forsk to iodine species. *Plant Nutrition and Fertilizer Science. 13(1): 123-128.*

Xie, W., Wang, G., Zhang, Q., and Guo, H. (2007). Effects of nitrogen fertilization strategies on nitrogen use efficiency in physiology, recovery, and agronomy and redistribution of dry matter accumulation and nitrogen accumulation in two typical rice cultivars in Zhejiang, China. *Journal of Zhejiang University. Science. B, 8(3), 208–16.*

Xin, Y., Wenhai, M., Shaofu, W., Lianghuan, W., and Jianqiu, C. (2017). Rice responses to single application of coated urea on yield, dry matter accumulation, and nitrogen uptake in Southern China. *Journal of Plant Nutrition, 40(15), 2181-2191..*

Xing, G.X. and Zhu, Z.L. (2000) An assessment of N loss from agricultural fields to the environment in China. Nutrient *Cycling in Agroecosystems, 57: 67–73.*

Xing, G.X., Cao, Y.C., Shi, S.L., Sun, G.Q., Du, L.J., and Zhu, J.G. (2002). Denitrification in underground saturated soil in a rice paddy region. *Soil Biology and Biochemistry., 34: 1593–1598.*

Xiang, J., Haden, V. R., Peng, S., Bouman, B. A. M., Huang, J., Cui, K., … Chen, H. (2013). Effect of deep placement of nitrogen fertilizer on growth, yield, and nitrogen uptake of aerobic rice. *Australian Journal of Crop Science, 7(6), 870–877.*

Xu, J., Liao, L., Tan, J., and Shao, X. (2013). Ammonia volatilization in gemmiparous and early seedling stages from direct seeding rice fields with different nitrogen management strategies: A pots experiment. *Soil and Tillage Research, 126, 169–176.*

Yamada Y., Ahmad A., Alcantara A. and Khan, N.H. (1979) Nitrogen efficiency study under flooded paddy conditions. In: *Proc. of Final INPUTS Review Meeting, pp 39–74, East West Center, Honolulu, Hawaii.*

Yao, Rand Guan, S. J. (1983). Transformation of urea - nitrogen in soil with deep placement and its efficiency. (in Chinese). *Soils and Fertilizers (1):15-16.*

Yaosse, G. (2009). Test de l'éfficacité de la technologie du placement en profondeur de l'urée briquette (UDP) sur le périmètre rizicole irrigué de la vallée de Zio. *Ecole Supérieure d'Agronomie, Université de Lomé*-Togo. *60 p*

Ye, Q., Zhang, H., Wei, H., Zhang, Y., Wang, B., Xia, K., Xu, K. (2007). Effects of nitrogen fertilizer on nitrogen use efficiency and yield of rice under different soil conditions. *Frontiers of Agriculture in China, 1(1), 30–36.*

Yoshida S, Forno, D.A., Cock, J.H., Gomez, K.A. (1972). Laboratory manual for physiological studies of rice, 2nd edn. The Philippines: *International Rice Research Institute (IRRI).*

Yoshida, S. (1981). Fundamentals of rice crop science. *International Rice Research Institute, LosBaños, Philippines.*

Yoshida, T., and Padre, B. C. (1974). Nitrification and denitrification in submerged Maahas clay soil. *Soil Science and Plant Nutrition, 20(3), 241-247.*

Yu, Q., Ye, J., Yang, S., Fu, J., Ma, J., Sun, W. Wang, Q. (2013). Effects of Nitrogen Application Level on Rice Nutrient Uptake and Ammonia Volatilization. *Rice Science, 20(2), 139–147.*

Zhang F,. Cui Z., Fan M., Zhang W., Chen X. and Jiang R. (2011). Integrated soil–crop system management: reducing environmental risk while increasing crop productivity and improving nutrient use efficiency in China. *J. Environ. Qual. 40: 1051– 1057.*

