ASSESSMENT OF NITROGEN USE EFFICIENCY AND YIELD BASED ON NITROGEN RATE AND FERTILIZATION PRACTICES IN LOWLAND RICE (*Oryza sativa* L.) IN YEZIN, NAYPYITAW, MYANMAR

PHYU PYA LWIN

DECEMBER 2019

ASSESSMENT OF NITROGEN USE EFFICIENCY AND YIELD BASED ON NITROGEN RATE AND FERTILIZATION PRACTICES IN LOWLAND RICE (*Oryza Sativa* L.) IN YEZIN, NAYPYITAW, MYANMAR

A thesis presented by

PHYU PYA LWIN

to

The Postgraduate Committee of the Yezin Agricultural University
as a partial fulfillment of the requirements
for the degree of Master of Agricultural Science
(Soil and Water Science)

Department of Soil and Water Science
Yezin Agricultural University

DECEMBER 2019

The thesis attached hereto, entitled "**ASSESSMENT OF NITROGEN USE EFFICIENCY AND YIELD BASED ON NITROGEN RATE AND FERTILIZATION PRACTICES IN LOWLAND RICE (*Oryza sativa* L.) IN YEZIN, NAYPYITAW, MYANMAR**" was prepared under the direction of the chairman of the candidate supervisory committee and has been approved by all members of that committee as a partial fulfillment of the requirements for the degree of **Master of Agricultural Science (Soil and Water Science).**

Dr. Aung Kyaw Myint
Chairman, Supervisory Committee
Associate Professor and Principal
Kyaukse Campus
Yezin Agricultural University

Dr. Su Su Win
External Examiner
Director
Soil Science, Water Utilization &
Agricultural Engineering Division
Department of Agricultural Research

Dr. Swe Swe Mar
Member, Supervisory Committee
Lecturer
Department of Soil and Water Science
Yezin Agricultural University

Dr. Thu Zar
Member, Supervisory Committee
Lecturer
Department of Agronomy
Yezin Agricultural University

Dr. Kyaw Ngwe
Professor and Head
Department of Soil and Water Science
Yezin Agricultural University

Date …………………..

This thesis was submitted to the Rector of the Yezin Agricultural University and was accepted as a partial fulfillment of the requirements for the degree of **Master of Agricultural Science (Soil and Water Science).**

Dr. Nang Hseng Hom

Rector

Yezin Agricultural University

Date …………………..

DECLARATION OF ORIGINALITY

This thesis represents the original works of the author, except where otherwise stated. It has not been submitted previously for a degree at any other University.

Phyu Pya Lwin

Date …………………..

DEDICATED TO MY BELOVED PARENTS

U MIN LWIN AND DAW SAN KYI

ACKNOWLEDGEMENTS

First and foremost, I express my deep gratitude to Dr. Nang Hseng Hom, Rector, Yezin Agricultural University (YAU) for her kind permission and administrative support to this study.

I am delighted to express my gratitude to Dr. Naing Kyi Win, Director General, Department of Agricultural Research, Ministry of Agriculture, Livestock and Irrigation, for his kind permission to attend post-graduate degree.

I deeply acknowledge to Dr. Soe Soe Thein, Pro-Rector (Academic Affairs), YAU for her guidance and comments throughout the study. I wish to express my gratitude and appreciation to Dr. Kyaw Kyaw Win, Pro-Rector (Administration), YAU, for his kindness, valuable comments and best suggestions in this study.

Mindful thanks are extended to Dr. Kyaw Ngwe, Professor and Head, Department of Soil and Water Science, YAU, for his kind attention, encouragement, invaluable suggestions, comments and various kinds of support on this manuscript.

I would like to express my sincere thanks and appreciation to my supervisor Dr. Aung Kyaw Myint, Associate Professor and Principal, YAU (Kyaukse Campus), for his valuable guidance, patient supervision, sharing his knowledge, suggestion, kindness, encouragement throughout the study and untiring help which has been a source of motivation at all stages of the work.

My heartfelt gratitude is to my external examiner, Dr. Su Su Win, Director, Soil Science, Water Utilization and Agricultural Engineering Division, Department of Agricultural Research, for her invaluable guidance, suggestions, comments and critical reading of this manuscript.

I wish to express my heartfelt appreciation and gratitude to Dr. Swe Swe Mar, Lecturer, Department of Soil and Water Science, YAU, for her comments, invaluable suggestion, constructive and critical reading, evaluation of my thesis and various kind of support throughout the preparation of this manuscript.

I sincerely show my deep gratitude to Dr. Thu Zar, Lecturer, Department of Agronomy, YAU, for her kind and valuable comments and suggestions on my work to be a perfect one.

My heartfelt thanks also go to my lovely teachers, classmate friends, junior post-graduate students and the staff of Department of Soil and Water Science, YAU.

I would like to thanks go to the monk of Myaungmya Mway Taw Pariyatti monastery, Venerable U Vilasagga and Htamanthi, Ywathit, Theravada monastery, Ashin Nandana(M.A Thesis) for their support, praying with good will throughout the student life.

Last but not the least, my deepest and heartfelt thanks go to my beloved parents, U Min Lwin and Daw San Kyi, and my younger brothers Lieutenant Colonel Sai Nyan Win, Ko Win Latt Lwin, Ko Aung Ko Lwin and my beloved son Wai Yan Lin Tun and beloved daughters Eaint Su Myant and Pu Tu and for their never-ending love, constant encouragement, patience, financial and moral support and very kind understanding towards me throughout my life.

ABSTRACT

To ensure the achievable rice yield, adequate fertilization especially nitrogen (N) plays a crucial role in rice production. Nitrogen management for respective rice cultivars in specific paddy cultivating areas should be formulated to promote the sustainable and profitable rice production while improving N use efficiency and the environmental conservation. Field experiment were undertaken in dry season and wet season through using Yadanar Toe rice variety and Sin Thukha rice variety respectively to investigate the suitable N rate for optimal rice production and to determine N use efficiency of rice in the research farm of Yezin Agricultural University in 2017. Eight treatments including different rates and application methods of N fertilizer; T1 (No fertilization), T2 (0 kg N ha^{-1}), T3 (30 kg N ha^{-1}), T4 (77.6 kg N ha^{-1} as prilled urea, PU), T5 (100 kg N ha^{-1}), T6 (130 kg N ha^{-1}), T7 (160 kg N ha^{-1}) and T8 (77.6 kg N ha^{-1} as urea super granule, USG) were laid out as randomized complete block design with three replications. The highest grain yield was achieved from the application of 100 kg N ha^{-1} in both seasons; 8.2 ton ha^{-1} in Yadanar Toe and 4.6 ton ha^{-1} in Sin Thukha. In both seasons, the optimum grain yield was observed from the application of 77.6 kg N ha^{-1} as either PU or USG. The plateau and the reduction of grain yield occurred at 130 kg N ha^{-1} and 160 kg N ha^{-1}. The application of USG and the highest N rate provided higher N uptakes in both seasons irrespective of rice varieties. The efficiency of N use ranged from 4.5 to 13.5 in summer and from -0.3 to 13.4 in monsoon, and the highest N use efficiency (NUE) was obtained from the application of 100 kg N ha^{-1} in summer and the application of 30 kg N ha^{-1} in monsoon. The isotopic technique using ^{15}N labeled urea revealed that the best NUE was obtained from USG (77.6 kg N ha^{-1}) among different application rates and methods in summer.

Key words: Nitrogen rate, Nitrogen use efficiency, Nitrogen uptake, Urea super granule, ^{15}N labeled urea, Rice

CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

Figure **Page**

LIST OF APPENDICES

CHAPTER I
INTRODUCTION

1.1 Introduction

Rice (*Oryza sativa* L.) is the most important food crop of the world and a staple food for more than 3 billion peoples or more than half of the world's population. It has been growing over a hundred countries with a total harvested area of about 160 million hectares, producing more than 700 million tons every year (International Rice Research Institute [IRRI], 2010). The increasing world population and the need to produce more food are putting increasing pressures on soil and water resources (Food and Agriculture Organization [FAO], 2002). In Myanmar, the total rice sown area is 7.26 million ha and the annual production is 25.62 million ton with the average yield of 3.36 ton ha^{-1} (Central Statistical Organization [CSO], 2018). By 2050, the production of four primary foodstuffs including rice is estimated to expand up to 87% more of the existing production for rising population and changing diet (Kromdijk & Long, 2016).

The average yield of Myanmar was not comparable to yields of other countries and the insufficient fertilizer applications in Myanmar might be one of the reasons (Denning, Baroang, & Sandar, 2013; Lwin et al., 2015; Thwe, Kristiansen, & Herridge, 2019). The mean yield of irrigated rice near Nay Pyi Taw was in the range of 2.8 ton ha^{-1} from no fertilizer application to 4.3 ton ha^{-1} from NPK (nitrogen, phosphorus and potassium) fertilizer application (Min Thiha et al., 2001).

Nitrogen (N) is a major essential plant nutrient of all plants and key input for increasing crop yield (Salman et al., 2012). Nitrogen is the most important nutrient for rice plants (Yoshida, 1981). The number of tillers and panicles in one square meter and the total number of spikelet were increased by the application of N resulting in the increase of grain productivity of rice (Khan et al., 2010). In Myanmar, the use of N fertilizer is significantly lower than comparable countries of South East Asia (IRRI 2014), and may be the main cause of the low yield of rice (Denning et al., 2013; Lwin et al., 2015; Thwe et al., 2019).

The most common farmers' practice for N fertilizer applications in the Yezin area of Central Myanmar was the surface broadcasting at a total of 28-57 kg ha^{-1} of N as urea. The application method was often two equal split applications; at 10 days after transplanting (10 DAT) and at the panicle initiation (PI) stage.

IRRI recommends surface N application in 3 splits; 14 days after transplanting (14 DAT), at mid-tillering (20-35 DAT), and at PI (40-50 DAT) (IRRI, 2017). Several research findings indicated that as much as half of the urea that applied as surface broadcast to paddy fields can be lost to the atmosphere by ammonia volatilization (Humphreys, Muirhead, Melhuish, & White, 1987; Vlek & Craswell, 1979).

According to the survey report of ACIAR project SMCN/2011/046, rice yields of Myanmar was about 2.5 ton ha^{-1} on average while sufficient fertilizer application with good crop management produced 4 to 5 ton ha^{-1} of rice (Edis, Willet, Farquharson & Chen, 2014) . The report suggested that, the management of nutrients is an essential issue for crop production in Myanmar although other crop management practices can also be a limiting factor for optimal crop yield. In order to achieve the economically profitable yield of rice, N application should be specific and efficient for each crop variety in different agro-climatic zones. Optimal fertilization not only promotes the sustainable rice production system together with high nutrient use efficiency but also decreases the pollution to the environment. A portion of N from applied fertilizers could not be taken up by plants within a season and they may be immobilized in soil organic matter and some, lost to the environment. To overcome the N losses from an agricultural system, using of good management practices (GAP) in fertilizer application at right rate, right time, right place and right form should be conducted in matching crop demands. In case of N, it should be split into two or more times to get higher achievement (Chien, Prochnow, & Cantarella, 2009).

Huda et al.,(2016) reported high N use efficiency and yield benefits in paddy rice crops from the deep placement of urea briquettes in Bangladesh and similarly, Liu et al.,(2016) reported good effects of granular urea in China. Among them, use of urea deep placement (UDP) technology using urea super granule (USG) is popular around the world. Compacted USG, a granular shape with 1-3 g was used commonly for deep placement as an effective N source. One or more USG are deep placed (7-10 cm depth) by hand at the center of every four rice hills in rice soil during or after rice transplanting. USG essentially cuts off ammonia volatilization and also significantly reduces denitrification losses compared to surface application of prilled urea. USG requires only one time application after rice transplanting (Chien et al., 2009). It can save 30% N compared to prilled urea. It increases absorption rate, improves soil health and ultimately increases rice yield (Savant, Ongkingco, Zarate, Torrizo, & Stangel, 1991).

Until recent years, researchers and farmers were still looking for suitable practices and sources to get better N use efficiency (NUE) in crop production. Nuclear isotope technology is being used in nutrient management studies especially in the investigation of crop uptake, losses and nutrient use efficiencies of a fertilizer, and tracing and dynamics of its fractions. Since the 1950s and 1960s there had been significantly developed and used isotopic tracers in soil and fertilizer N research. Both ^{15}N enriched and ^{15}N depleted materials have been utilized as tracers in a wide range of crops, soils and environments (FAO, 2002). There has been limited information concerning with suitable N source and N management. So the experiment was carried out the following objectives.

Objectives

1. To investigate the suitable N rate for optimal rice production in YAU rice field.
2. To determine N use efficiency of rice varieties with different rates and application method of N in a rice field.

Hypothesis

Inadequate N application rates and improper application methods may not give optimal yield of rice. Correct rates and timing with suitable N sources may give high NUE and grain yield of rice.

CHAPTER II
LITERATURE REVIEW

2.1 The Role of Nitrogen in Rice Cultivation

The importance of N in plants and noted that N is a major part of all amino acids, a component of nucleic acids (DNA and RNA), used in chlorophyll, and essential for carbohydrate use. A healthy plant typically contains 2.5 to 4.0% N in the tissue (Brady & Weil, 1999).

Nitrogen (N) is the most critical externally added input for any crop production system. The half of the global population directly or indirectly depends on nitrogenous fertilizers for food supply. Today, rice, wheat, and maize are consuming more than 90% of total nitrogenous fertilizer used in cereals. Underuse of nitrogen is associated with lower crop production while overuse leads to several soil and environmental related consequences. Therefore, response to applied nitrogen and its use efficiency have to be monitored properly for obtaining the maximum potential and sustainable yield. Efficiency of applied nitrogenous fertilizers is very low due to its various losses i.e. volatilization, leaching, surface runoff and denitrification from soil-plant system. Therefore, the proper understanding of advanced soil and plant management practices which helps in enhancement of nitrogen recovery efficiency is one of the key factors to enhance crop output, decreasing cost of cultivation, and to maintain environmental quality which ultimately adds towards the goal of achieving long term sustainable production system (Yadav et al., 2017).

Irrigated rice is a production system that can be accessed at high levels of returns, but nitrogen is the main factor limiting yields of these systems (Segda, 2006). Rice commonly utilizes less than 40% of applied fertilizer nitrogen. Ammonia volatilization and denitrification losses are thought to be the major causes of this inefficiency. Losses by both of these mechanisms are apparently reduced considerably when the fertilizer is placed deep in the anaerobic soil layer. For transplanted rice, a practical means of deep placement is point placement of 1 to 3 g urea briquettes or super granules at 8 to 12 cm depth. This method and the laborious mud ball technique which it replaces have frequently proven superior to split application of urea in a series of coordinated experiments conducted recently in 10 Asian countries. However, on some sites, the super- granules produce much lower yields than split application.

Rice production is been requiring in large amount Nitrogen that it's heavy system losses when applied as inorganic sources in puddle field. It was observed that urea super granules (USG) can minimize the loss of N from soil and hence the effectivity increased up to 20-25%. Urea can be applied in different ways. Crystal urea is applied mostly as top dressing. But top dressing sometimes induces imbalance in yield components and decreases yield.

All plants utilize N in the form of NO_3^- and NH_4^+. It is most imperative element for proper growth and development of plants which significantly increases and enhances the yield and its quality by playing a vital role in biochemical and physiological functions of plant. Pivotal N is required in larger quantity about 1000 mg kg^{-1} dry matter, so, it is compulsory supplied to plants (Leghari et al., 2016).

2.1.1 Importance of rice

Rice is life, for most people living in Asia. Rice has shaped the cultures, diets and economies of thousands of millions of people. For more than half of humanity rice is life. Rice grows in a wide range of environments and is productive in many situations where other crops would fail. Most classifications of rice environments are based on hydrological characteristics (Huke, 1982).

Rice is a staple food for some 4 billion people of worldwide, rice provides 27% of calories in low and middle income countries. With expected population growth, income growth, and decline in rice area, global demand for rice will continue to increase from 479 million tons of milled rice in 2014 to 536-551 million tons in 2030. Historically, an important political objective in most rice-growing countries has been to achieve self-sufficiency in rice production and maintain price stability through domestic procurement and adjustment of stocks. In recent years this has been less necessary because the world rice market has become deeper and more stable (Dawe, 2002).

2.1.2 Rice production in Myanmar

Myanmar is the second largest country in Southeast Asia. The largest country in Southeast Asia is Indonesia. Due to its geographic size, it varies considerably both topographically and meteorologically. Annual precipitation and monthly mean maximum/minimum temperatures also show considerable variation over time and space, and are particularly affected by the summer monsoons associated with heavy rainfall. Myanmar has a long tradition of rice production. In the years immediately prior to World War II it was the largest rice-producing nation in the world, and it continues to be one of the ten largest rice-producing countries in terms of total yield (IRRI, 2002). Most major rice growing areas, such as the Ayeyarwady, Yangon and Bago Regions, are naturally provided with fertile deltaic alluvial soil and abundant monsoon rainfall.

Agriculture in Myanmar, dominated by paddy rice cultivation, generates a direct or indirect economic livelihood for over 75% of the population. Rice is grown throughout the country by resource poor rural farmers and landless agricultural laborers on small farms averaging only 2.3 ha in size (Okamoto, 2004). Although a shift to high yielding rice varieties (HYVs) in the 1980s was meant to increase production, average grain yields have stagnated at around 3.0 ton ha^{-1}. With an annual population growth rate of 2%, an increase in rice yield has become vital to both matching the rising caloric demand for this staple and contributing to the income of the rural poor. There exists only one recent comprehensive survey in the literature on rice production in Myanmar (Garcia, Garcia, Oo, & Hossain, 2000), but little is known about the actual inputs used and the overall constraints limiting rice productivity.

2.1.3 Nitrogen uptake of rice

Nitrogen uptake is the N concentration in plant tissues multiplied by dry matter accumulation by the plant part. N content is another term. The worldwide nitrogen use efficiency of cereal crops is estimated to be around 33% (Raun & Johnson, 1999). Rice can recover 53 to 75% of the N applied, depending on application time. NH_3 volatilization from urea accounts for 84 to 88% of the total N lost in rice and denitrification accounts for 6 to 10% (Wilson, Wells, & Norman, 1989). The 4R Nutrient Stewardship program promotes the right fertilizer source, right rate, right time, and right place (Bruulsema, Fixen, & Sulewski, 2016). Following these general rules in N management is important to maximizing crop N use efficiency and reducing N losses. Extensive field research has been conducted to characterize crop response to N fertilization strategies (Jokela & Randall, 1989; Norman, Helms, & Wells, 1992; Wilson, Wells, & Norman, 1994) and lab research has been conducted to understand the N cycle as influenced by environmental conditions (Clay, Malzer, & Anderson, 1990; Norman et al., 1992; Reynolds & Wolf, 1987).

Soil moisture, temperature, pH, and microbial activity can greatly reduce the efficiency of surface-applied urea. Urea is prone to substantial NH_3 volatilization if it is not incorporated quickly by either irrigation or rainfall. The amount of rainfall needed to incorporate urea is reportedly between 0.64 and 1.27 cm depending on soil texture (Meyer, Olson, & Rhoades, 1961). Urea can lose around 30% of the N applied in 3 day after application and up to 90% by 7 days via NH_3 volatilization if not incorporated (He, Alva, Calvert, & Banks, 1999).