Zhang Q., Yang, Z., Zhang, H., Yi, J. (2012). Recovery efficiency and loss of 15N-labelled urea in a rice–soil system in the upper reaches of the Yellow River basin. Agriculture, *Ecosystems and Environment, 158, 118-126.*

Zhao, L. (2010). Rice yield, nitrogen utilization and ammonia volatilization as influenced by modified rice cultivation at varying nitrogen rates. *Agricultural Sciences, 1(1), 10–16.*

Zhao, Z. D., Zhang, J. Sand Ren, S. R. (1986). Ammonia volatilization from fertilizers applied to upland crops. In Agricultural Chemistry and Soil Biology and Biochemistry Committees, Soil Science Society of China (eds.), Advances and Prospects for Soil Nitrogen Research in China. (in Chinese) *pp. 82–91.*

Zhao-lian, Z., (1997). Fate and management of fertilizer nitrogen in agro-ecosystems. In: Zhu, Z., Wen, Q., Freney, J.R. (Eds.), *Nitrogen in Soils of China. Kluwer Academic Publishers, Dordrecht.*

Zhao-liang., Qi-xiao, W., and Freney, J. R. (1997). Nitrogen in soils of china. (Z. W. Q. J. R. F. Zhao-liang, Ed.) (1 st editi). Malaysia: Kluwer Academic Publishers.

Zhenghu, D., and Honglang, X. (2000). Effects of soil properties on ammonia volatilization. Soil Science and Plant Nutrition, 46(4), 845–852.

Zhilin, L., Sarker, R.S., Nayak, S.K., Ravi, I. and Li, J.L. (1997). Physiological effect of nitrogen application on aromatic rice. *Journal of South China Agricultural University. 18:13–17.*

Zhong-cheng, L., Ye, S., Dai, Q., Jia Y., Gu, H., Chen, J., Xu L., Zhang H.,Huo Z., Xu K., Wei H. Wei, H. (2012). Effects of Nitrogen Application Level on Ammonia Volatilization and Nitrogen Utilization in Rice Growing Season. *Rice Science, 25(1), 125–137.*

Zhu, Z .L., Chen, D. L. (2002). Nitrogen fertilizer use in China-Contributions to food production, impacts on the environment and best management strategies. *Nutrient Cycling in Agroecosystems, 63, 117-127.*

Zhu, Z. (1997). Fate and management of fertilizer nitrogen in agro-ecosystems. In: Zhu, Z., Wen, Q., Freney, J.R. (Eds.), *Nitrogen in Soils of China. Kluwer Academic Publishers, Dordrecht.*