Nutrient uptake is that the movement of nutrient to the plants. It refers to the quantity of solute, which is far away from the external medium. Nutrients generally exist in the kind of ions. They will be cations or anions. For ions to be absorbed to plant roots they need to be in contact with the basis of the root surface. Plants usually don't tend to accumulate higher amounts of NH4+ ions as a contrast to nitrate ions. Therefore, with the exception of some crops like as rice, toxicity symptoms commonly take place if crop plants are grown-up in NH4+ within the absence of nitrate. The nitrogen requirement for macro-molecule synthesis within the developing kernel is met by the mobilization of formerly assimilated N available in vegetative tissues and through direct uptake and assimilation of N throughout grain filling. Mobilization of earlier assimilated N has been recommended as the major supply of N for the kernel. The crop life cycle with respect to the management of N will be roughly separated into two most important phases occurring sequentially in some species or overlapping with others. Throughout the primary section, i.e. the vegetative section, young developing roots and leaves work as sink organs for the assimilation of inorganic N and also the synthesis of amino acids creating from the N pre-occupied before flowering so reduced via the nitrate assimilatory pathway . These amino acids are promoting the synthesis of enzymes and proteins mostly concerned with building up plant building and also the totally different parts of the chemical process machinery (Waqar et al., 2014).

2.2 N Cycle in Wetland Rice System

2.2.1 N dynamics in soil

Rhizosphere of a submerged lowland rice field may support aerobic N reactions such as nitrification, mineralization of organic N via oxidative deamination and biological N_2 fixation by aerobes and facultative anaerobes (Keeney & Sahrawat, 1986). N cycling in relation to soil-plant system is complex and dynamic due to variable impact of different factors (climate, soil, and plant factors) and their interactions (Ladha et al., 2003). It is sequence of various biochemical changes of N from its entry in living system to its final transformation back into its original state through several interdependent transformation and decomposition processes (Addition, transformation, losses and assimilation of N).

Addition of N to the soil-plant system either through organic sources or inorganic sources is the first and most essential step in N cycle. In most of the crop production systems, N is supplied in larger quantity through inorganic source (chemical fertilizers) due to its faster availability to plant while small quantity N is added through organic sources i.e. crop residues, organic manure, biological N fixation and organic manures (Manning et al., 2001).

Mineralization is simply the process where organic form of N get transformed into inorganic form of N (NO_3^- and NH_4^+) with the help of soil microbes (Pathak et al., 2003). Mineralization is essentially a two-step process. The first step of mineralization involves enzymatically mediated microbial hydrolysis of organic –N compounds into NH_4^+-N, termed as ammonification (Regmi & Ladha, 2006). In second step above transformed NH_4^+ is oxidized to NO_3^- with the help of soil microbes, this process called nitrification (Dobermann & Cassman, 2004).

2.2.2 Ammonification

Many of the transformations of nitrogen are mediated by bacteria that use different forms of nitrogen to fuel some of their metabolic processes. During the processes of decomposition, the nitrogen in proteins is transformed eventually to ammonia, (NH_3) or ammonium (NH_4^+) by certain kinds of bacteria. These processes are called ammonification. Nitrogen leaves the septic tank primarily as ammonium in leachate. Some of the ammonium becomes adsorbed to soil particles and is effectively immobilized from further transport.

2.2.3 Nitrification

Other kinds of bacteria change ammonia to nitrite. And still other kinds of bacteria can change nitrite to nitrate. These processes are called nitrification. Nitrification is an aerobic process. That means nitrification can occur only in the presence of oxygen. The septic tank ammonium that escapes adsorption is subject to nitrification in aerobic leaching field soils. In a flooded soil system because as soon as NO_3^- is formed it diffuses down to the reduced layer and is lost from the system by denitrification or reduced to NH_4^+ by dissimilatory NO_3^- reduction. Occurrence of nitrification is recognized as a mechanism of N loss via nitrification-denitrification in flooded soils and has led to the conclusion that NO_3^- is an inefficient source of N for submerged rice culture (Keeney & Sahrawat, 1986). Placement of fertilizer N in the reduced zone of a flooded soil reduces nitrification. While the NH_4^+ formed may diffuse to the oxidized layer, the amount susceptible to nitrification will be much less than if N fertilizer is applied to the surface. Also, application of fertilizer N when the rice root system is established and N is being rapidly taken up greatly reduces the availability of $NH_4^+$for nitrification. Use of nitrification inhibitors, such as nitrapyrin or dicyandiamide, should be helpful in retarding nitrification, particularly in lowland rice fields (Keeney & Sahrawat, 1986).

2.2.4 Denitrification

Microbial mediated reduction of nitrate form of N to variety of gaseous form of N (NO, N_2O and N_2) under anaerobic conditions is termed as de-nitrification (Bolan & Hedley, 2003). Bacterial species can take nitrate and change it back to nitrogen gas through a process called denitrification. Denitrification is an anaerobic process. This means it only takes place when no oxygen or extremely low concentrations of oxygen are available. Denitrification also requires a source of carbon. Some of the nitrate escaping the leaching field soils is denitrified in the unconsolidated soils and groundwater as it flows to the estuary.

Several factors including soil pH, organic matter content, temperature, O_2 diffusion, and nitrification rate affect the denitrification rate in a flooded soil. N_2O is not a significatnt gaseous product of denitrification loss in lowland rice soils (Keeney & Sahrawat, 1986).

2.2.5 Losses of N

Soil applied N is taken up and used by the crops for their growth and development but at the same time a significant part of this applied N can be lost from the soil plant-system through various mechanisms i.e. soil erosion, surface runoff, leaching, de-nitrification, ammonia volatilization (Yadav et al., 2017).

Soil erosion and surface runoff

N adsorbed on soil particles can be lost through wind as well as water erosion. N loss through wind erosion is more common in arid and semiarid climatic regions while, water erosion is most commonly reported mechanism of N loss in humid and sub humid areas. After a heavy rain surface applied nitrate can be dissolved in water and lost through the process of runoff (Fageria, 2002).

Leaching

In flooded soils with sandy texture, the losses of N due to leaching could be significant (Yadav et al., 2017). As nitrate form of N is mobile in nature and not strongly adsorbed on soil particles so it can be easily move beyond the soil profile through the process termed as leaching (Randall et al., 2003). Under these situations, nitrification inhibitors should be more effective than urease inhibitors in minimizing loss of NO_3^{-}. Perhaps the best answer to minimize leaching loss of N still lies in cultural practices such as split application of fertilizer N and puddling of the rice fields before planting. Slow-release sulfur-coated urea also minimizes N losses by leaching and maximizes N use efficiency.

Ammonia volatilization

The process of conversion of NH_4^+-N into NH_3 gas and its loss to the atmosphere is termed as ammonia volatilization. This mechanism of nitrogen loss is found to be more severe where organic manure and chemical nitrogenous fertilizers (NH_4^+ containing) is surface applied through broadcasting (Bolan & Hedley, 2003). Urea and urea based fertilizer when surface-applied and not incorporated immediately into the soil are more prone to volatilization losses. This mechanism of N loss is more severe in alkaline soil and warm sunny condition, under this condition as much as 20% of N may volatilize and lost to atmosphere within a week (Hutchinson et al., 2002).The NH_3 volatilization is significant as N loss mechanism in flooded rice soils. Ammonium can be leached more readily in a reduced than in an arable soil. Of the several factors that affect NH_3 volatilization, the pH of the floodwater has been recently recognized as the single most important determinant (Keeney & Sahrawat, 1986). In general, losses of NH_3 are higher in alkaline and calcareous soils and increase with an increase in soil pH, temperature and solar radiation but decrease with an increase in CEC of the soil and other cultural and management practices including the presence of rice canopy activities which decrease the amount of NH_3 in solution. Also, higher losses of volatile NH_3 are reported from urea fertilizer compared to other NH_4^+ sources because hydrolysis of urea provides alkalinity which can maintain or initiate volatile loss of NH_3. Among the soil characteristics, organic matter content as measured by organic C and total N account for the most variation in NH_4^+ production under anaerobic incubation. In addition to soil and environmental factors, the quantity and quality (C/N ratio) of organic residues added also affect the release of NH_4^+ in submerged soils. Ammonification is also affected by tillage and other operations used for preparation of lowland rice fields (Keeney & Sahrawat, 1986).

2.3 N Fertilizers

Nature provides available nitrogen for plant growth in the soil from decaying plant and animal matter. The atmosphere is 80 per cent nitrogen, but in this gaseous form it cannot be used directly by plants. Some nitrogen is converted from the air to a usable form by the bacteria found in the nodules on the roots of legumes. Certain soil organisms also have the ability to fix nitrogen for use by plants.

Commercial fertilizers carrying nitrogen in a readily available form, however, can be used with profit on most crops. Nitrogen fertilizer does the following: Stimulates growth of non legumes. Increase the active organic matter supply of the soil by speeding up the decomposition of dead roots. Provides available nitrogen for both grass and legume growth when the soil temperature is too low or the soil is too wet for natural nitrification processes.

Ammonium Sulphate

Pure ammonium sulphate contains 21.2 percent N and 27.5 percent sulphur. The ammonium sulphate sold for fertilizer has a guaranteed analysis of 20 to 21 per cent nitrogen in the ammonia (NH_3) form. It is a fine crystalline salt varying in color from white through various shades of gray. All of the nitrogen in ammonium sulphate, sometimes called sulphate of ammonia, is in the ammonia form. Ammonia nitrogen does not leach out of the soil as readily as nitrate nitrogen. For this reason it is a very good source of nitrogen, especially in the irrigated sections of the state.

Ammonium Nitrate

Ammonium nitrate fertilizer contains 32.5 to 33.5 per cent nitrogen. One-half of the nitrogen, about 16.5 per cent, is in the ammonia (NH_3) form and the other half is in the nitrate (NO_3^-) form. The ammonium nitrate on the market now is granular and varies in color from white to pink. Pure ammonium nitrate is a white, crystalline material that draws moisture readily and cakes so badly that it cannot be applied with a regular fertilizer drill.

Ammo-phos

Ammo-phos is the abbreviation for ammonium phosphate, a material containing both nitrogen and phosphorous. Several combinations can be made but represents two. They are 11-48 and 16-20. 11-48 is manufactured by combining ammonia and phosphoric acid. As the common name 11-48 indicates, this material contains 11 per cent available nitrogen in the ammonia form and 48 per cent available P_20_5. 16-20 is manufactured by combining phosphoric acid, sulphuric acid, and ammonia. It contains 16 per cent available nitrogen in the ammonia form, 20 per cent P_20_5, and about 14 per cent sulphur in the sulphate form. Many farmers and agricultural workers have noticed that 11-48 and 16-20 give better results on most crops than comparable amounts of straight nitrogen fertilizer and superphosphate.

Urea

This is a semigranular product analyzing 42 per cent nitrogen, an amount greater than that found in any other commercial solid nitrogenous fertilizer. The urea in this product is identical in chemical composition with that found in animal urine. This material is completely soluble in the soil solution, but it must be converted to ammonia and nitrates before it can be utilized by most crops.

Sodium Nitrate

Sodium nitrate sold as a fertilizer usually contains about 16 per cent available nitrogen, all in the nitrate (NO_3^-) form. All of the nitrogen is in the nitrate form; so it is immediately available to a growing crop.

Calcium Nitrate

Calcium nitrate, sometimes called "Norwegian saltpeter," Calcium nitrate sold as a commercial nitrogen fertilizer analyzes about 15.5 per cent available nitrogen in the nitrate form. It is granular in structure and has good spreading qualities, but has a tendency to draw moisture when it is exposed to the air.

Cyanamide

Calcium cyanamide is sold on the market under various trade names. Most of the cyanamide sold in contains 20 to 22 per cent nitrogen. It is black in color because it contains free carbon. The nitrogen in calcium cyanamide is just as resistant to leaching as the nitrogen in urea and ammonia fertilizers.

Anhydrous Ammonia

Ammonia is formed by combining nitrogen from the air with some source of hydrogen as the first step in manufacturing most forms of synthetic nitrogen fertilizer. Ammonia is commonly known as the gas used in commercial refrigeration. Under atmospheric conditions it is a gas but it can be compressed to a liquid. The compressed ammonia weighs five pounds per gallon and carries 81 to 82 per cent nitrogen, all in the NH_3 form. Each gallon then contains 4.1 pounds of nitrogen.

Aqueous Ammonia

This material is injected into the soil. The basic equipment is the same as described for anhydrous ammonia except that to maintain a constant pressure it is necessary that the material be pumped to the chisel points. Aqueous ammonia may also be applied by metering the material into irrigation water used for rill irrigation.

Nitrogen in complete fertilizers

The nitrogen carried in complete fertilizers may be supplied by any one or more of the nitrogen-carrying materials described. If most of the nitrogen is supplied in the nitrate form, precautions should be taken against possible leaching. If substantial quantities of nitrogen are applied as cyanamide or urea, ample time should be allowed for these materials to become available in the soil.

Organic nitrogen fertilizers

Dried blood, meat meal, bone meal, and other byproducts of the packing industry are sometimes used as nitrogen fertilizers. Most of these products, however, are used in complete fertilizer mixtures or in high protein animal feeds. The nitrogen content of these materials varies greatly and is considerably less than the nitrogen content of most of the inorganic or mineral nitrogen fertilizers. The organic nitrogen fertilizers from plant and animal origin are not soluble in water. Activated sewage sludge is another low-grade carrier of nitrogen that will be more readily available in the future (Leroy & Arthur, 1950).

Green manuring

A wide range of legume species has potential for green manuring. Legumes are superior green manure crops compared to non-leguminous crops because they have potential to fix atmospheric free N in the soil. Annual N accumulation by legumes ranges from 20 kg ha^{-1} to as much as 300 kg ha^{-1} (Vyn et al., 2000). For smart green manure crops, the plants should have some important characteristics viz. quick growing and short duration crops for easy adjustment into intensive cropping systems, capacity to produce larger dry matter; can fix atmospheric free nitrogen; and they should cultivated with minimum cultural practices (Sharma et al., 2011). Beneficial effects of these green manure crops depend largely on amount and quality of residue available, soil type and fertility status, soil acidification, micro-biological diversity, moisture status of the soil, and thermal regime (Mary & Recous, 1994). Soil N supply through biological nitrogen fixation (BNF) by associated microbial populations is the principal source of N for cereal crop production. The indigenous soil N supply in wetland rice may decline with intensive rice cultivation unless it is restored by BNF (Fageria et al., 2003). On the contrary green manure crops and leguminous cropping patterns can produce higher rice yield as compared to commonly practiced rice-wheat cropping pattern (Ali et al., 2012).

2.4 Use of Chlorophyll Meter in N Management

Nitrogen status of crops can be estimated through chlorophyll meter since most of plant nitrogen is found in chloroplasts hence, it is closely related to leaf chlorophyll content (Olesen et al., 2004). To quantify N status of crops the Soil Plant Analysis Development (SPAD) differently known as chlorophyll meter offers relative measurements of leaf chlorophyll content. Chlorophyll meters are able to self calibrate for different soils, seasons, and varieties. It is also recommended to assess the effectiveness of late applied nitrogen in standing crops to increase grain yield and protein content (Singh et al., 2012). SPAD meter based SSNM approach has been extensively demonstrated in Southwest Asia (China, India and Bangladesh). It is reported that compared with traditional local nitrogen management practices, SPAD meter based SSNM in rice crop can increases yield, REN, and net return to the tune of 7, 30, and 12% respectively (Dobermann et al., 2004).

2.5 Nitrogen Use Efficiency (NUE)

Nitrogen Use Efficiency is dynamic and complex term including a range of components. It’s a ratio that considers an output as the numerator and input (N applied) as the denominator. Scientific fraternity is measuring N use efficiency differentially under different situations. The common thing in all the indices is that they generalized idea about how efficiently N would used to produce the final product (Yadav, 2017). NUE is a dynamic and complex concept, affected by a number of factors, can be classified into three groups namely factors related to nitrogen demand, factors controlling the N supply to the plants and factors controlling the losses of N from soil-plant system (Yadav, 2017).

Nitrogen recovery can be improved through adoption of locally as well as scientifically available means of nitrogen management to ensure efficient use of agricultural inputs (chemical fertilizers, land, water, and crops) that will enhance beneficial use of N in crops and minimize its losses. Strategies/practices used for nitrogen management of crops should be focused on two core principles (1) either it enhance beneficial use of externally applied fertilizer nitrogen as well as native soil N during the growing season itself (2) either it conserve soil nitrogen by reducing the quantum of N losses through various mechanisms and ensure higher beneficial use of this conserved N by the subsequent grown crops of the production system (Balasubramanian et al., 2002).

2.5.1 Site specific nutrient management (SSNM)

SSNM is a concept which involves field specific N management strategies that includes quantitative knowledge of field specific variability in crop N requirement and expected soil N supplying power. The fundamental underlying assumption of this concept is to establish an optimum synchronization between supply and demand of N for plant growth (Giller et al., 2004). On the basis of when and what type of decisions are made, SSNM can be grouped in two categories, A) prescriptive SSNM, (2) corrective SSNM (Dobermann et al., 2004). In former approach of N management, the amount and its application time are analyzed prior to sowing based on N supplying power of the soil, expected crop N requirement for assumed yield target, expected N efficiency of fertilizer products in use. Contrast to this, corrective nitrogen management strategy involves use of diagnostic tools to assess nitrogen status of standing crop. The interpretation of these recorded data is serving as the basis for decisions about timing and quantity of N applications (Schroeder et al., 2000). Chlorophyll meters (SPAD), nutrient expert and leaf color charts (LCC) are the promising and gaining importance in recent years for corrective N management in cereals.

2.5.2 Integrated nitrogen management (INM)

INM involves optimum use of indigenous N components i.e. crop residues, organic manure, biological N fixation as well as chemical fertilizer and their complementary interactions to increases N recovery (Olesen et al., 2004). The proper understanding and exploitation of these positive interactions among the plant nutrient is keys for increasing returns to the farmers in terms of yield as well as soil quality and NUE of applied N (Aulakh & Malhi, 2004). The complementary interaction of N with secondary and several micronutrients could lead to considerable improvements in yield and NUE. Therefore, use of balanced and judicious use of nitrogen from all available means will lead to higher productivity due to complimentary effect.

2.5.3 Slow release fertilizer

The form of applied nitrogenous fertilizers has significant role in controlling various N losses hence, affecting nitrogen availability and recovery. Compare to amide and ammoniums containing N fertilizers, nitrate containing fertilizers are susceptible to leaching. But contrast to this, ammonium and amide containing fertilizers are more prone to volatilization loss than nitrate containing nitrogen fertilizers. A range of slow release fertilizers is now marketed which have the potential to reduce various N losses and improve NUE (Giller et al., 2004). These compounds can reduce N losses due to their potential to delayed N release pattern which may improve the synchronization between crop demand and that of soil N supply. Neem coated urea is widely used and demonstrated slow release N fertilizer in India. But, still controlled release fertilizer is accounted only 0.15% of the total N fertilizer consumption. High cost in manufacturing and non- availability are two principle reasons for limited use of these compounds by farmers from developing countries (Shivay et al., 2001).

2.5.4 Nitrification inhibitors

NH_4^+ ion can be adsorbed on soil colloids and retained for a longer period which provide an opportunity for higher nitrogen use efficiency by minimizing leaching and de-nitrification losses of applied N. Addition of nitrification inhibitors can check conversion of ammonium-N into nitrate-N and ensure higher concentration of ammonical form of nitrogen in soil medium, to increase NUE and crop yield (Shivay et al., 2001). Dicyandiamide (DCD), a commercially available and largely demonstrated nitrification inhibitor suitable for use in rice cultivation (Bharti et al., 2000). In India farmer barely used these fertilizer due to their high cost and limited availability.