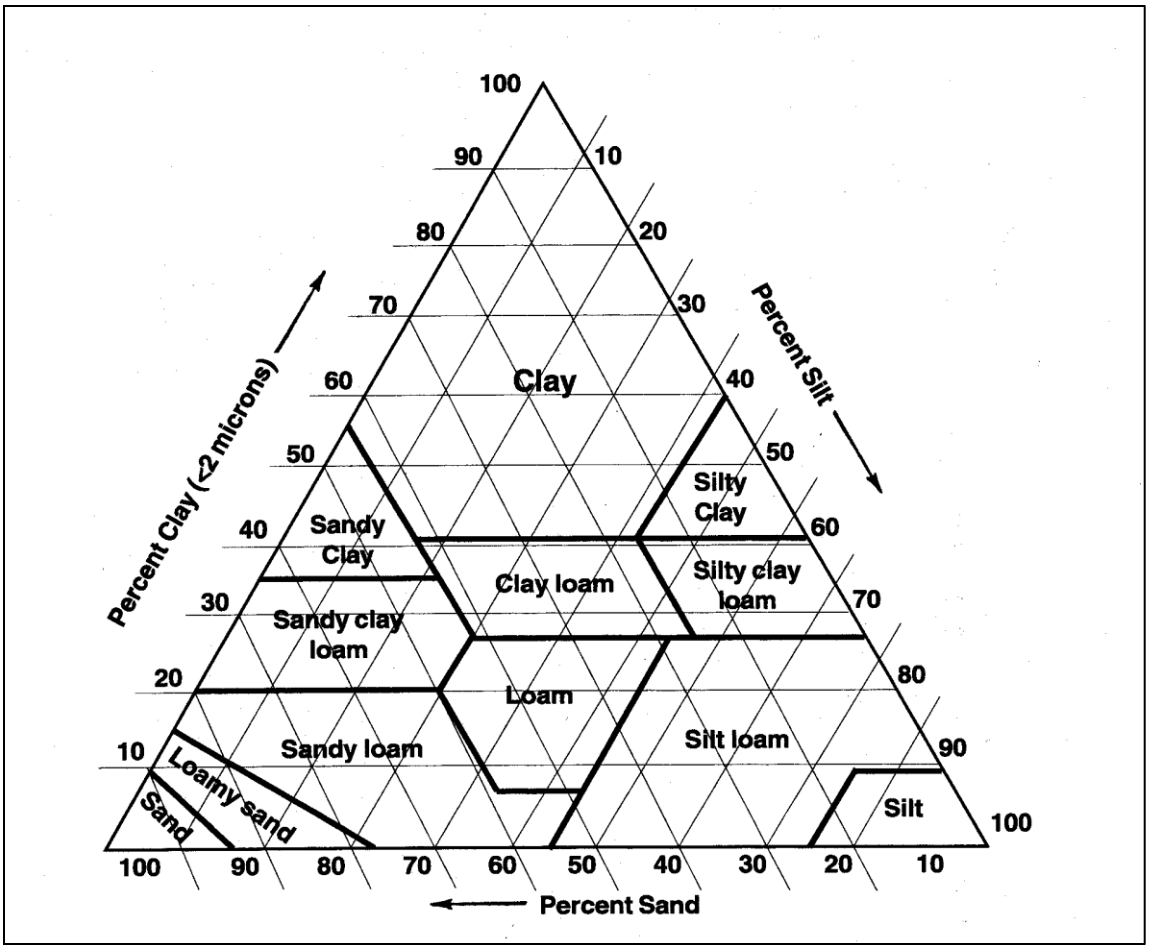
Zhu, Z.L., Simpson, J.R., Zhang, S.L., Cai, G.X., Chen, D.L., Freney, J.R., Jackson, V.A., (1989). Investigations on nitrogen losses from fertilizers applied to flooded calcareous paddy soil. *Acta Pedologica Sinica 26 (4), 337–343.*

Zhong-cheng, L., Ye, S., Dai, Q., Jia, Y., Gu, H., Chen, J., Wei, H. (2012). Effects of Nitrogen Application Level on Ammonia Volatilization and Nitrogen Utilization in Rice Growing Season. *Rice Science, 25(1), 125–137*.

APPENDICES

Appendix 1: USDA textural triangle used for textural class determination

USDA textural triangle



Appendix 2: Interaction effect between rice variety, type of urea and N rate on rice growth, yield components and grain and straw yields. Ablotsri site, Season 1