2.5.5 Improved method of application

Among the various methods of N application, deep placement, use of super granules and foliar spray of N fertilizer can enhance the recovery of applied N fertilizer. Broadcasting of nitrogen fertilizers is very common practice leads to large N losses e.g. ammonia volatilization, results in lower nitrogen recovery (McBratney et al., 2005). Use of modified form of N fertilizer (urea super-granules) and deep placement of urea based fertilizers has been reported to enhance NUE. At Australia, from large scale demonstration it has been reported that recovery efficiency was 37% for broadcasting and 49% for deep placement of USG in rice; hence deep placement of N fertilizers can improve nitrogen recovery (Balasubramanian et al., 2002). Further, foliar feeding of nitrogen either through urea spray, can also improve NUE as it reduce different losses i.e. runoff, volatilization, immobilization and de-nitrification prior to being absorbed by the plant (Balasubramanian et al., 2002).

2.5.6 4R nutrient stewardship

The definition of BMPs varies considerably, but can best be described here as "practices which have been proven in research and tested through farmer implementation to give optimum production potential, input efficiency and environmental protection" (1). This definition comes from the fertilizer industry, and places emphasis on practicality and productivity, while at the same time including efficiency and environmental protection. It is from this background that fertilizer use practices were evaluated in the effort to come up with acceptable fertilizer BMPs. With this in mind the fertilizer industry has formulated and launched the Global 4R Nutrient Stewardship Framework as a means of linking science to practice, and supporting effective communications with all stakeholders (2-3). The 4R Nutrient Stewardship framework promotes the application of nutrients using the right source (or product) at the right rate, right time and right place (Figure 2.1). The framework was established to help convey how fertilizer application can be managed to ensure alignment with economic, social and environmental goals (Johnston & Bruulsema, 2014).

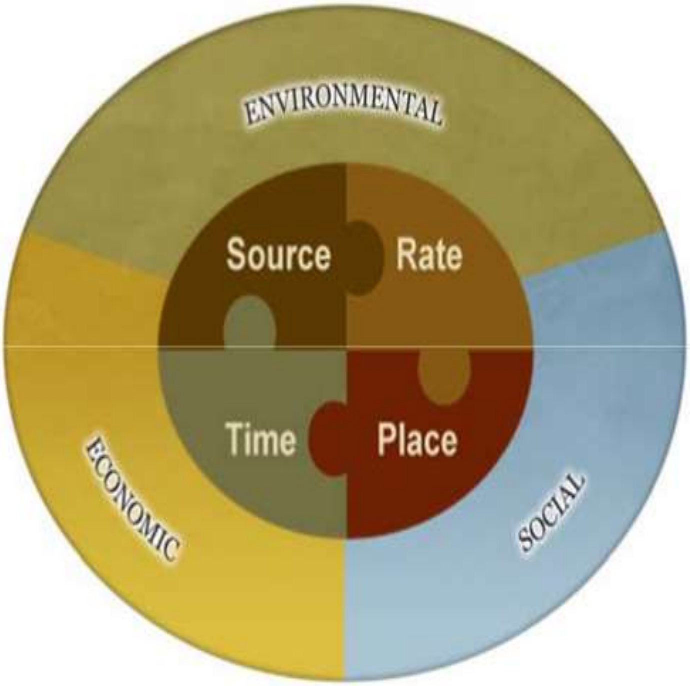

Figure 2.1 The 4R nutrient stewardship concept defines the right source, rate, time, and place for fertilizer application as those producing the economic, social, and environmental outcomes desired by all stakeholders to the plant ecosystem (Johnstona & Bruulsema, 2014)

Selecting the right source

Selecting a fertilizer source starts with an assessment of which nutrients are necessary. This information comes from some form of site diagnostics, such as soil or tissue testing, crop removal rates in harvested crops or deletion plot assessment. Fertilizer forms include fluid fertilizers, fertilizer suspensions and dry granular products in the form of straight grades (e.g., urea), compound fertilizers (e.g., 20-20-20) and bulk blends developed for a specific crop or location. Selection of a fertilizer source also requires attention to how it is to be managed. For example, if placed with the seed the salt index of the fertilizer, and tolerance of the crop, must be considered (Johnston & Bruulsema, 2014).

Selecting the right rate

Under or over application of nutrients posses a major challenge to agriculture production in most parts of the developing world. The selection of that fertilizer rate which is most likely to achieve optimized production and profit requires careful attention to a number of soil, crop and environmental parameters. The first step in establishing the right rate of fertilizer is understanded the yield commonly grown in a field, and the associated removal of nutrients from the field. Secondly, we need to somehow assess the soil's indigenous nutrient supplying ability, this is how much nutrients can we count on coming from the soil?

Soil testing has traditionally been the most commonly recommended means of assessing fertilizer rates. A soil test really involves 3 components, the sampling, the chemical analysis of the sample, and finally the recommendation based on the philosophy of the laboratory or advisory service. Plant based approaches to assessing nutrient requirements are also used in areas where access to soil testing is limited by either cost, excessive number of farm holdings or timeliness in multiple cropping systems. Factors affecting a recommendation include the crop to be grown, the soil nutrient supply, the yield goal of the farmer and environmental factors that impact on yield such as water supply and temperatures. In season tools like leaf color charts, SPAD meters and optical sensors have also been used to assess in-season N requirements of crops. These tools provide a means of assessing the crop nutrient supply based on the color or biomass production of the crop (Johnston & Bruulsema, 2014).

Right timing of application

The optimum timing of nutrient applications to crops ensures their adequate supply during peak uptake and critical growth stages .Timing also plays a major role in reducing the loss of nutrients into the environment by ensuring a supply when crop demand is high. Timing considerations are usually site specific, being impacted by the local environmental conditions and management practice capabilities of the farmer. The fertilizer form selected can often impact on optimal timing of application. The best example of this is where N is fall applied before the planting of a spring crop, with only ammonia N sources being recommended. Avoiding nitrate-N sources is critical to avoid over-winter losses of N. Phosphorus fertilizer application timing has largely been dealt with using basal, or planting time, application. This helps to ensure the P is available to early developing plants, as well as concentrating the fertilizer application close to the crop seeds minimizing any P fixation by the soil (Johnston & Bruulsema, 2014).

Right placement

Fertilizer placement can play a major role in nutrient uptake, especially with immobile nutrients and in those soils with a capacity to fix nutrients. So for nutrients, like P, where early season access to the nutrient is critical for cereal crop growth, placement in or near the seed row can have a major impact on crop response. This response occurs as a result of increased branching on the part of cereal crops when they intercept bands of P and N, increasing crop uptake (Murrell et al., 2009).

2.6 Urea Super Granules

The origin of 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 & Stangel, 1991). 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 & 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 & Hammond, 2004). 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. Deep point placement of USG decreases the de-nitrification process and minimizes urea concentration in flood water, thus reduce N loss and improve N absorption by the rice crop. A good alternative may be the deep placement of USG for higher yield of rice. USG was more efficient than PU at all respective levels of nitrogen in producing all yield component and in turn, grain and straw yields. (Mishra, Das, Dash, Jena, & Swain, 1999) conducted an experiment to study the effect of USG in wetland rice soil. Placement of USG 75 kg N ha^{-1} significantly increased both the grain and straw yields of rice compared to PU or USG broadcast.

Generally urea is broadcast in three equal splits- one as basal dose at the time of final land preparation, one at maximum tillering stage and the remaining one at prior to panicle initiation stage. But under this practice the efficiency of urea fertilizer in wetland rice culture is very low due to loss as ammonia volatilization, denitrification, and surface run-off and leaching. Numerous experiments have shown that the efficiency at which N is utilized by wetland rice is only about 30% of the applied fertilizer N and in many cases even less (Nguu & De Datta, 1979). However, the nature and magnitude of N loss largely depend upon the sources of N fertilizer and methods of N fertilizer application. This loss of N may be reduced by the deep placement of urea super granule (USG) instead of broadcasting prilled urea (PU). Point placement of USG can increase the efficiency of N utilization by rice in wet season (Roy, 1985).

One, two, three and four pellets of USG (1 g by weight and 11.5 mm in diameter) equivalent to 40, 80, 120 and 160 kg N ha^{-1}, respectively were placed manually at a depth of 6-8 cm at the center of four consecutive hills of two adjacent rows at 7 days after transplanting. That can be applied in the rice root zone at 8-10 cm depth of soil (reduced zone of rice soil) which can save 30% nitrogen than prilled urea, increase absorption rate, improve soil health and ultimately increase the rice yield (Savant et al., 1991). In south and South East Asia, rainfed and irrigated transplanted rice occupies nearly two thirds of the rice-growing area and produces more than 80% of the paddy rice. In these areas, prilled urea (PU) conventionally applied by farmers is very inefficiently used by transplanted rice largely because of serious losses (up to 60% of applied N) via NH_3 volatilization, denitrification, leaching, and/or runoff. In order to minimize N loss, especially loss due to denitrification. Because the deep-placed USG-N is well protected from various N loss mechanisms (except leaching) at the placement sites in soils and the spatial ammonium concentration gradients help to improve its plant availability, (1) uptake of N by rice plants (recovery) is significantly increased, (2) relatively smaller amounts of USG-N as nonexchangeable ammonium and/or immobilized organic N stay in soil, and (3) eventually N losses (gaseous and runoff) are markedly decreased. Thus, this practice is agronomically efficient as well as environmentally safe. Several hundred field trials conducted by national and international institutions in south and southeast Asia since 1975 have demonstrated the agronomic superiority of the deep placement of USG vis-a-vis split applications of PU in transplanted rice. In general, paddy yield responses to deep-placed USG tend to be more curvilinear than do those to split-applied PU, thus resulting in higher agronomic efficiency for deep-placed USG in the lower range of N rates (30–80 kg N ha^{-1}) than in the higher range of N rates (> 90 kg N ha^{-1}). Depending on agro-climate and N rates used, in general deep-placed USG can help to provide a saving of urea fertilizer of up to 65% with an average of 33% and can help to increase grain yields up to 50% with an average of 15% to 20% over that with the same amount of split-applied N as PU, especially in the lower range of N rates.

In using USG, consideration of the following factors should help to ensure agronomic efficiency of deep-placed USG and increase the chances of obtaining additional yield.

1. Soil factors: Only use in soils having a low water percolation rate and a CEC $\geqslant$ 10 meq 100 g^{-1} soil.
2. Plant factors: Give preference to short- to medium-duration dwarf rice varieties. For the long duration variety, basal deep-placed USG with a suitable topdressing of N as PU at panicle initiation stage would be helpful.
3. Management factors: Apply basally 30 to 60 kg USG-N ha^{-1} using only USG of the right weight (1–2 g urea $granule^{-1}$). Place one super granule for each four hills at 7–10 cm soil depth using the right plant population and modified spacing. Use modified 20 cm × 15 cm or 20 cm × 20 cm spacing to facilitate efficient placement of USG by hand or machine. Workers should always use the so-called traffic lane of the modified spacing for performing all post-transplanting field operations. When deep placement of USG is delayed after transplanting, extra care is necessary to close the holes left at the placement sites. When puddling is inadequate or improper and deep placement is done during transplanting, some care may be required to close the holes. (Koudjega ,2018)

2.7 Use of Isotope in Nutrient Management Study

Isotopes of a given element have the same atomic number (same number of protons in their nuclei) but different atomic weights (different number of neutrons in their nuclei).

2.7.1 Radioactive isotopes as tracers

Radioactive isotopes can be used to follow a particular element through various pathways and quantitative measurements may be made. They have the advantage of behaving in the same way that their stable counterparts do, but they can be readily traced. Radioactive isotopes can be likened to a color dye. They have a wide range of uses and are particularly valuable in plant nutrition research. The physical properties of a radioactive nuclide determine its usefulness as a tracer. The three most important are half-life, mode of decay and decay energy. If the half-life of a nuclide is very short, any compound labelled with it will be difficult to prepare, use and measure within the time of decay. The mode and energy of decay determine how the nuclide will be measured.

2.7.2 Stable isotopes

Stable isotopes are used in the same way as radioactive isotopes in soil/plant studies. Whereas radioactive isotopes emit particles which are captured in photomultiplier tubes and counted stable isotopes are separated from each other by passing a gas containing them through a strong magnetic field, which deflects them differentially according to their mass. Stable isotopes are elements that have variations in the number of neutrons in their atoms, but these atoms do not decay as with radioactive isotopes. For example, nitrogen has an atomic weight of 14 (^{14}N), with seven protons and seven neutrons, but other N atoms may have six (^{13}N) or eight (^{15}N) neutrons (and more in some cases). Nitrogen atoms with six neutrons (^{13}N) are unstable, emitting a positron (β+). With a half-life of less than 10 minutes, the practical application of ^{13}N is limited for anything other than short-term physiological experiments (TCS, 2001). Of the two stable isotopes of N, the lighter isotope ^{14}N is naturally much more abundant than ^{15}N. The isotopic abundance of the minor isotope (^{15}N) is usually expressed as a percentage of the total N present (atom% ^{15}N) (Table 2.1):

$$\text{Atom \% } ^{15}N = (^{15}N / (^{15}N + ^{14}N)) \times 100$$

The abundances of the stable isotopes of N are routinely measured by mass spectrometry. Emission spectrometry is also possible, but only for enrichments of 15N >0.05 atom% excess.

2.7.3 ^{15}N analysis by mass or emission spectrometry

Stable isotope analysis is a specialized field requiring sophisticated, well maintained equipment and highly skilled technicians. Generally, we recommend sending samples for analysis to a reputable, established laboratory. It is important to consult with the laboratory prior to preparing your samples for analysis as each analysis and laboratory will have very specific requirements. If samples are to be sent by mail or courier to another country for weighing and analysis, ensure that they are dry and enclose them in heat-sealed or ‘ziplocked’ plastic bags. Although small paper envelopes may appear to seal well, the shaking that samples experience during transport means that they tend to leak, with consequent risk of cross-contamination.

Table 2.1 Terms associated with ^{15}N stable isotope methods (TCS, 2001)

Term	Definition
Atom % ^{15}N	Abundance of ^{15}N atoms as a percentage of the total ($^{15}N/(^{14}N+^{15}N))\times 100$
Natural abundance	Atom% ^{15}N naturally present in materials
^{15}N abundance of atmospheric N_2	0.3663 atom% ^{15}N
$\delta^{15}N$(%)	Sample natural abundance expressed as parts per thousand relative to atmospheric N_2 1000×(sample atom% ^{15}N-0.03663)/(0.03663)
δ ^{15}N atmospheric N_2	0%
^{15}N-enriched nitrogen	Nitrogen with artificially elevated ^{15}N content
Atom %^{15}N excess	A measure of a sample's ^{15}N content above the atmospheric N_2 sample atom% ^{15}N-0.3663
Labelled nitrogen	Material generated with a specific ^{15}N enrichment
%Ndfa	The percentage of plant N derived from atmospheric N_2

2.7.4 Measurement of stable isotopes

Isotopes have identical chemical properties but some slightly different physical properties. Detection methods use one of these properties such as mass, emission spectrum, IR absorption. The most common and most precise method to measure stable isotopes is mass spectrometry. Mass spectrometer, Mass spectrometry (MS) is an analytical technique in which atoms or molecules from a sample are ionized, separated according to their mass-to-charge ratio (m/z), and then recorded. There is a wide range of mass spectrometers for different type of samples with different ionization and separation methods. This chapter focuses on instruments capable of determining the isotope ratios of light element stable isotopes (H, C, N, O and S). Instruments of this type are often called Isotope Ratio Mass Spectrometers (IRMS). The sample has to be converted to a gas (N_2, CO_2, H_2, SO_2) by means of a suitable preparation system. This gas is fed into the mass spectrometer where the ratios of the isotopes of interest are determined.

2.7.5 Isotopic method

The only direct means of measuring nutrient uptake from the applied fertiliser is through the use of isotopes. Extensive work has been conducted using N-fertilisers labelled with the stable isotope ^{15}N. The principal tracer isotopes used in soil-plant relationships studies are shown in Table (2.2). The chemical elements have been grouped into 3 categories. The first two groups refer to the essential plant nutrients i.e. macro and micronutrients, respectively, while the third one consists of a miscellaneous group of trace elements and others used in soil-plant relationships and related studies. It is often argued that the labelled fertilizers loose their identity in the soil since they became incorporated into the organic matter, soil solution, ion exchange processes, etc. resulting in just one pool of nutrients. The only basic assumption made when utilising isotopically labelled fertilizer is that the behavior of the isotope and the carrier is identical in the soil-plant system. In other words there should not be any isotope effect. The isotopic labelling of the fertilizer is best done during the manufacturing process by specialized firms.

Table 2.2 Isotopes useful in soil/plant studies (TCS, 2001)

Element	**Most abundant isotope**	**Tracer isotope**	**Characteristics**	**Typical Applications**
1-Macronutrients				
Nitrogen	^{14}N	^{13}N	R,$T_{1/2}$ =10 min β emitter(1.2 MeV) and γ(0.511 MeV)	Limited because of short half-life.Very short term studies on N_2 fixation,denitrification
		^{14}N	S,natural abundance=99.634% $^{15}N/^{14}N$=MS	N-14 enrished(N-15 depleted) materials for single season fertilizer use efficiency studies
		^{15}N	S,natural abundance=0.366% $^{15}N/^{14}N$ ratio either by MS or ES	Fertilizer N use efficiency,biological nitrogen fixation,N balance, N transformation in soils,N availability from organic-materials,animal nutrition studies

2.7.6 Isotopic techniques in N fertilizer use efficiency studies

In isotopic-aided fertilizer experiments, a labelled fertilizer is added to the soil and the amount of fertilizer nutrient that a plant has taken up is determined. In this way different fertilizer practices (placement, timing, sources, etc.) can be studied. The first parameter to be determined when studying the fertilizer uptake by a crop by means of the isotope techniques is the fraction of the nutrient in the plant derived from the (labelled) fertilizer, i.e.: fdff.

Often this fraction is expressed as a percentage, i.e.:

$$\% \text{ dff} = \text{fdff} \times 100 \text{(TCS, 2001)}$$

2.7.7 Calculations for experiments with ^{15}N

% 15N abundance is transformed into atom % ^{15}N excess by subtracting the natural abundance (0.3663 atom %N) from the % N abundance of the sample. Afterwards the following calculations can be made:

$$\%\text{Ndff} = \frac{\text{atom } \%^{15}\text{N excess}_{\text{plant}}}{\text{atom } \%^{15} \text{ excess}_{\text{fertilizer}}} \times 100$$

$$\%\text{fertilizer N utlization} = \frac{\text{Fertilizer N yield}}{\text{Rate of N application}} \times 100 \text{(TCS,2001)}$$

Since the isotopic method is normally complementary to conventional or classical methods in agricultural investigations, the research team should ideally consist of scientists not only trained in the use of the method but also skilled and experienced in field experimentation. Although it is known that isotopic techniques are a powerful tool in agricultural research, in deciding to use them to full advantage, one must consider if the following criteria are met:

— the isotopic method is the only way to solve a particular question or to obtain a particular piece of information, and

— if other methods are available, the isotopic method is a quick and cost effective means to obtain the needed information.

In the context of fertilizer studies, it is essential to determine first when and where the isotope method will be applied during the experimentation phase. Where the isotope method is utilized mainly in phase II to refine and improve existing fertilizer management practices. It is evident that the method must be used only when it is advantageous and cost effective under local conditions.