Interaction	Height (cm)	Number of tillers per hill	Length of panicles (cm)	weight of 1000 grains (g)	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index
IR-841 x PU x Ctrl	71.63	10.00	17.50	24.00	1717	2033	45.79
IR-841 x PU x N52	90.07	14.67	22.53	26.26	2600	2992	46.52
IR-841 x PU x N78	106.80	19.33	23.93	27.83	5058	5725	46.90
IR-841 x PU x N104	113.50	20.33	25.87	28.13	5433	6067	47.23
IR-841 x USG x Ctrl	71.33	10.33	17.50	24.00	1600	1892	45.83
IR-841 x USG x N52	98.77	16.00	23.23	26.26	3842	5100	42.97
IR-841 x USG x N78	112.07	23.00	25.83	27.83	5808	6617	46.75
IR-841 x USG x N104	113.62	21.67	25.83	28.13	5925	6467	47.82
TG-405 x PU x Ctrl	71.33	10.33	17.50	24.30	1808	2067	46.71
TG-405 x PU x N52	86.00	15.33	23.30	26.46	2783	3225	46.32
TG-405 x PU x N78	105.60	19.00	25.67	28.06	5200	5617	48.05
TG-405 x PU x N104	107.93	20.00	26.17	28.06	5133	5675	47.50
TG-405 x USG x Ctrl	71.63	10.67	17.13	24.30	1625	1883	46.32
TG-405 x USG x N52	92.47	17.00	24.73	26.46	3950	5392	42.32
TG-405 x USG x N78	108.73	21.33	26.50	28.06	6067	6667	47.65
TG-405 x USG x N104	108.10	21.00	26.37	28.06	6058	6433	48.51
Fpr	0.704	0.854	0.672	0.933	0.511	0.816	0.872
CV	1.9	7.3	4.0	3.1	5.8	507	1.6
LSD	3.081	2.037	1.552	1.371	387.6	441.0	1.215

Appendix 3: Interaction effect between rice variety, type of urea and N rate on rice nitrogen uptake and nitrogen use efficiency. Hahome site season 1

Interaction	Nitrogen uptake (kg N ha^{-1})	Agronomy efficiency (kg kg N^{-1})	Physiology efficiency (kg kg N^{-1})	Nitrogen Recovery (%)
IR-841 x PU x Ctrl	25.80	-	-	-
IR-841 x PU x N52	53.36	43	67	53
IR-841 x PU x N78	63.69	43	186	49
IR-841 x PU x N104	73.10	36	163	45
IR-841 x USG x Ctrl	23.53	-	-	-
IR-841 x USG x N52	69.87	43	118	89
IR-841 x USG x N78	90.04	54	134	85
IR-841 x USG x N104	107.28	42	106	81
TG-405 x PU x Ctrl	25.55	-	-	-
TG-405 x PU x N52	54.44	19	74	56
TG-405 x PU x N78	66.63	43	169	53
TG-405 x PU x N104	75.53	32	139	48
TG-405 x USG x Ctrl	24.06	-	-	-
TG-405 x USG x N52	71.67	45	123	92
TG-405 x USG x N78	92.53	57	135	88
TG-405 x USG x N104	109.40	43	105	82
Fpr	0.969	0.607	0.301	0.834
CV	3.1	7.6	8.1	2.2
LSD	3.274	5.101	17.33	2.498

Appendix 4: Interaction effect between rice variety, type of urea and N rate on rice growth, yield components and grain and straw yields. *Ablotsri site, Season 2*

Interaction	Height (cm)	Number of tillers per hill	Length of panicles (cm)	weight of 1000 grains (g)	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index
IR-841 x PU x Ctrl	71.13	9.67	16.50	23.24	1508	1758	46.14
IR-841 x PU x N52	84.70	15.00	20.33	26.67	2617	3058	46.11
IR-841 x PU x N78	104.30	19.33	22.49	27.64	4800	6108	44.35
IR-841 x PU x N104	104.93	19.00	23.32	27.69	5183	5708	47.57
IR-841 x USG x Ctrl	71.20	10.00	17.43	24.58	1642	1892	46.44
IR-841 x USG x N52	98.40	14.33	23.03	26.30	4592	6167	42.73
IR-841 x USG x N78	106.73	21.67	24.83	27.83	5283	5883	47.30
IR-841 x USG x N104	106.10	21.33	25.37	27.93	5933	6475	47.81
TG-405 x PU x Ctrl	71.63	10.00	16.60	23.99	1758	2017	46.63
TG-405 x PU x N52	86.73	15.33	21.50	25.70	2867	3275	46.68
TG-405 x PU x N78	106.80	20.67	22.97	27.59	5067	5700	47.04
TG-405 x PU x N104	111.83	20.67	23.30	27.19	5533	6075	47.68
TG-405 x USG x Ctrl	71.33	9.33	17.21	24.80	1825	2108	46.45
TG-405 x USG x N52	99.64	16.00	22.50	26.89	4858	5342	47.63
TG-405 x USG x N78	113.06	21.00	24.03	27.76	5883	6408	47.86
TG-405 x USG x N104	114.25	21.00	23.79	27.92	6033	6833	46.89
Fpr	0.467	0.854	0.753	0.574	0.324	0.069	0.075
CV	2.0		3.9		4.7	8.0	3.3
LSD	NS	NS	NS	NS	NS	NS	NS