Therefore, correct application of the ^{15}N techniques is absolutely necessary to obtain high quality data and the valuable information desired. This, in turn, demands that adequate field experimentation techniques (field experiment layout, plot design, application of N labelled products, chemical and isotopic analyses, data calculations, etc.) be utilized (TCS, 2001).

CHAPTER III
MATERIALS AND METHODS

3.1 Site Description

A two-season field experiment was conducted at the research farm of Yezin Agricultural University (YAU), which is situated at 15˚52΄ N latitude and 96˚07΄ E longitude and 1644 feet above sea level, Nay Pyi Taw, Myanmar.

Before conducting the experiment, the physicochemical properties of soil were analyzed. Soil cores were randomly collected at 0-20 cm depth and a composite sample was used for characterization. The physicochemical properties of experimental soil were as showed in Table (3.1).

3.2 Experimental Arrangement

The experiment was conducted continuously two seasons; summer season (February to June) and monsoon season (June to October) in 2017. The rice (*Oryza sativa* L.), varieties Yadanar Toe (125 days) in summer season and Sin Thukha (140 days) in monsoon season, were used as tested variety. Twenty-day-old seedlings were transplanted with the spacing of 20 cm × 20 cm in both seasons. Standard agronomic practices for rice were applied in this experiment.

3.3 Experimental Design, Treatments and Layouts

The experiment was laid out in a randomized complete block design with 3 replications (Figure 3.1). Treatments were shown in the Table (3.3).

Treatment 1 was the control with no fertilizer application. Treatments 2 to 8 were N application rates and application methods (Table 3.3). Nitrogen fertilizers in respective treatments were equally split into two times at (10 DAT) and (60 DAT). In T8, a different N source, urea super granule (USG), was applied and each USG weighed about 2.7 g. It was applied only once to a depth of 5 - 7 cm into the soil between four alternative hills at 10 DAT.

Except T1, all treatments received 25 kg P ha^{-1} as triple super phosphate fertilizer and 75 kg K ha^{-1} as muriate of potash fertilizer. All P fertilizers were applied as basal but K fertilizers were equally split into three times as basal, at active tillering and panicle initiation (PI) stages. To avoid the nutrient limitation, 25 kg ha^{-1} of gypsum was applied as basal. For Zn fertilization, root dipping of rice seedlings was performed in a 2% $ZnSO_4$ solution just before transplanting.

Table 3.1 Physicochemical properties of the experimental soil before cultivation

Properties	Values	Range
Soil Texture		
Sand (%)	64.2	
Silt (%)	8.5	Sandy loam
Clay (%)	27.3	
pH	5.43	Moderately acid
Electrical Conductivity (dS m^{-1})	0.09	Non saline
Total N (%)	0.08	
Available N (ppm)	77	Medium
Available P (ppm)	17.1	Medium
Exchangeable K (ppm)	109	Low
Cation Exchange Capacity (meq 100 g^{-1})	4.4	Very low
Organic carbon (%)	1.1	Low

Table 3.2 List of soil and plant analyses and methods used for analysis

Analytical Item	Analytical Method	Remark
Soil texture	Pipette method (Day, 1965)	Soil
Soil pH	1:5 (soil: water) pH meter	Soil
Electrical Conductivity	1:5 (soil: water) EC meter	Soil
Cation Exchange Capacity	Bascomd's method (Chapman,1965)	Soil
Organic Carbon	Walkley and Black method (Mc Leod,1973)	Soil
Total Nitrogen	Modified Kjeldahl Digestion method (Ohyama et al., 1991)	Soil and plant
Available Nitrogen	Alkaline permanganate method (Bremner, 1965)	Soil
Available Phosphorus	9C-Olsen's P-Malachite green (Olsen and Dean, 1965)	Soil
Available Potassium	1 N Ammonium acetate extraction (Pratt, 1965)	Soil

Table 3.3 Treatments and their descriptions

Treatment name	N Rate (kg N ha^{-1})	Form	^{15}N isotope Treatment*	Time of application
T1	No fertilizer		-	-
T2	0		-	-
T3	30	Prilled urea	+	2 times (at 10 and 60 DAT)
T4	77.6	Prilled urea	+	2 times (at 10 and 60 DAT)
T5	100	Prilled urea	-	2 times (at 10 and 60 DAT)
T6	130	Prilled urea	-	2 times (at 10 and 60 DAT)
T7	160	Prilled urea	+	2 times (at 10 and 60 DAT)
T8	77.6	USG	+	1 time (After transplanting)

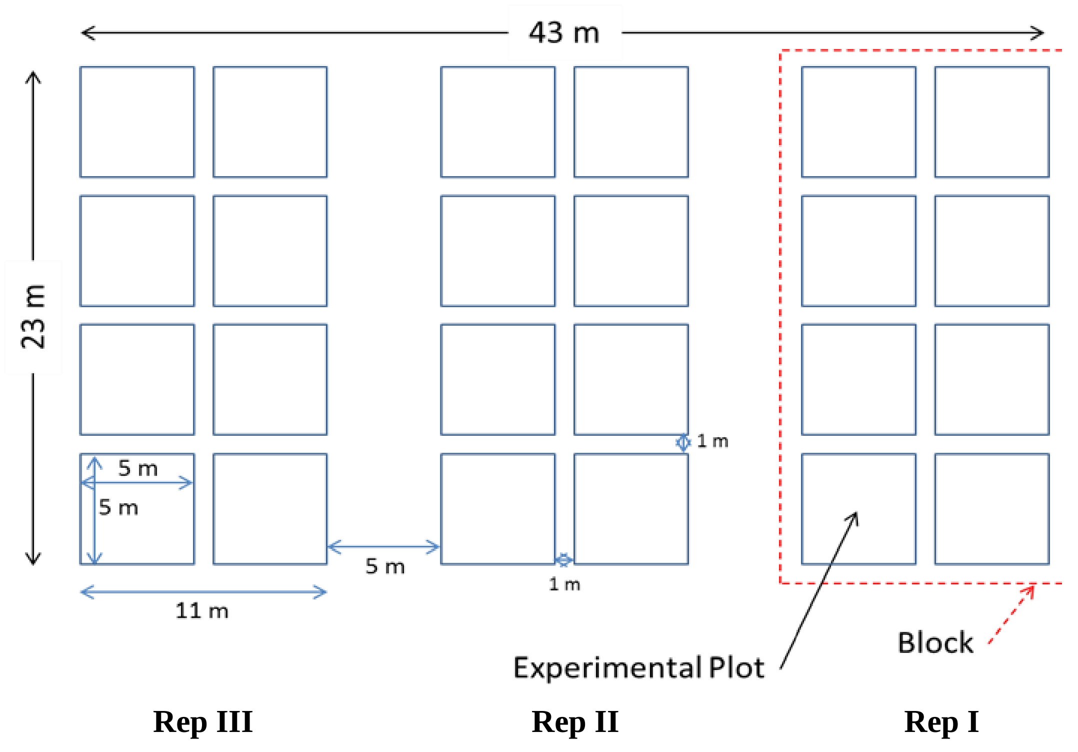

Figure 3.1 Experimental Layout Design

The individual plot size was 5 m × 5 m enclosed with double band. Experimental plots were 1.0 m away from each other to prevent contaminations such as mixing fertilizer during irrigation or drainage. Replications were separated by 5.0 m. The total experimental area was 989 m^2.

3.4 Data Collection

3.4.1 Growth parameters

During the growing season, agronomic characters such as, plant height, number of tiller per hill and chlorophyll meter (SPAD meter) value were recorded weekly from 30 DAT to harvest. Each parameter was measured from five random samples. SPAD value was recorded using a SPAD-502 meter (Minolta Co., Japan).

3.4.2 Soil and plant sampling

During the growing seasons, (T2, T4, T5, T7 and T8) were selected to analyze soil mineral N and plant uptake. The T2 was selected because it was zero N application which can be used for comparing the effect of N treatments. T4 and T8 were selected because these treatments used the N from two different sources with the same rate (prilled urea and USG of 77.6 kg ha^{-1}). The T5 was selected because it was the medium N rate (100 kg ha^{-1}) and T7 was the highest N rate (160 kg ha^{-1}).

Soil samples and plant samples were collected from two layers: 0-10 cm and 10-20 cm, at 30 DAT, 60 DAT, maturity and harvest to determine mineral N (NH_4- N) content of the soil.

Soil sample collection was undertaken from selected treatments Plant samples were also taken from selected treatments (T2, T4, T5, T7 and T8) at 30 DAT, 60 DAT, maturity and harvest of both summer and monsoon growing seasons to determine dry matter yield and analyze total N content. Then N uptake of rice plants was calculated in respective growth stages. Two hills of rice plants were removed from sampling area setting to ensure each sampling point was surrounded by border plants.

3.4.3 Yield and yield components

At harvest, data of yield and yield components were recorded and calculated for the following variables;

1) Grain yield (ton ha^{-1})
2) Straw yield (ton ha^{-1})

3) Number of panicle per plant
4) Number of spikelet per panicle
5) Filled grain (%)
6) 1000 grain weight (g)
7) Harvest index

The harvest area (1.8 m × 1.8m) was set in the middle of each experimental plot. Manual harvesting using a sickle was carried out in this experiment. Total fresh weight of straw and grain were recorded, and all grain samples were sun-dried while subsample of straw was oven-dried at 70°C. Immediately after the dry weight of grain was measured, its moisture content was determined using a grain moisture meter. Grain dry weight was then adjusted to 14% moisture for the calculation of grain yield. Yield component characters mentioned above were recorded from 6 rice hills inside the harvest area following standard practices mentioned in (Dobermann & Fairhurst, 2000).

Harvest index of each treatment was calculated by the following equation.

$$\text{Harvest Index} = \frac{\text{Economic yield (grain yield)}}{\text{Biological yield (grain yield + straw yield)}}$$

(Fageria, 2016)

3.5 Nitrogen Use Efficiency

Nitrogen use efficiency was calculated according to the following equation for both season.

$$\text{Nitrogen Use Efficiency} = \frac{\text{Yield fertilized-Yield unfertilized}}{\text{fertilizer N applied}}$$

(Cassman, Gines, Dizon, Samson, & Alcantara, 1996)

Furthermore, the NUE was also investigated using isotopic method. The preparation and procedure were as followed.

The ^{15}N-labeled fertilizer was applied to the micro-plot with the respective rates only in treatment 3, 4, 7 and 8. A steel plate micro-plot (80 cm length × 40 cm width × 40 cm height) was installed inside the selected plot so that it was placed into the soil to have 20 cm above ground and 20 cm below ground to protect the movement of ^{15}N-labeled urea across the plot.

Plant samples from micro plots were taken at harvest. The samples were placed air dry and finely ground. And then, these sub plant samples were taken and sent to laboratory of school of Agriculture and Food, Faculty of Veterinary and Agricultural Science, University of Melboure, Australia to analyze by ^{15}N dilution method using Mass spectrometer.

3.6 Statistical Analysis

Analysis of variance (ANOVA) for observed data was undertaken using a statistix (8^{th} version) software and treatment means were compared by least significant difference value (LSD) at 5% level.

3.7 Weather Data of Yezin

Monthly temperature and rainfall data of Yezin were taken from Yezin Meteorological Station for two rice seasons in 2017.

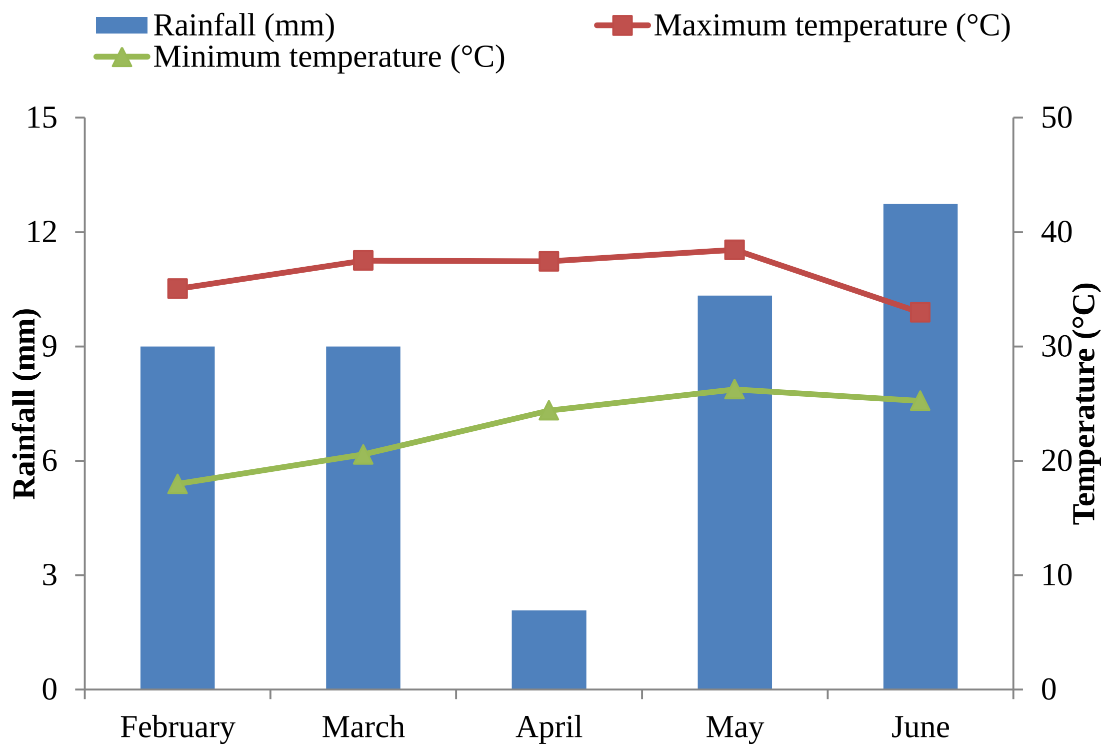

Figure 3.2 Monthly maximum and minimum temperature and monthly rainfall of Yezin during summer season rice, 2017

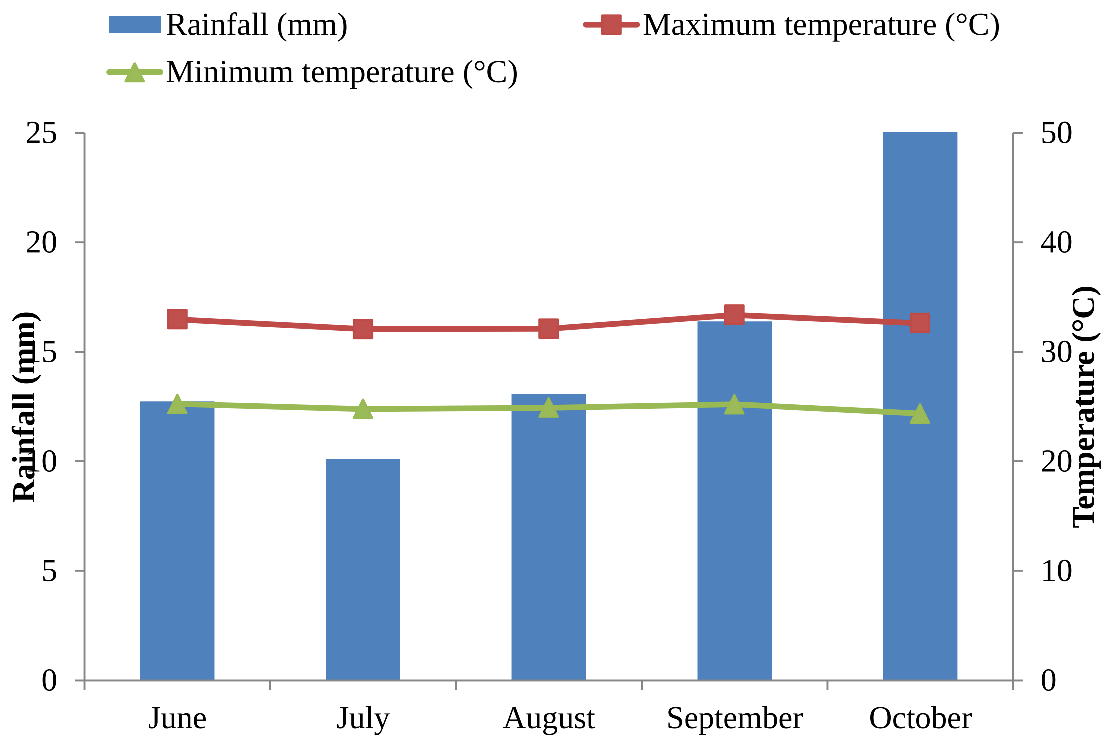

Figure 3.3 Monthly maximum and minimum temperature and monthly rainfall of Yezin during monsoon season rice, 2017

CHAPTER IV
RESULTS AND DISCUSSION

4.1 Assessment of Yield and Nitrogen Use Efficiency based on Nitrogen Rates and Fertilization Practices in Lowland Rice (*Oryza sativa* L.) at Yezin, Naypyitaw, Myanmar in Summer Season

4.1.1 Plant growth parameters at weekly interval

(a) Plant height

The plant height of Yadanar Toe in summer season (February-June, 2017) is shown in Figure (4.1). There was no significant difference in plant height of different N fertilizer treatments in each week except the fourth and sixth weeks Figure (4.1). In the fourth week, T8 (77.6 kg N ha^{-1}as USG) gave the highest plant height (86.6 cm) which was statistically higher than other treatments except T7 (160 kg N ha^{-1}). In the sixth week, the same result of plant height as the fourth week was observed.

In fourth week and sixth week, plant heights were coincident with early and mid-tillering stages of the summer rice. Rice plant needs much N at early and mid-tillering of active growth period to increase rice growth and the number of panicle (De Datta, 1986). As N fertilizers except USG were applied to the rice field with two equal splits at 10 DAT and 60 DAT, plants received only half of the N dose at fourth week and the full dose at sixth week. At fourth and sixth weeks, plants received N efficiently from USG treatment and large N amount from 160 kg N ha^{-1} treatment and therefore, they might contributed resulting in the higher plant heights (Appendix 1)

(b) Tiller number per plant

Among the treatments, there was no significant difference of tiller numbers of Yadanar Toe rice in summer season Figure (4.2). The number of tillers per plant ranging from (19 to 22) and second week gave the highest tiller numbers in this trial conducted in summer season. Throughout the season, T5 (22) and T8 (22) were higher than other treatments (Appendix 3). In the last week, the number of tiller per plant reduced to 13-16. The gradual reduction of tiller numbers occurs when young tillers fail in competition for assimilates with developing panicles and their growth is eventually suppressed (Fageria & Baligar, 2001).