Appendix 5: Interaction effect between rice variety, type of urea and N rate on rice nitrogen uptake and nitrogen use efficiency. Ablotsri site season 2

Interaction	Nitrogen uptake (kg N ha^{-1})	Agronomy efficiency (kg kg N^{-1})	Physiology efficiency (kg kg N^{-1})	Nitrogen Recovery (%)
IR-841 x PU x Ctrl	21	-	-	-
IR-841 x PU x N52	48	21.31	89	52
IR-841 x PU x N78	59	42.2	197	49
IR-841 x PU x N104	66	35.34	169	43
IR-841 x USG x Ctrl	25	-	-	-
IR-841 x USG x N52	71	56.73	155	90
IR-841 x USG x N78	90	46.69	116	85
IR-841 x USG x N104	106	41.27	109	78
TG-405 x PU x Ctrl	24	-	-	-
TG-405 x PU x N52	53	21.31	82	56
TG-405 x PU x N78	65	42.41	169	53
TG-405 x PU x N104	73	36.3	160	47
TG-405 x USG x Ctrl	27	-	-	-
TG-405 x USG x N52	75	58.33	133	91
TG-405 x USG x N78	96	52.03	123	88
TG-405 x USG x N104	110	40.46	109	79
Fpr	0.802	0.472	0.071	0.713
CV	3.7	8.2	9.3	3.2
LSD	3.868	5.731	21.21	3.638

Appendix 6: Interaction effect between rice variety, type of urea and N rate on rice growth, yield components and grain and straw yields. *Hahome site , Season 1*

Interaction	Height (cm)	Number of tillers per hill	Length of panicles (cm)	weight of 1000 grains (g)	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index
IR-841 x PU x Ctrl	71.63	7.00	16.60	23.99	1467	1758	45.51
IR-841 x PU x N52	89.17	10.33	21.17	25.33	2167	2492	46.50
IR-841 x PU x N78	102.47	14.33	22.63	25.99	4100	4575	47.25
IR-841 x PU x N104	103.02	14.00	22.87	25.83	4792	5267	47.64
IR-841 x USG x Ctrl	71.67	8.33	17.63	24.99	1425	1633	46.60
IR-841 x USG x N52	89.77	12.33	21.90	25.59	3467	4033	46.23
IR-841 x USG x N78	104.07	14.33	23.37	26.66	4250	4792	47.01
IR-841 x USG x N104	104.62	16.00	23.53	26.73	5192	5675	47.78
TG-405 x PU x Ctrl	72.07	6.67	17.10	24.13	1392	1600	46.48
TG-405 x PU x N52	88.43	13.33	21.90	25.19	2392	2775	46.25
TG-405 x PU x N78	101.07	14.33	23.67	25.79	4033	4967	44.90
TG-405 x PU x N104	103.73	15.00	24.17	26.46	5075	5550	47.76
TG-405 x USG x Ctrl	73.23	8.33	17.57	24.29	1392	1675	45.38
TG-405 x USG x N52	89.27	12.00	23.03	25.49	4200	4958	45.88
TG-405 x USG x N78	103.87	14.67	24.83	27.06	4842	5467	46.97
TG-405 x USG x N104	106.90	16.33	25.37	27.19	5567	6158	47.48
Fpr	0.962	0.591	0.329	0.943	0.054	0.558	0.058
CV	1.7	15.1	9.7	5.6	4.5	5.5	1.9
LSD	NS	NS	NS	NS	NS	NS	NS