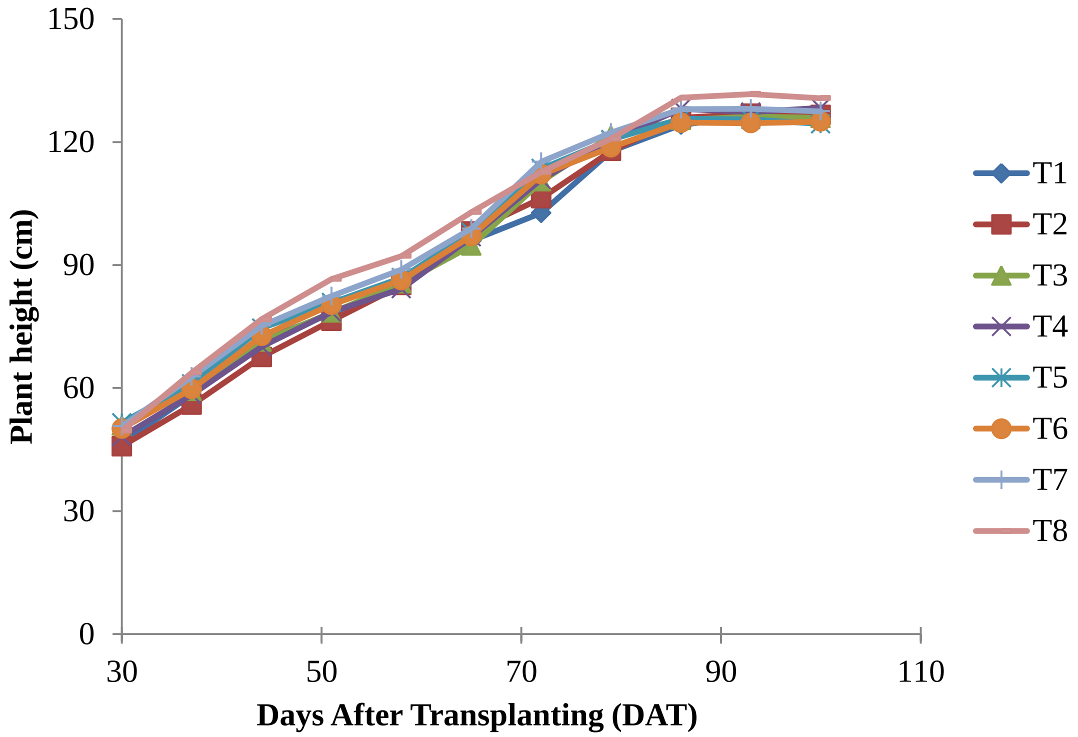

Figure 4.1 Plant height (cm) of Yadanar Toe grown as summer at YAU research farm in 2017

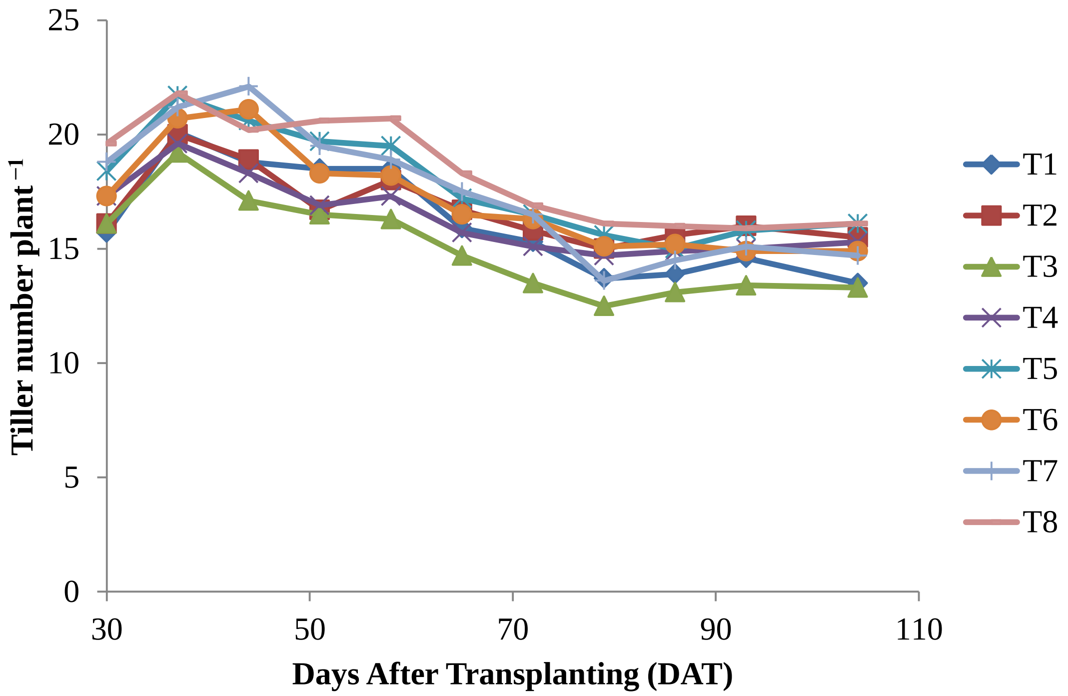

Figure 4.2 Number of tillers per plant of Yadanar Toe grown as summer at YAU research farm in 2017

(c) SPAD value

Chlorophyll meter readings (SPAD value) given by the treatments were significantly different at seventh, eighth and last weeks of measurement Figure (4.3). No significant difference of SPAD value was found among different treatments in other weeks (Appendix 5).

In the seventh week, the highest readings (40) were resulted from T5, T6 and T7 along with N fertilizers of 100, 130 and 160 kg ha^{-1}, respectively but, they were not statistically different from T4 and T8 (77.6 kg N ha^{-1} of both prilled urea and USG). T1, T2 and T3 provided the lowest SPAD value (35-36) in seventh week in this trial.

In the eighth week, the highest SPAD value was observed in T4, T5, T6 and T7 while the lowest in T1, T2 and T3. In the last week, T1 and T2 with no N fertilizer showed the lowest SPAD values however, T4, T5, T6, T7 and T8 with N rates ranging from 77.6 to 160 kg ha^{-1} gave the highest values.

The SPAD values increased with the increasing trend of fertilizer N rate (Lin, Zhu, Chen, Cheng, & Uphoff, 2009). The SPAD values can lie from 25 to 44 depending on N uptake and growth stage of rice. It is well believed that there are many factors to affect the SPAD values such as growth stage, variety, leaf thickness, plant density, soil and/or climate (Turner & Jund, 1994). The threshold value of 35 is revealed for transplanted dry season rice (Balasubramanian, Morales, Cruz, & Abdulrachman, 1998). In the present study, the SPAD value of rice leaves were found to be above the threshold level in all N treatments including zero N plots.

4.1.2 Soil, plant sampling and analysis

(a) Mineral N content (NH_4-N) of soil at 30 DAT, 60 DAT, maturity and harvest

Mineral N contents of soils collected from 0-10 cm and 10-20 cm depths at 30 DAT, 60 DAT, maturity and harvest stages were presented in Figure (4.4). At 30 and 60 DAT, no significant difference in mineral N content of soils was found among different N treatments in both 0-10 and 10-20 cm depths. Mineral N contents collected at 30 DAT ranged from 15 to 28 mg kg^{-1} at 0-10 cm and from 9 to 24 mg kg^{-1} at 10-20 cm. In each treatment of this stage, the amount of mineral N content was found higher at 0-10 cm compared to 10-20 cm.

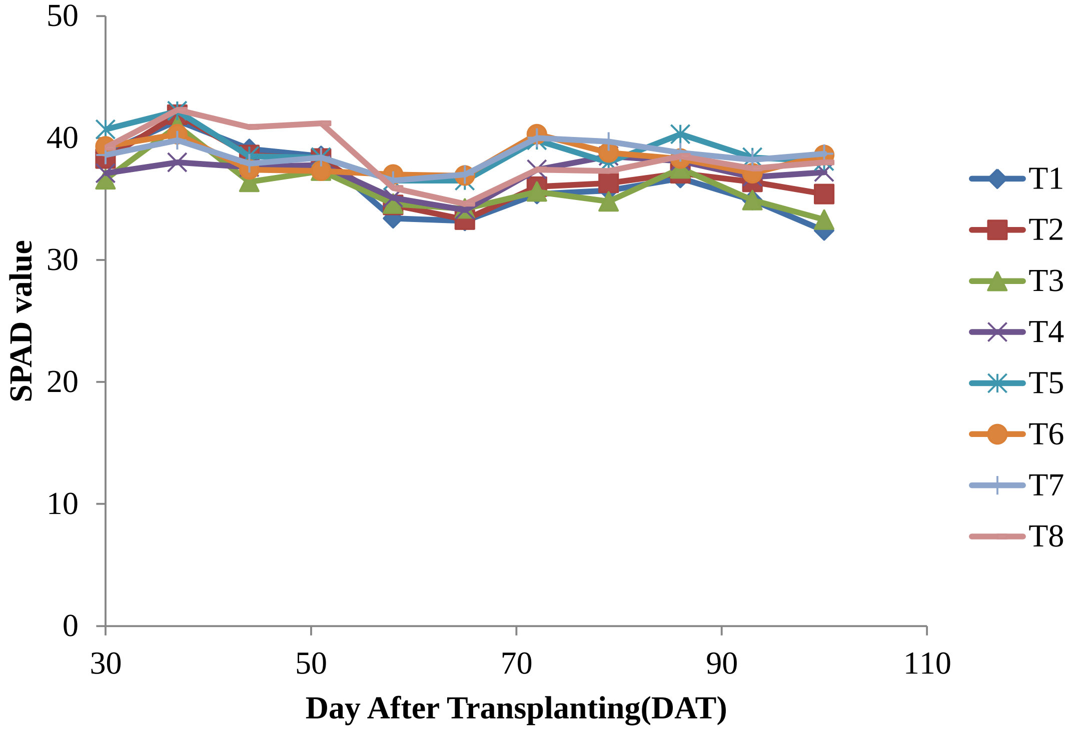

Figure 4.3 SPAD value of Yadanar Toe grown as summer at YAU research farm in 2017

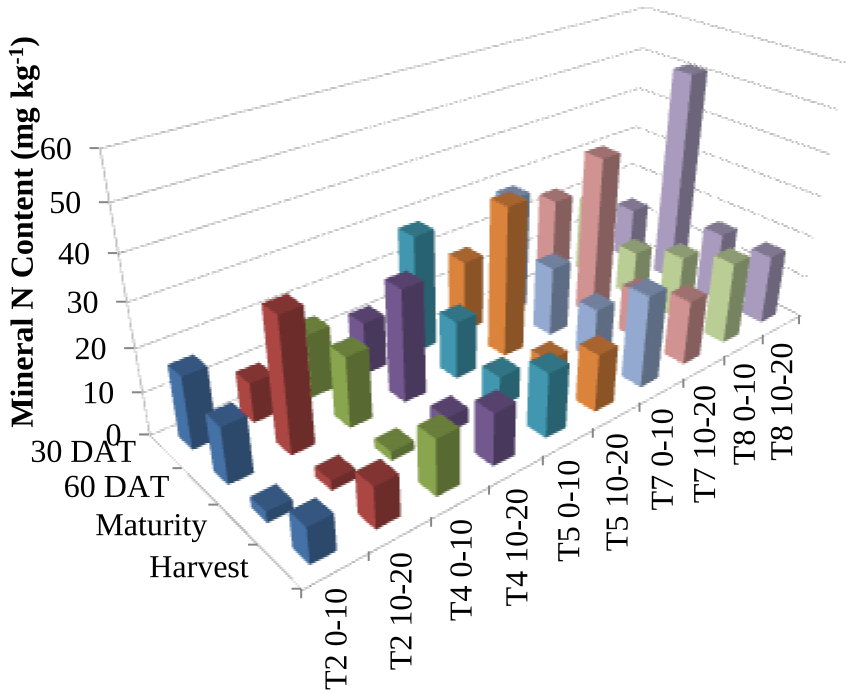

Figure 4.4 Mineral N content (NH_4-N) of soil at 30 DAT, 60 DAT, maturity and harvest stages of Yadanar Toe grown as summer at YAU research farm in 2017

At 60 DAT, mineral N content of soils ranged from 9 to 17 mg kg^{-1} at 0-10 cm and from 26 to 41 mg kg^{-1} at 10-20 cm. In each treatment of this stage, the amount of mineral N content was found higher at 10-20 cm compared to 0-10 cm.

Mineral N content of soil collected at maturity stage of Yadanar Toe ranged from 2.1 mg kg^{-1} to 15.4 mg kg^{-1} at 0-10 cm depth and from 2.3 mg kg^{-1} to 16.8 mg kg^{-1} at 10-20 cm depth Figure (4.4). N application positively related the mineral N content of soil at maturity stage in both soil layers. Despite the same rate of N application (77.6 kg N ha^{-1}), Urea Super Granule (T8) showed higher mineral N content than Prilled Urea (T4) in both soil layers. At 0-10 cm depth, the application of 160 kg N $ha^{-1}$was responsible for the highest mineral N content (15.4 mg kg^{-1}) which was not significantly different from that of 77.6 kg N ha^{-1}as USG. At 10-20 cm depth, the highest mineral N content of soil was left by the application of 77.6 kg N ha^{-1}as USG followed by the application of 160 kg N ha^{-1}.

\As small portion as 30% of N applied is consumed by irrigated rice and the remaining vast amount is lost through various processes (Craswell & Vlek, 1983). In the case of USG applied to the reduced zone, the large amount of N is ammonium form that is less mobile than nitrates in soil. Consequently, the majority of N applied using USG is available to the crop throughout the growing period (Kapoor et al., 2008). The loss of USG is about 4% of the N applied while it is about 35% from the practice of urea broadcasting (Lal & Stewart, 2014).

At harvest, different N treatments affected significantly on the amount of mineral N left in the soil at 0-10 cm and 10-20 cm layers. At 0-10 cm layer, the amount of available N remained was the highest (21.6 mg kg^{-1}) in T7 which did not differ with from that of T8. T2 left the lowest amount of mineral N (8.3 mg kg^{-1}) at 0-10 cm depth. At 10-20 cm layer of soil at harvest, mineral N contents left by T7 and T8 were not statistically different among each other but they were standing high compared to other treatments. The lowest amount of mineral N (9.6 mg kg^{-1}) was given by T2 at 10-20 cm depth.

When comparing mineral N contents of soil throughout the growing season, the maturity stage had the lowest mineral N range 2.5 to 15.4 and 2.3 to 16.8 mg kg^{-1}, respectively at both layers. It may be due to the gradual decreases in the soil solution NH_4-N content during the rice growth stage (Yana et al., 2018).

(b) Dry matter and N uptake of rice during the cropping season

Dry matter yield of Yadanar Toe at 30 DAT, panicle initiation, maturity and harvest were shown in relation to selected treatments: T2, T4, T5, T7 and T8 (Figure 4.5). Dry matter yield of Yadanar Toe rice plant ranged from 0.4 to 0.9 ton ha^{-1}at 30 DAT, from 4.5 to 6.3 ton ha^{-1} at panicle initiation, from 12.8 to 17.7 ton ha^{-1} at maturity and from 10.9 to 13.7 ton ha^{-1} at harvest. The dry matter yield was the maximum at maturity stage and declined at harvest.

The highest dry matter accumulation (15.5 ton ha^{-1}) was observed at 95 days after transplanting (maturity) and the dry matter accumulation increased statistically with different N treatments in all growth stages of rice (Chaturvedi, 2005). This finding was partly in line with the current study in terms of crop growth stage which gave the highest dry matter yield. The dry matter yield of rice in the current study was comparable to Chaturvedi (2005)'s finding.

Dry matter yield of different N treatments was found to be significant at 30 DAT and maturity stages ($P<0.05$). At 30 DAT, dry matter yield given by T8 was the highest (0.93 ton ha^{-1}) but it did not differ with that of T4 and T7. At maturity, T8 was the highest dry matter yield (13.7 ton ha^{-1}) and the rest treatments were not significantly differ.

Nitrogen uptake of Yadanar Toe was significantly different among N treatments at 30 DAT, panicle initiation, maturity and harvest stages at $P<0.05$ Figure (4.6). At 30 DAT, the highest N uptake (29 kg ha^{-1}) was found in T8 (77.6 kg N ha^{-1} as USG), which was not statistically different from T4 (77.6 kg N ha^{-1} as prilled urea). T2, T5 and T7 (0, 100 and 160 kg N ha^{-1}, respectively) were not significantly different from each other in N uptake.

At panicle initiation stage, T8 (77.6 kg N ha^{-1} as USG) contributed the highest N uptake, 127 kg ha^{-1}, followed by T7 (160 kg N ha^{-1}) whose N uptake was 108 kg ha^{-1}. The amount of N uptake given by treatments T2, T4 and T5 were not statistically different from panicle initiation stage.

The maximum N uptake (200 kg ha^{-1}) was observed in plants receiving 77.6 kg N ha^{-1} as USG at maturity stage and it was followed by the amount of N uptakes given by T5 and T7 (100 and 160 kg N ha^{-1}, respectively). Zero N and 30 kg N ha^{-1} application were found to take up the least amount of N among different N treatments.

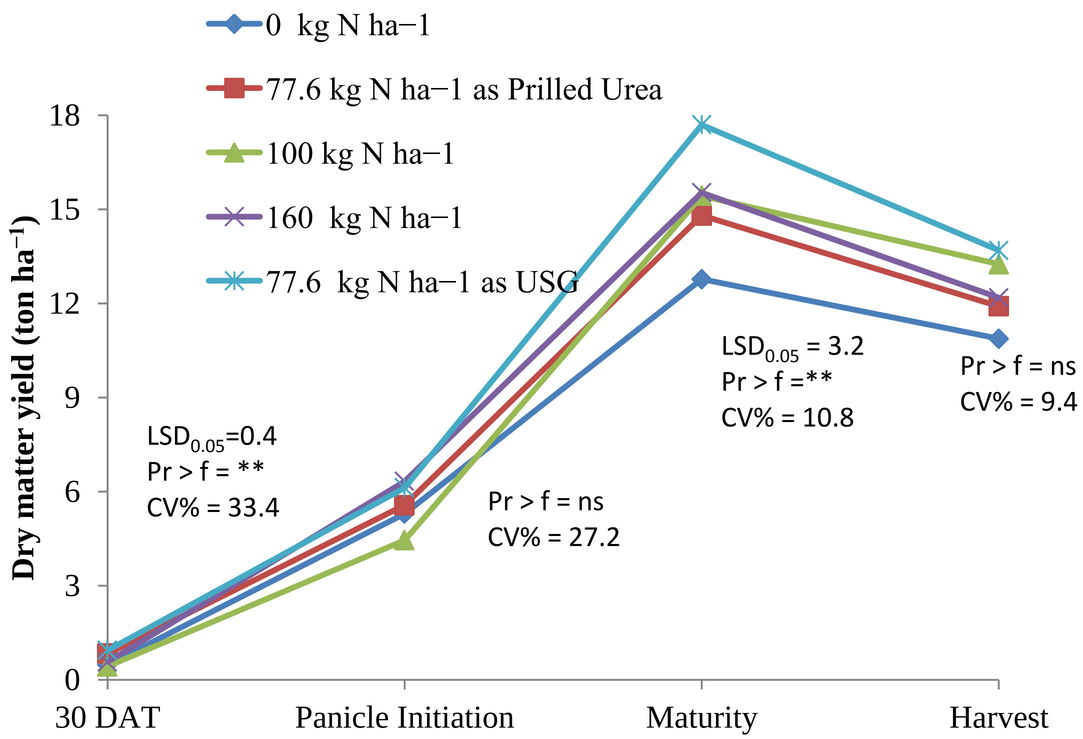

Figure 4.5 Dry matter yield (ton ha^{-1}) of Yadanar Toe at 30 DAT, panicle initiation, maturity and harvest stages as affected by different N at YAU research farm in 2017

The application of different N fertilizer treatments positively affected the N uptake of rice compared to zero N application at harvest ($P<0.01$). The effects of 77.6 kg N ha^{-1} application as either USG or prilled urea were the same in terms of N uptake in Yadanar Toe. The application of 100 kg N ha^{-1}contributed the highest N uptake (270 kg ha^{-1}), similar to the application of 160 kg N ha^{-1}.