Appendix 7: Interaction effect between rice variety, type of urea and N rate on rice nitrogen uptake and nitrogen use efficiency. Hahome site season 1

Interactions	Nitrogen uptake (kg N ha^{-1})	Agronomy efficiency (kg kg N^{-1})	Physiology efficiency (kg kg N^{-1})	Nitrogen Recovery (%)
IR-841 x PU x Ctrl	21	-	-	-
IR-841 x PU x N52	44	13	62	44
IR-841 x PU x N78	55	34	162	43
IR-841 x PU x N104	62	32	166	40
IR-841 x USG x Ctrl				
IR-841 x USG x N52	21	39	100	85
IR-841 x USG x N78	65	36	97	79
IR-841 x USG x N104	83	36	106	72
TG-405 x PU x Ctrl	95	-	-	--
TG-405 x PU x N52	21	19	86	49
TG-405 x PU x N78	46	34	169	46
TG-405 x PU x N104	57	35	170	43
TG-405 x USG x Ctrl	66	-	-	-
TG-405 x USG x N52	22	54	135	87
TG-405 x USG x N78	67	44	112	83
TG-405 x USG x N104	87	40	111	75
Fpr	0.955	0.195	0.871	0.851
CV	4.5	5.110	10.4	5.8
LSD	NS	NS	NS	NS

Appendix 8: Interaction effect between rice variety, type of urea and N rate on rice growth, yield components and grain and straw yields. *Hahome site, Season 2*

Interaction	Height (cm)	Number of tillers per hill	Length of panicles (cm)	weight of 1000 grains (g)	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index
IR-841 x PU x Ctrl	69.97	7.33	15.41	23.76	1408	1700	45.30
IR-841 x PU x N52	88.83	10.00	20.70	24.26	2108	2617	44.64
IR-841 x PU x N78	104.60	14.67	22.46	25.83	3833	4458	46.22
IR-841 x PU x N104	106.91	15.33	22.94	25.63	4625	5133	47.41
IR-841 x USG x Ctrl	71.67	8.67	16.65	24.56	1317	1633	44.60
IR-841 x USG x N52	91.43	12.00	22.11	24.40	3325	4067	44.98
IR-841 x USG x N78	106.23	16.00	23.21	26.34	4600	5300	46.45
IR-841 x USG x N104	107.62	15.67	23.00	25.67	5192	5642	47.94
TG-405 x PU x Ctrl	71.87	6.67	16.01	24.13	1342	1600	45.69
TG-405 x PU x N52	90.87	11.67	21.98	25.34	2225	2567	46.41
TG-405 x PU x N78	103.30	15.00	23.20	25.60	4100	4558	47.34
TG-405 x PU x N104	106.40	15.00	24.13	26.84	5117	5167	49.78
TG-405 x USG x Ctrl	73.93	7.33	17.47	24.44	1367	1583	46.33
TG-405 x USG x N52	93.40	11.00	23.13	25.67	3633	4150	46.66
TG-405 x USG x N78	105.97	16.33	24.92	26.57	4608	5192	47.02
TG-405 x USG x N104	107.63	17.00	25.15	26.27	5317	5617	48.65
Fpr	0.988	0.130	0.910	0.953	0.256	0.813	0.321
CV	2.1	8.7	5.8	5.4	5.9	6.0	2.1
LSD	NS	NS	NS	NS	NS	NS	NS

Appendix 9: Interaction effect between rice variety, type of urea and N rate on rice nitrogen uptake and nitrogen use efficiency. Hahome site season 2