At 30 DAT, the maximum N uptake from the application of 77.6 kg N ha^{-1} either as USG or prilled urea was probably explained by the using of balanced amount of other nutrients, such as P and K. In plants receiving higher N rates (100 and 160 kg N ha^{-1}), however, the uptake of N was reduced. The panicle initiation stage of rice plant is considered as one of the nutrient demanding stages especially N turning from the vegetative to reproductive stage. Therefore, the application of USG and the highest N rate could provide the highest N uptake compared with other N treatments in this stage. At maturity and harvest stages, the higher N rates were found to relate with the higher N uptake of rice. This shows that rice plants consume a lot of N nutrient throughout the growing season. The consistent effectiveness of using USG regarding with N uptake of rice could remarkably be noted in this experiment. It can suggest that the use of USG might promote higher N, P and K uptakes comparing with broadcasting prilled urea (Bandaogo et al., 2015).

4.1.3 Yield and yield components of rice at harvest

(a) Yield components of rice

Statistically, the effects of different N treatments did not show the differences on plant height, tiller number per plant, panicle number per hill, spikelet number per panicle, percentage of filled grain and 1000 grain weight of Yadanar Toe rice grown in summer season, 2017 ($P>0.05$) Table (4.1). On the contrary, significant increase of leaf area, yield component and grain yield was reported from the increasing rates of N up to 120 kg N ha^{-1}(Abou-Khalifa, 2012).

(b) Grain yield, straw yield and harvest index

Grain yield

Significant differences of grain yield were observed among the treatments ($P<0.05$) and grain yield ranged from 6.85 to 8.22 ton ha^{-1} Table (4.2). The high grain yields (8.20 and 8.22 ton ha^{-1}) were provided by the application of 100 and 130 kg N ha^{-1}, respectively but, which were not statistically different from T4 and T8 (7.68 and 7.72 ton ha^{-1}, respectively). There was no difference of grain yield between no fertilization, zero N, low rate (30 kg N ha^{-1}) and the highest rate (160 kg N ha^{-1}) applications.

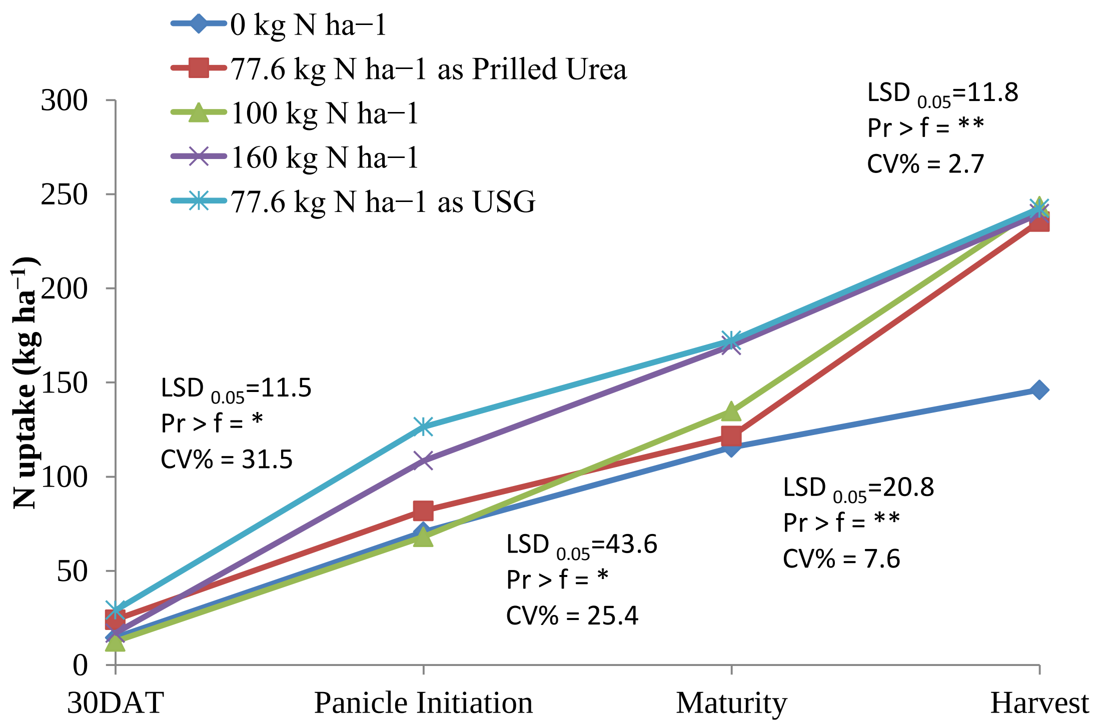

Figure 4.6 N uptake of Yadanar Toe at 30 DAT, panicle initiation, maturity and harvest stages as affected by different N treatments at YAU research farm in 2017

Table 4.1 Effect of different N fertilizer treatments on plant height, tiller numbers per plant and yield components of Yadanar Toe grown at YAU research farm in summer season in 2017

Treatment	Plant Height (cm)	Tiller number	Panicle hill^{-1}	Spikele panicle^{-1}	Filled grain (%)	1000 grain wt. (g)
T1= Control	126	14	14	68	95	24.9
T2= 0 kg N ha^{-1}	127	15	15	62	95	25.1
T3= 30 kg N ha^{-1}	126	13	15	87	95	25.4
T4= 77.6 kg N ha^{-1}	128	15	14	81	94	25.4
T5=100 kg N ha^{-1}	124	16	16	82	93	24.9
T6=130 kg N ha^{-1}	125	15	17	84	94	24.9
T7=160 kg N ha^{-1}	127	15	15	83	94	25.8
T8= USG 77.6 kg N ha^{-1}	131	16	15	73	94	24.7
CV%	3.2	11.3	12.5	13.0	0.9	2.0
Pr>f	ns	ns	ns	ns	ns	ns
LSD $_{(0.05)}$	-	-	-	-	-	-

The grain yield of Yadanar Toe was the highest in 100 kg N ha^{-1}application and there was still a stagnant of grain yield at 130 kg N ha^{-1} rate although the application was further increased. Moreover, the decline of grain yield was observed at 160 kg N ha^{-1}. The increasing rate of N (80 to 160 kg ha^{-1}) could not promote the grain yield of rice as a result of luxury consumption of N (Hirzel & Rodríguez, 2013). In accordance with the law of diminishing return, rice grain yield inclines up to an optimum level at a certain N rate. Once the optimum level reached, the yield declination occurs resulting in the change of one limiting factor to another. In other words, the fertilization has to be balanced so that the availability of each element is proportional to the yield (Wit, 1992).

Straw yield

Straw yield was found to be statistically different among different N treatments ranging from 9.04 to 13.70 ton ha^{-1} (Table 4.2). The applications of 77.6 kg N ha^{-1} as USG and 100 kg N ha^{-1} produced the maximum straw yields (13.70 and 13.26 ton ha^{-1}) which did not statistically differ with those provided by other N treatments (30, 77.6, 130 and 160 kg N ha^{-1} as urea). Zero N application gave higher straw yield (10.88 ton ha^{-1}) than that of no fertilizer application, whose yield was the lowest (9.04 ton ha^{-1}) among the treatments.

Harvest Index

Harvest Index (HI); the ratio of economical yield to above ground biological yield (N. Fageria & Baligar, 2001) was positively affected by different N treatments at ($P<0.05$) Table (4.2). Treatments with no fertilizer application and with 130 kg N ha^{-1} contributed the maximum HI value 0.43 and 0.40 while other treatments provided statistically the same HI value ranging from 0.36 to 0.39. The range of harvest index in the current study was in line with (Yoshida, 1981) who reported that the range of harvest index was from 0.40 to 0.49 for lowland rice cultivars.

Table 4.2 Effect of different N fertilizer treatments on grain yield, straw yield and harvest index (HI) of Yadanar Toe grown 2017 in YAU research farm in summer season

Treatment	Grain yield (ton ha^{-1})	Straw yield (ton ha^{-1})	HI
T1= Control	6.96^{bc}	9.04^{c}	0.43^{a}
T2= 0 kg N ha^{-1}	6.85^{c}	10.88^{b}	0.39^{bc}
T3= 30 kg N ha^{-1}	7.17^{bc}	12.40^{ab}	0.36^{c}
T4= 77.6 kg N ha^{-1}	7.68^{ab}	11.91^{ab}	0.39^{bc}
T5=100 kg N ha^{-1}	8.20^{a}	13.26^{a}	0.38^{bc}
T6=130 kg N ha^{-1}	8.22^{a}	12.04^{ab}	0.40^{ab}
T7=160 kg N ha^{-1}	7.56^{bc}	12.18^{ab}	0.38^{bc}
T8= USG 77.6 kg N ha^{-1}	7.72^{ab}	13.70^{a}	0.36^{c}
CV%	5.77	8.79	5.59
Pr>f	**	**	*
LSD $_{(0.05)}$	0.08	1.84	0.04

Means followed by different letters in the same column are significantly different by LSD test at 5% level.

* **Significant difference at 1% level and *****Significant difference at 5% level

4.1.4 Grain and straw N uptake at harvest

Nitrogen uptake of grain increased with N application rate ranging from 74 to 133 kg ha^{-1}at harvest stage of Yadanar Toe rice grown in summer season, 2017 Figure (4.7). Zero N application along with addition of other nutrients was responsible for the lowest grain N uptake. The amounts of grain N uptake provided by the 0 kg N ha^{-1} and 30 kg N ha^{-1} application were statistically the same and higher than that of no fertilizer (T1) application. Increasing trend of grain N uptake inclined up to 130 kg N ha^{-1} (with 133 kg N ha^{-1}) and declined at 160 kg N ha^{-1} application i.e. it did not contribute more grain N uptake (Appendix 7).

Straw N uptake was observed to be the similar trend of grain N uptake. The application of 160 kg N ha^{-1} provided the highest straw N uptake followed by the application of 100 kg N ha^{-1}. The straw N uptake was not significantly different among 130 kg N ha^{-1} and 77.6 kg N ha^{-1} either as USG or prilled urea. The straw N uptake (130 kg ha^{-1}) was found to be the highest and the straw N uptake (53 kg ha^{-1}) was the smallest from the initial soil condition.

As observed in other evidences (Swain et al., 2006), the uptake of grain and straw N increased with the increasing trend of N supply and this increase ceased at a certain N level, 130 kg N ha^{-1}in grain uptake and 160 kg N ha^{-1} in straw uptake in this study. (Jiang et al., 2004) stated that the high N rate applied to rice produced the high N uptake of rice but, reduced the efficiency of N use.

4.1.5 Nitrogen use efficiency

Nitrogen use efficiency (NUE) as affected by different N treatments for Yadanar Toe rice grown in summer season, 2017 was presented in Figure (4.8). The NUE given by different N rates and sources ranged from 4.5 to 13.5 in this trial. The lowest grain yield (4.5 kg) was produced by the highest N rate (160 kg ha^{-1}) and the highest grain yield (13.5 kg) was supported by 100 kg ha^{-1}. This clearly stated that the highest N rate produces the lowest NUE of rice and this finding was in line with (Liu et al., 2016). As N is the main limiting factor of crop growth and yield, the rate of yield increase is substantial at low rates of N supply. When the N rate becomes higher than optimal, the amount of yield becomes smaller because other yield determinants are becoming in limited condition with the approach of the maximum yield potential (Dobermann, 2005).

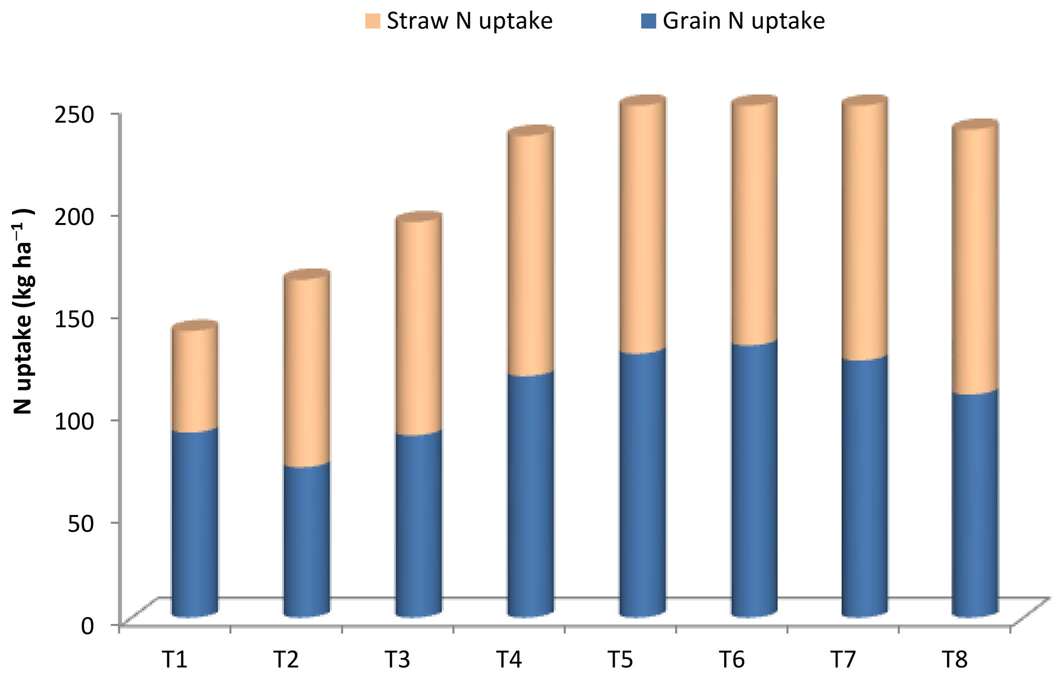

Figure 4.7 Grain N uptake and straw N uptake of Yadanar Toe grown in summer season, 2017 as affected by different N treatments at YAU research farm

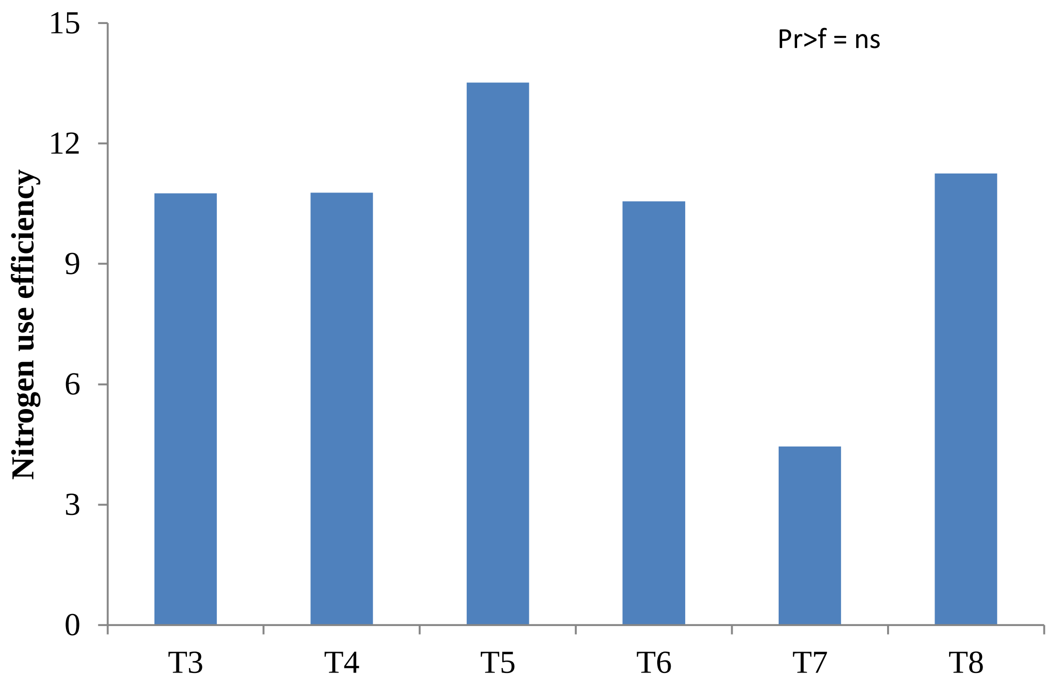

Figure 4.8 Nitrogen use efficiency of Yadanar Toe in summer season, 2017 as affected by different N treatments at YAU research farm

4.1.6 Nitrogen use efficiency measured by ^{15}N isotopic technique

The NUE data measured by ^{15}N dilution method using ^{15}N labeled urea given by T3,T4 and T7 as prilled urea were not different among each other (Table 4.3). The urea deep placement (UDP) technique using USG returned the highest NUE and it was about double compared to other treatments. Deep placement of USG significantly improved grain yield, straw yield and nitrogen use efficiency of rice and reduced the volatilization loss of ammonia relative to the application of prilled urea (Jena et al., 2003). Koyama (1971) reported that in a Bangkhen soil, the recovery in rice plant of fertilizer N in deep placement was twice as high as in the case of surface application.

Table 4.3 Nitrogen use efficiency of Yadanar Toe(summer) measured by ^{15}N isotopic technique

Treatment	N rate ($kg\ N\ ha^{-1}$)	% NUE plant	
		Mean	**SD**
T3	30	36.5[b]	3.7
T4	77.6	33.4 [b]	1.5
T7	160	30.2 [b]	4.9
T8	77.6(UDP)	61.0 [a]	4.0
	$LSD_{(0.05)}$	8.1	

4.2 Assessment of Nitrogen Use Efficiency and Yield based on Nitrogen Rates and Fertilization Practices in Lowland Rice (*Oryza sativa* L.) at Yezin, Naypyitaw, Myanmar in Monsoon Season

4.2.1 Plant growth parameters at weekly interval

(a) Plant height

The plant height of rice cultivated in monsoon season (June-October, 2017) is shown in Figure (4.9). Effect of different N rates affected significantly on the plant height of Sin Thukha recorded at weekly interval starting from 30 DAT to harvest. However, no significant difference was found among treatments in the first, sixth and seventh weeks (Figure 4.9). The results of plant height were found to be in the identical trend in each week. Among the treatments tested, the highest plant height of Sin Thukha was always provided by T8 with the application of 77.6 kg N ha^{-1}as USG in this trial (Appendix 2). Treatments with no fertilization and zero N application were mostly responsible for the shortest plant height. The plant heights of other treatments were not statistically different. Nitrogen fertilization increased plant height of rice plant significantly (Azam et al., 2012).

(b) Tiller numbers per plant

The number of tiller per plant recorded at weekly interval starting from 30 DAT to harvest was not affected by different N treatments except in the fourth week Figure (4.10). In the fourth week, T8 with N application at 77.6 kg N ha^{-1} as USG contributed the largest number of tillers (15) followed by T7 (160 kg N ha^{-1}) and they did not differ statistically (Appendix 4). The smallest number of tillers per plant (11) was provided by T1 (no fertilization) but other treatments also gave the similar results ranging from 11 to 13. From the field perspective of rice cultivation, the application of N fertilizer is believed to enhance the tiller population as the cytokinin content within tiller nodes which favors the germination of the tiller primordium is increased by N fertilization (Wang et al., 2017). The increased number of effective tillers was observed in the application of 80 kg N ha^{-1} as USG over prilled urea (Ahmed, Islam, Kader, & Anwar, 2000; Bandaogo et al., 2015).

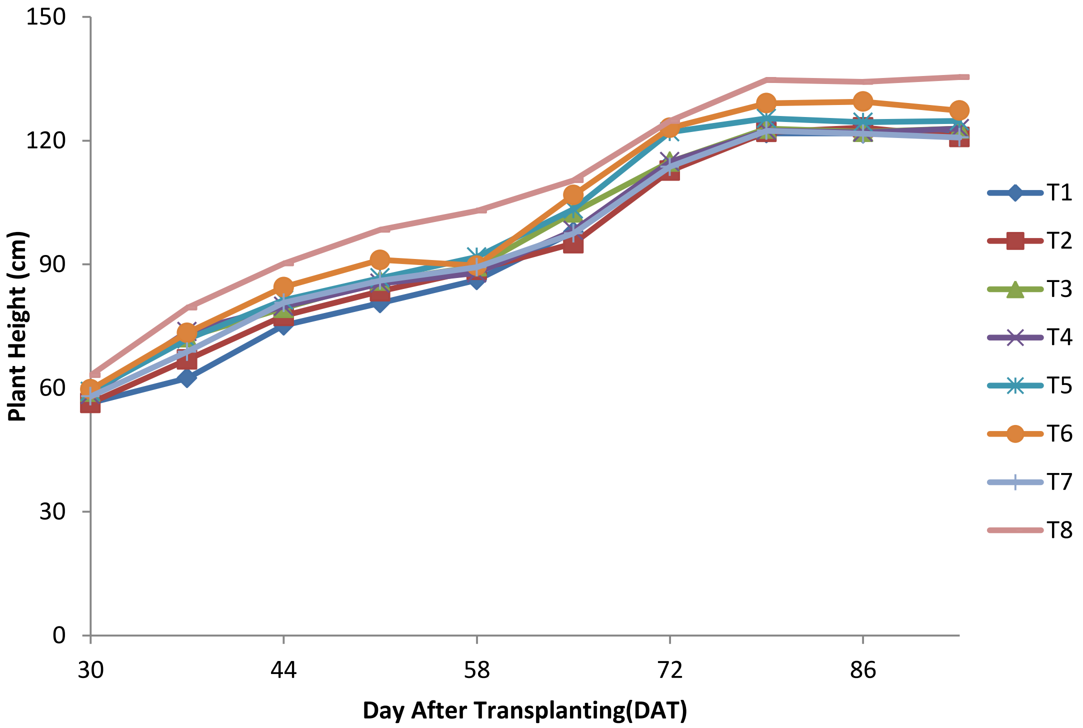

Figure 4.9 Plant height (cm) of Sin Thukha grown as monsoon at YAU research farm in 2017

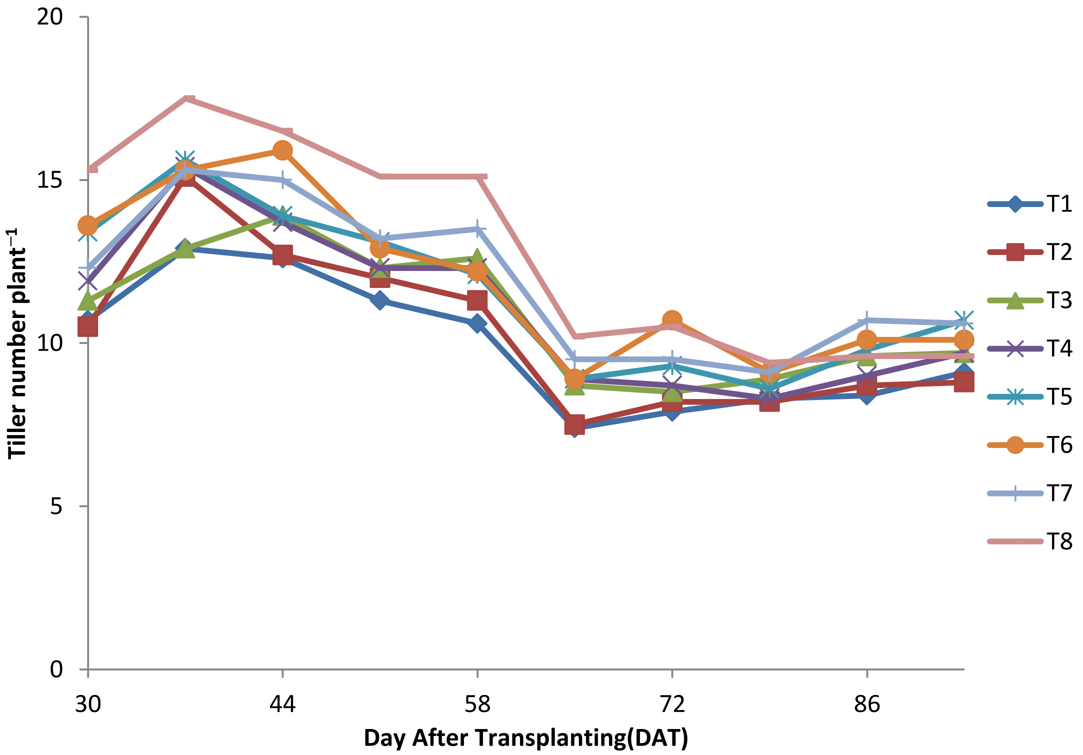

Figure 4.10 Number of tillers per plant of Sin Thukha grown as monsoon at YAU research farm in 2017

(c) SPAD value

SPAD value readings were recorded at weekly interval from 30 DAT to harvest were presented in (Figure 4.11) and different N fertilizer treatments affected significantly on chlorophyll meter readings of Sin Thukha rice in most of the weekly data ($P<0.05$). Applying N fertilizers increased the SPAD values over no fertilization and zero N application (Balasubramanian et al., 1998). Generally, SPAD values were improved with the N rates especially in younger growth stages. In no fertilization (T1) and zero N application (T2), the SPAD values ranged from 34 to 41 during the study period. Within the different N rates from 30 to 160 kg N ha^{-1} the minimum SPAD value was 36 and the maximum was 44 (Appendix 6).

4.2.2 Soil, plant sampling and analysis

(a) Mineral N content (NH_4-N) of soil at 30 DAT, 60 DAT, maturity and harvest

N application positively affected the mineral N (NH_4-N) content of soil collected from 0-10 cm depth at 30 and 60 DAT (Figure 4.12). At 30 DAT, T2 was the lowest mineral N content (17 mg kg^{-1}) and the highest mineral N content (35 mg kg^{-1}) was observed from plot that obtained the application of USG at T8. However, the mineral content of soil gathered from 10-20 cm depth was not significantly different among tested treatments. 0-10 cm depth at 60 DAT, T2 was the lowest mineral N content (30 mg kg^{-1}) and the highest mineral N content (42 mg kg^{-1}) was observed from plot that obtained the application of USG at T8. Likewise at 30 DAT, the mineral content of soil gathered from 10-20 cm depth was not significantly different among tested treatments.

Positive response of N fertilization to mineral N content of soil was observed at maturity stage of Sin Thukha at 0-10 cm and 10-20 cm layers Figure (4.12). Mineral N content of soils ranged from 10.0 mg kg^{-1} to 24.2 mg kg^{-1} in the first layer and from 7.6 to 18.7 mg kg^{-1} in the second layer. At 0-10 cm depth, mineral N content of soil increased with the increasing trend of N fertilizer rate. However, the content of mineral N was higher (24.2 mg kg^{-1}) in the application of USG fertilizer than that 16.0 mg kg^{-1} of prilled urea at the same rate of N application (77.6 kg ha^{-1}). This finding was supported by that of Huda et al. (2016).

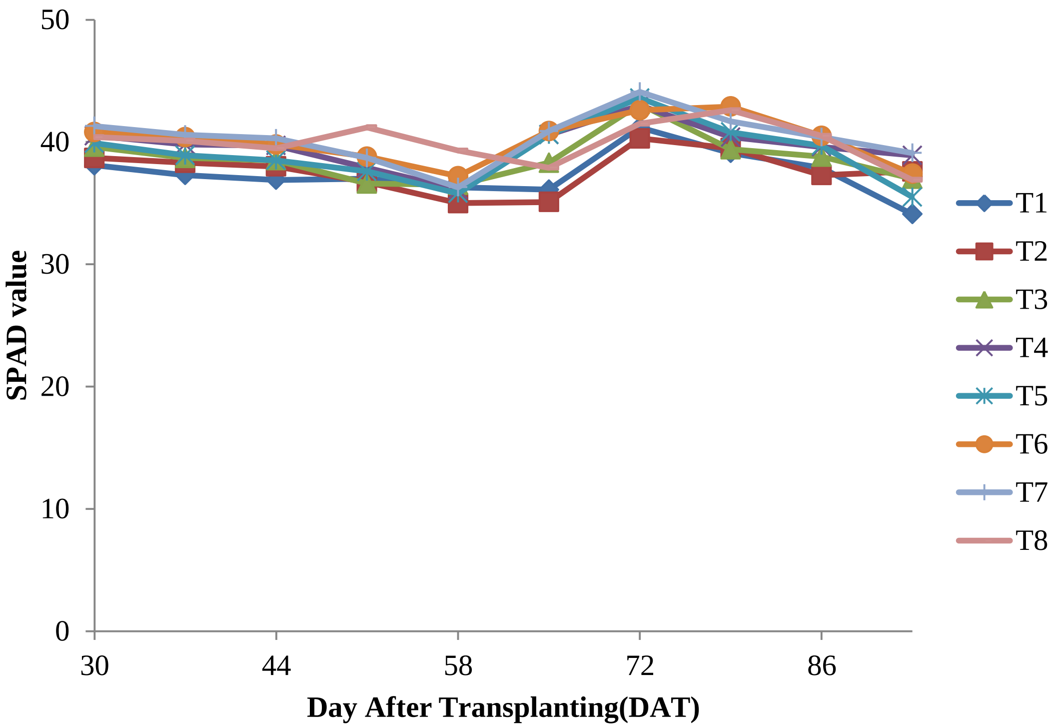

Figure 4.11 SPAD value of Sin Thukha grown as monsoon 2017 in YAU research farm

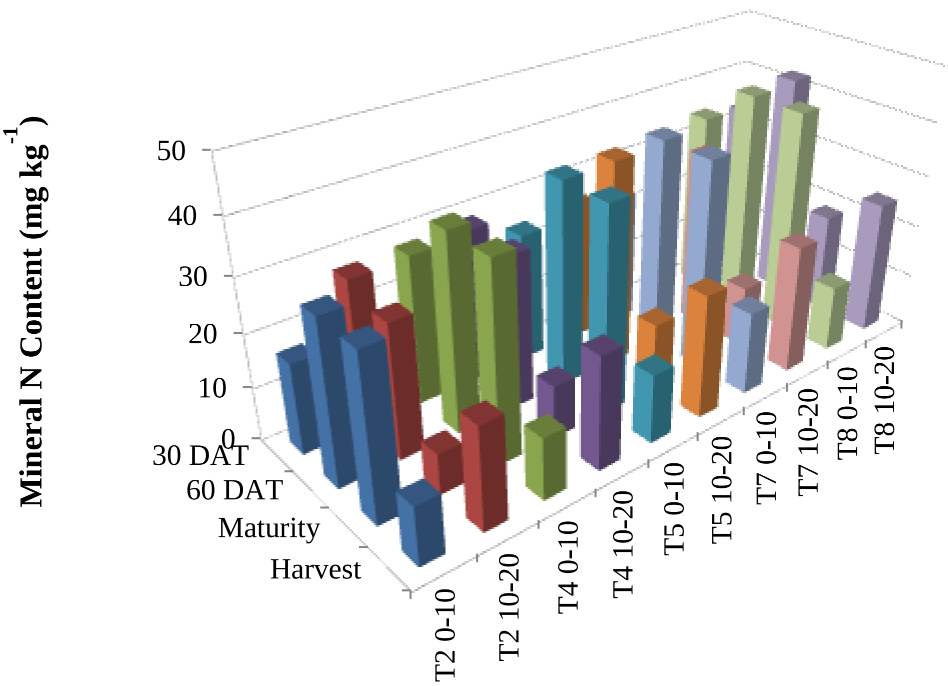

Figure 4.12 Mineral N content (NH_4-N) of soil at 30 DAT, 60 DAT, maturity and harvest grown as monsoon at YAU research farm in 2017

The amount of ammonium N in floodwater was reduced in deep placement of urea compared to broadcasting prilled urea (Huda et al., 2016). At 10-20 cm depth, the positive effect of N fertilization was observed. The mineral N contents of T5, T7 and T8 were statistically the same.The application of 77.6 kg N ha^{-1} as USG provided the highest mineral N content (18.7 mg kg^{-1}) whereas the same N rate as prilled urea provided the lower amount of mineral N (9.9 mg kg^{-1}). The practice of deep placement was responsible for the loss of ammonium volatilization and runoff resulting in the much amount of them remained in the soil (Huda et al., 2016).

At harvest stage, mineral N contents of soil collected from 0-10 cm and 10-20 cm depths of Sin Thukha were presented in Figure 4.13. There were significant differences of mineral N content among different N treatments ($P<0.05$) at 0-10 cm. At 0-10 cm depth, the highest mineral N amount (18.9 mg kg^{-1}) was found in T8 followed by the amounts given by T7. The lowest mineral N content (10.8 mg kg^{-1}) was observed from T2. At 10-20 cm depth, there was no significant difference of mineral N left in the soil collected from different N treatments. Mineral N content left in the soil ranged from 19.0 mg kg^{-1} to 25.2 mg kg^{-1} at 10-20 cm depth. The smallest amount of mineral N content was found in T2 while the largest amount was observed in treatment 8 at this depth. It is generally learnt that the amount of N left increased with the rate of N application in both soil layers.

(b) Dry matter and N uptake of rice during the cropping season

Dry matter yields of Sin Thukha as affected by T2, T4, T5, T7 and T8 were recorded at 30 DAT, panicle initiation, maturity and harvest stages Figure (4.13). There was no significant difference of dry matter yield at 30 DAT but effect of different N treatments was found on the dry matter yield at panicle initiation, maturity and harvest stages.

At panicle initiation, dry matter yield increased with N rates ranging from 3.4 to 5.3 ton ha^{-1} but dry matter yield given by the application of 77.6 kg N ha^{-1} as USG only significantly differed with 0 kg N ha^{-1} application. Dry matter yield was significantly higher in application of USG than in prilled urea despite the same N rate. Despite the positive effect of N fertilization on dry matter yield at panicle initiation stage, the effect of balanced nutrition was more prominent in this study. The maximum dry matter yield was found in plots receiving 77.6 kg N ha^{-1} as USG which was in match with other nutrients. The same N rate applied as prilled urea with two equal splits gave the lower yield because plants received half of the dose at panicle initiation stage.

At maturity stage, zero N application gave the lowest dry matter yield (8.0 ton ha^{-1}) while the application of 160 kg N ha^{-1} provided the highest dry matter yield (9.9 ton ha^{-1}). The application of 77.6 kg ha^{-1} responded to the same dry matter yield either using as USG or prilled urea. The dry matter yield reached the peak at maturity stage and declined at harvest time. Leaf senescence of rice might be the reason of this declination (Fageria & Baligar, 2001).

At harvest stage, the highest dry matter yield (9.1 ton ha^{-1}) was observed from the application of 77.6 kg N ha^{-1} as prilled urea. The decline of dry matter yield from maturity to harvest was the minimum in this treatment. The application of N at the rates of 77.6 kg ha^{-1} as USG, 100 kg ha^{-1} and 160 kg ha^{-1} provided statistically the same yield ranging from 7.3 to 7.7 ton ha^{-1}.

Nitrogen uptake of Sin Thukha rice as affected by different N treatments at 30 DAT, panicle initiation, maturity and harvest stages was presented in Figure (4.14) and they were significantly different at panicle initiation and harvest stages ($P<0.05$). At panicle initiation stage, the application of 77.6 kg N ha^{-1} as USG gave the highest N uptake (81 kg ha^{-1}) which was followed by the yield (56 kg ha^{-1}) from the application of 160 kg N ha^{-1}. The uptakes of N were not statistically different among the rest treatments. At harvest, the N uptakes as affected by 77.6 kg N ha^{-1} both as USG and prilled urea and 100 kg N ha^{-1} were the highest ones and statistically the same among each other. The lowest N uptake was found from zero N application treatment. The highest N uptake (108 kg ha^{-1}) was observed with USG (104 kg N ha^{-1}) followed by USG (78 kg N ha^{-1}) gave (91 kg ha^{-1}) and the lowest N uptake (26 kg ha^{-1}) was obtained with the control (Koudjega , 2018).

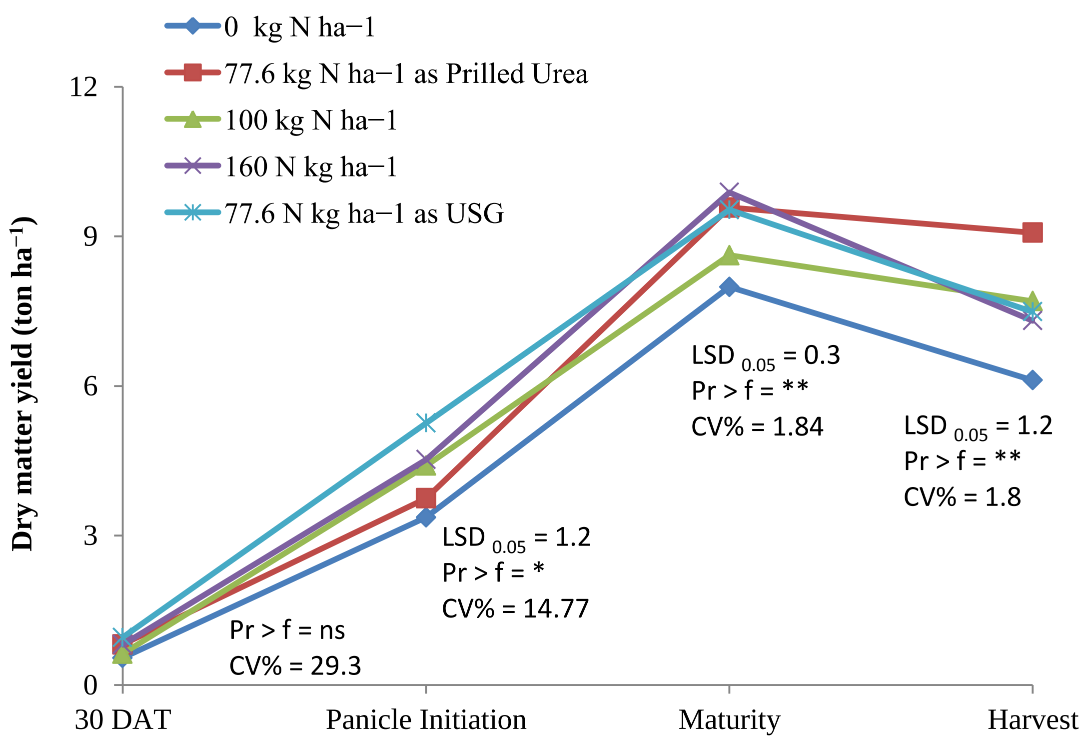

Figure 4.13 Dry matter yield (ton ha^{-1}) of Sin Thukha at 30 DAT, 60 DAT, maturity and harvest stages as affected by different N treatments at YAU research farm in 2017

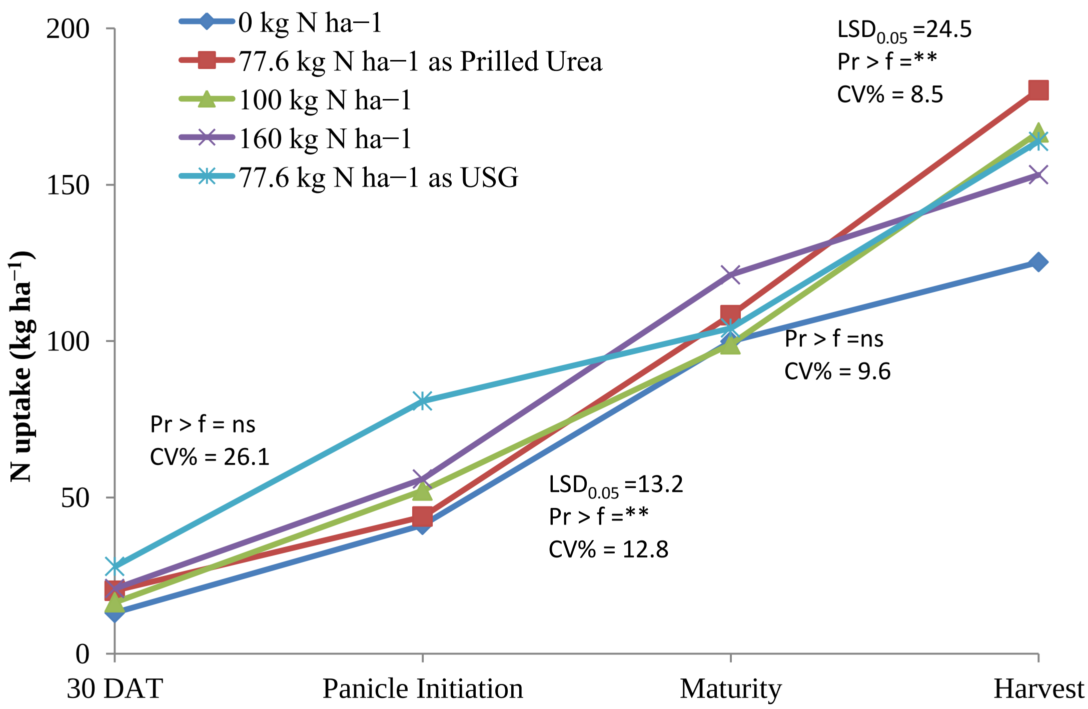

Figure 4.14 N uptake of Sin Thukha at 30 DAT, panicle initiation, maturity and harvest stages as affected by different N treatments at YAU research farm in 2017

Since monsoon rice growing had already received the N treatments according to the first summer season, it is understandable to see the significant difference of N uptake only in the panicle initiation and harvest stages. The respective experimental plots only received half of the dose of N fertilizers except USG at the most nutrient demanding panicle initiation stage according to the N fertilization pattern. Like the summer season rice, the effect of USG and the highest N rate (160 kg N ha^{-1}) was seen in this monsoon rice. At harvest, the optimum range of N uptake was given by the range of N rate from 77.6 to 100 kg N ha^{-1} in the monsoon season rice.