Interaction	Nitrogen uptake (kg N ha^{-1})	Agronomy efficiency (kg kg N^{-1})	Physiology efficiency (kg kg N^{-1})	Nitrogen Recovery (%)
IR-841 x PU x Ctrl	20	-	-	-
IR-841 x PU x N52	44	13	65	48
IR-841 x PU x N78	53	31	155	43
IR-841 x PU x N104	61	61	160	40
IR-841 x USG x Ctrl	20	-	-	-
IR-841 x USG x N52	64	39	102	84
IR-841 x USG x N78	81	42	113	79
IR-841 x USG x N104	94	37	107	71
TG-405 x PU x Ctrl	19	-	-	-
TG-405 x PU x N52	45	17	71	50
TG-405 x PU x N78	57	35	153	48
TG-405 x PU x N104	67	36	155	45
TG-405 x USG x Ctrl	21	-	-	-
TG-405 x USG x N52	62	44	119	79
TG-405 x USG x N78	82	42	111	79
TG-405 x USG x N104	95	38	108	72
Fpr	0.801	0.481	0.864	0.851
CV	5.8	10.5	11.7	5.8
LSD	5.313	6.007	23.41	5.992

Appendix 10: Interaction effect between rice variety, type of urea and N rate on rice growth, yield components and grain and straw yields. *Kouto site, Season 1*

Interaction	Height (cm)	Number of tillers per hill	Length of panicles (cm)	weight of 1000 grains (g)	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index
IR-841 x PU x Ctrl	69.97	7.33	16.53	21.02	1117	1342	45.366
IR-841 x PU x N52	89.33	10.00	21.50	26.46	2117	2533	45.555
IR-841 x PU x N78	101.97	14.67	21.63	27.13	3617	4200	46.260
IR-841 x PU x N104	104.63	15.33	22.87	27.40	4208	4583	47.883
IR-841 x USG x Ctrl	70.63	8.67	16.57	21.11	1108	1325	45.536
IR-841 x USG x N52	89.67	12.00	22.49	26.83	2292	2608	46.781
IR-841 x USG x N78	108.27	16.00	24.00	27.73	3708	4100	47.490
IR-841 x USG x N104	107.97	15.67	24.23	27.86	4358	4958	46.778
TG-405 x PU x Ctrl	71.87	6.67	16.53	21.12	1133	1408	44.539
TG-405 x PU x N52	90.97	11.67	22.40	26.36	2292	2775	45.220
TG-405 x PU x N78	105.27	15.00	23.87	26.96	3750	4208	47.118
TG-405 x PU x N104	105.82	15.00	25.37	27.63	4408	4742	48.176
TG-405 x USG x Ctrl	71.43	7.33	17.37	21.90	1200	1442	45.464
TG-405 x USG x N52	95.97	11.00	23.73	26.96	2533	2892	46.667
TG-405 x USG x N78	109.27	16.33	25.33	28.03	3617	4058	47.134
TG-405 x USG x N104	109.15	17.00	25.57	28.10		5250	47.475
Fpr	0.152	0.525	0.473	0.990	0.465	0.953	0.334
CV	2.0	12.5	4.1	5.1	5.6	5.9	1.5
LSD	NS	NS	NS	NS	NS	NS	NS

Appendix 11: Interaction effect between rice variety, type of urea and N rate on rice nitrogen uptake and nitrogen use efficiency. *Kouto site season 1*

Interaction	Nitrogen uptake (kg N ha^{-1})	Agronomy efficiency (kg kg N^{-1})	Physiology efficiency (kg kg N^{-1})	Nitrogen Recovery (%)
IR-841 x PU x Ctrl	17	-	-	-
IR-841 x PU x N52	42	19	90	47
IR-841 x PU x N78	52	32	156	44
IR-841 x PU x N104	58	30	156	39
IR-841 x USG x Ctrl	17			
IR-841 x USG x N52	47	23	82	58
IR-841 x USG x N78	57	33	137	52
IR-841 x USG x N104	66	31	144	47
TG-405 x PU x Ctrl	15	-	-	-
TG-405 x PU x N52	39	22	109	45
TG-405 x PU x N78	48	34	169	41
TG-405 x PU x N104	57	31	160	40
TG-405 x USG x Ctrl	17	-	-	-
TG-405 x USG x N52	50	26	84	63
TG-405 x USG x N78	63	31	112	58
TG-405 x USG x N104	72	34	136	53
Fpr	0.660	0.640	0.616	0.895
CV	8.4	11.3	12.6	11.3
LSD	NS	NS	NS	NS

Appendix 12: Interaction effect between rice variety, type of urea and N rate on rice growth, yield components and grain and straw yields. *Kouto site, Season 2*

Interaction	Height (cm)	Number of tillers per hill	Length of panicles (cm)	weight of 1000 grains (g)	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index
IR-841 x PU x Ctrl	69.37	7.67	14.93	20.21	1150	1367	45.69
IR-841 x PU x N52	87.04	11.33	21.97	25.26	2083	2508	45.40
IR-841 x PU x N78	102.62	13.33	21.93	26.36	3642	4125	46.89
IR-841 x PU x N104	104.16	16.00	22.67	26.40	4308	4867	46.99
IR-841 x USG x Ctrl	69.27	7.67	15.63	21.48	1075	1325	44.79
IR-841 x USG x N52	88.86	12.00	22.43	26.71	2417	2800	46.34
IR-841 x USG x N78	108.87	15.33	22.24	27.61	3700	4125	47.31
IR-841 x USG x N104	106.77	15.67	24.37	27.31	4467	4842	47.97
TG-405 x PU x Ctrl	73.07	6.67	17.33	21.12	1058	1342	44.12
TG-405 x PU x N52	89.22	10.33	22.06	26.36	2425	2933	45.30
TG-405 x PU x N78	105.27	13.67	25.45	26.96	3850	4433	46.47
TG-405 x PU x N104	105.11	15.00	25.77	27.63	4408	4933	47.18
TG-405 x USG x Ctrl	70.07	7.33	17.12	21.07	1092	1325	45.19
TG-405 x USG x N52	94.34	14.33	24.03	26.93	2042	2342	46.57
TG-405 x USG x N78	108.27	16.33	25.73	27.70	3617	3967	47.66
TG-405 x USG x N104	108.37	16.67	25.39	27.60	4700	5050	48.20
Fpr	0.587	0.464	0.494	0.992	0.093	0.084	0.381
CV	3.6	9.5	6.6	6.1	7.9	8.0	1.5
LSD	NS	NS	NS	NS	NS	NS	NS

Appendix 13: effect between rice variety, type of urea and N rate on rice nitrogen uptake and nitrogen use efficiency. Kouto site season 2

Interaction	Nitrogen uptake (kg N ha^{-1})	Agronomy efficiency (kg kg N^{-1})	Physiology efficiency (kg kg N^{-1})	Nitrogen Recovery (%)
IR-841 x PU x Ctrl	17	-	-	-
IR-841 x PU x N52	39	18.0	96.9 a	40.6
IR-841 x PU x N78	51	31.9	154.5 c	43.6
IR-841 x PU x N104	60	30.4	157.5 c	40.6
IR-841 x USG x Ctrl	18	-	-	-
-IR-841 x USG x N52	44	25.8	109.1 ab	49.2
IR-841 x USG x N78	55	33.7	147.4 c	47.5
IR-841 x USG x N104	67	32.6	143.5	46.9
TG-405 x PU x Ctrl	17	-	-	-
TG-405 x PU x N52	39	26.3	134.2 bc	42.3
TG-405 x PU x N78	55	35.8	155.5 cc	49.1
TG-405 x PU x N104	63	32.2	150.5 c	45.1
TG-405 x USG x Ctrl	17	-	-	-
TG-405 x USG x N52	40	18.3	82.4 a	45.6
TG-405 x USG x N78	52	32.4	144.4 c	45.8
TG-405 x USG x N104	61	34.7	164.1 c	43.1
Fpr	0.575	0.106	0.015	0.925
CV	8.9	15.3	13.0	10.5
LSD	6.439	7.621	30.12	7.750