4.2.3 Yield and yield components of rice at harvest

(a) Yield components of rice

Statistically, the effects of different N treatments did not show the differences on tiller number per plant, panicle number per hill, spikelet number per panicle, percentage of filled grain and 1000 grain weight except plant height of Sin Thukha grown in monsoon season, 2017 ($P<0.05$) (Table 4.4). The application of 77.6 kg N ha^{-1} as USG provided the highest plant height (135 cm) compared to the rest treatments. The deep placement of USG showed significant increase in rice height and length of panicles over the PU surface broadcasting (Koudjega ,2018).

(b) Grain yield, straw yield and harvest index

Grain yield

Significant differences of grain yield were observed among the treatments ($P<0.05$) and grain yield ranged from 3.40 to 4.62 ton ha^{-1} (Table 4.5). The maximum grain yield (4.62 ton ha^{-1}) was provided by the application of 100 kg N ha^{-1} and this yield was not statistically different with T3, T4, T6 and T8. Regardless of N source, the application of 77.6 kg N ha^{-1} contributed the similar grain yield (4.28 and 4.39 ton ha^{-1}). Despite the effectiveness in reduction of ammonium concentration of floodwater and in saving of N fertilizer, the yield difference could not be noted between USG and prilled urea application at the same rate of N (Islam et al., 2016). No fertilization gave the minimum grain yield (3.40 ton ha^{-1}) which did not statistically differ with zero N application and 160 kg N ha^{-1}. High yielding rice varieties grown in Research farm of Cuu Long Delta Rice Research Institute produced the grain yield in an increasing trend from 0 to 80 kg N ha^{-1} but the yield reduction occurred by the further increase of N fertilizer from 120 to 160 kg N ha^{-1} (Van Hach & Nam, 2006).

Table 4.4 Effect of different N fertilizer treatments on plant height, tiller numbers per plant and yield component characters of Sin Thukha grown in monsoon season at YAU research farm in 2017

Treatment	Plant Height (cm)	Tiller number	Panicle $hill^{-1}$	$Spikeletpanicle^{-1}$	Filled Grain (%)	1000 Grain Wt. (g)
T1= Control	123^{b}	9	9	130	87	21.4
T2= 0 kg N ha^{-1}	121^{b}	9	9	148	93	21.6
T3= 30 kg N ha^{-1}	123^{b}	10	10	152	91	21.8
T4= 77.6 kg N ha^{-1}	123^{b}	11	10	142	90	21.2
T5=100 kg N ha^{-1}	125^{b}	11	9	148	91	21.1
T6=130 kg N ha^{-1}	127^{b}	10	10	124	92	21.2
T7=160 kg N ha^{-1}	121^{b}	11	9	143	91	20.5
T8= USG 77.6 kg N ha^{-1}	135^{a}	10	9	134	96	21.0
CV%	3.26	14.2	13.2	25.6	4.1	3.1
Pr > F	*	ns	ns	ns	ns	ns
$LSD_{(0.05)}$	7.1	-	-	-	-	-

Means followed by different letters in the same column are significantly different by LSD test at 5% level.

*****Significant difference at 5% level, ns non-significant difference

Straw yield

Straw yield of Sin Thukha rice was statistically different among tested N treatments (Table 4.5). The application of 77.6 kg N ha^{-1} as prilled urea provided the maximum straw yield (9.08 ton ha^{-1}) and it was statistically the same as the application of 77.6 kg N ha^{-1} as USG, 100 kg N ha^{-1}and 160 kg N ha^{-1}. The rest of the tested treatments (No fertilization, zero N, 30 kg N ha^{-1}and 130 kg N ha^{-1}) gave the minimum straw yield ranging from 6.10 to 6.29 ton ha^{-1}. It could be noted that the positive effect of N fertilizer was found on straw yield of Sin Thukha and the optimum N rate for straw yield was 77.6 kg N ha^{-1} regardless of N source. USG was more efficient than PU at all respective levels of nitrogen in producing all yield component and in turn, grain and straw yields. (Mishra et al., 1999) conducted an experiment to study the effect of USG in wetland rice soil.

Harvest Index

Harvest Index (HI), the ratio of economical yield to above ground biological yield, was not statistically different among different N treatments (Table 4.5). The value of harvest index ranged from 0.32 to 0.42 in Sin Thukha variety grown in YAU research farm. No significant effect of the urea mode of application was observed on harvest index (Koudjega , 2018).

4.2.4 Grain and straw N uptake at harvest

Nitrogen uptake of grain ranged from 50 to 77 kg ha^{-1}at harvest stage of Sin Thukha grown in monsoon season, 2017 (Figure 4.15). N fertilization generally increased the grain N uptake of rice but there were no significant effect between tested N treatments except the highest N rate. Regardless of N source, the application of 77.6 kg N ha^{-1} contributed the same amount of grain N uptake by 73 kg ha^{-1}. At the highest N rate of 160 kg ha^{-1}, the grain N uptake reduced to 67 kg ha^{-1} (Appendix 7).

Straw N uptake of Sin Thukha was significantly affected by different N treatments. The application of 100 kg N ha^{-1} provided the highest straw N uptake (133 kg ha^{-1}) which did not statistically differ with the application of 77.6 kg N ha^{-1} as prilled urea or USG, 130 kg N ha^{-1} and 160 kg N ha^{-1}. The lowest straw N uptake was observed from no fertilization and zero N application. There were not statistically different with the amounts from 30 kg N ha^{-1}.

Table 4.5 Effect of different N fertilizer treatments on grain yield, straw yield and harvest index (HI) of Sin Thukha grown in monsoon season at YAU research farm in 2017

Treatment	Grain Yield (ton ha^{-1})	Straw Yield (ton ha^{-1})	HI
T1= Control	3.40^{d}	6.10^{b}	0.36
T2= 0 kg N ha^{-1}	3.79^{bcd}	6.11^{b}	0.38
T3= 30 kg N ha^{-1}	4.20^{abc}	6.25^{b}	0.40
T4= 77.6 kg N ha^{-1}	4.28^{ab}	9.08^{a}	0.32
T5=100 kg N ha^{-1}	4.62^{a}	7.70^{ab}	0.37
T6=130 kg N ha^{-1}	4.29^{ab}	6.29^{b}	0.42
T7=160 kg N ha^{-1}	3.75^{cd}	7.31^{ab}	0.34
T8= USG 77.6 kg N ha^{-1}	4.39^{a}	7.49^{ab}	0.37
CV%	7.40	16.16	12.68
Pr>F	**	*	ns
LSD $_{(0.05)}$	0.53	1.79	-

Means followed by different letters in the same column are significantly different by LSD test at 5% level.

* *****Significant difference at 1% level, *****Significant difference at 5% level and ns non-significant difference

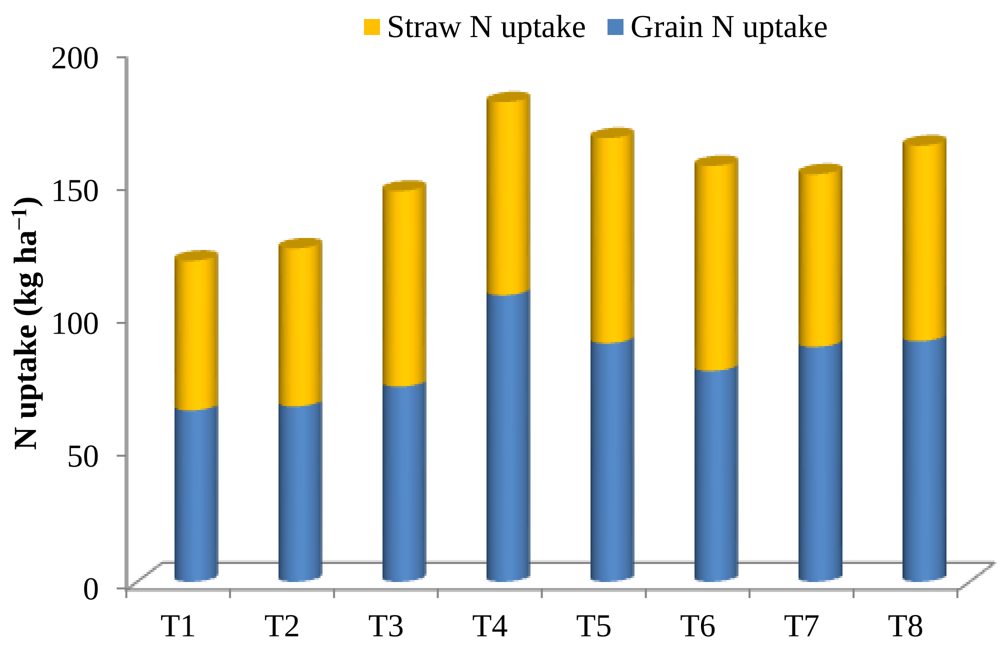

Figure 4.15 Grain N uptake and Straw N uptake of Sin Thukha grown in monsoon season as affected by different N treatments at YAU research farm in 2017

The uptake of grain and straw N of rice increased with the increasing trend of N fertilizer rate (Swain et al., 2006). Sin Thukha variety grown as monsoon rice in YAU farm, the maximum N rate for both grain and straw N uptake was 77.6 kg N ha^{-1} irrespective of N source (USG and prilled urea). The N rate of 100 kg ha^{-1} also believed to give the optimum uptake of both grain and straw N in this study. The fixed time N management with the rate of 100 kg N ha^{-1} provided the maximum total N uptake (Peng et al., 1996).

4.2.5 Nitrogen use efficiency

Nitrogen use efficiency of Sin Thukha variety grown in monsoon season, 2017 was presented against the different N rates (Figure 4.16). The range of nitrogen use efficiency from -0.3 to 13.4 was observed from the application of 30 to 160 kg N ha^{-1}. The lowest N fertilizer rate (30 kg N ha^{-1}) was responsible for the highest NUE (13.4) and the highest N rate (160 kg N ha^{-1}) was relate with the lowest NUE (-0.3) of monsoon rice. This finding was in accordance with other finding which reported the reverse relation of N application and NUE of rice (Liu et al., 2016). Although the use of prilled urea changed the NUE considerably in the different N rates, the use of USG did not reduce its NUE as much as prilled urea.

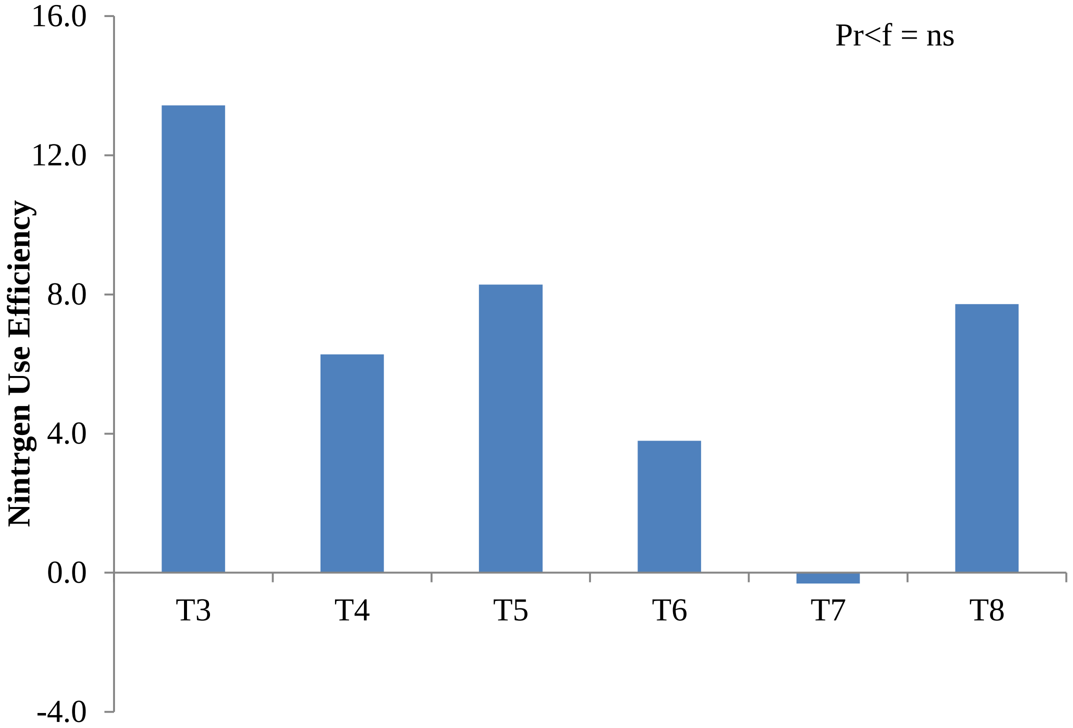

Figure 4.16 Nitrogen use efficiency in relation to different N treatments applied to Sin Thukha grown in monsoon season at YAU research farm in 2017

CHAPTER V
CONCLUSION

The present study evaluated the different rates and application methods of N fertilizers to investigate the suitable N rate and to determine the N use efficiency of rice in relation to these different N rates and application approaches for optimal rice production in Yezin Agricultural University's research farm.

The application of USG at 77.6 kg N ha^{-1} and the highest N rate at 160 kg N ha^{-1} showed high N uptake. Based on the results of grain yield, the highest rice yield was investigated from the application of 100 kg N ha^{-1} in both seasons using Yadanar Toe and Sin Thukha rice varieties in YAU research farm. The plateau of the rice yield occurred when the N rate higher than 100 kg N ha^{-1} was applied and moreover, the yield was declined at 160 kg N ha^{-1}. The application of 77.6 kg N ha^{-1} as either prilled urea or USG was the optimum rice yield in this study.

In summer season rice, the maximum NUE was attained at the rate of 100 kg N ha^{-1} followed by the application of 77.6 kg N ha^{-1} as USG which contributed the second highest NUE in this season. Remarkably, the highest NUE was achieved from the application of 30 kg N ha^{-1} in the second rice season (monsoon) and it was about 50% higher than those of 100 kg N ha^{-1} and 77.6 kg N ha^{-1} as USG. The use of USG was observed more resistant to the change of NUE compared with prilled urea. Yezin rice field was quite responsive to N application and the response became higher in the second season after receiving the N application continuously. Considering the high N rate (160 kg ha^{-1}), both the rice yield and the NUE dropped obviously compared to the lower N rates.

Together with the suitable amount of other nutrients, it can be anticipated that the application of N fertilizers at the rate of 100 kg ha^{-1} can bring the maximum rice yield in YAU research farm. The regular application of 77.6 kg N ha^{-1} as either USG or prilled urea can bring the optimum rice yield. Since the resistance in change of NUE by using USG, the choice of USG may be valuable in terms of both yield improvement and NUE in the long run if further clarification supports this fore-finding.

According to isotopic technique (^{15}N dilution method) using ^{15}N labeled urea, NUE in 30, 77.6, and 160 kg N ha^{-1} treatments as prilled urea were not different among each other. However, NUE in urea deep placement (UDP) technique using USG was the highest and about double compared to other treatments.

REFERENCES

Abou-Khalifa, A. A. B. (2012). Evaluation of some rice varieties under different nitrogen levels. *Advances in Applied Science Research, 3*(2), 1144-1149.

Ahmed, M., Islam, M., Kader, M., & Anwar, M. (2000). Evaluation of urea super granules as source of nitrogen in transplant aman rice. *Pakistan J. Biol. Sci, 3*(5), 735-737.

Ali, R., Awan, T., Ahmad, M., Saleem, U., & Akhtar, M. (2012). Diversification of rice-based cropping systems to improve soil fertility, sustainable productivity and economics. *Journal of Animal and plant sciences, 22*(1), 108-112.

Andrews, M., Raven, J., & Lea, P. (2013). Do plants need nitrate? The mechanisms by which nitrogen form affects plants. *Annals of applied biology, 163*(2), 174-199.

Aulakh, M. S., & Malhi, S. S. (2004). Fertilizer nitrogen use efficiency as influenced by interactions with other nutrients. *Agriculture and the nitrogen cycle: Assessing the Impacts of Fertilizer use on Food Production and the Environment*, 181-192.

Azam, M., Ali, M., Karim, M., Rahman, A., Jalal, J., & Mamun, A. (2012). Growth and yield of boro rice as affected by different urea fertilizer application method. *Interaction, 1*(3), 2.

Balasubramanian, V., Makarim, A., Kartaatmadja, S., Zaini, Z., Huan, N., Tan, P., . . . Buresh, R. (2002). *Integrated resource management in Asian rice farming for enhanced profitability, efficiency, and environmental protection.* Paper presented at the International Rice Congress, Beijing, China.

Balasubramanian, V., Morales, A., Cruz, R., & Abdulrachman, S. (1998). On-farm adaptation of knowledge-intensive nitrogen management technologies for rice systems. *Nutrient cycling in agroecosystems, 53*(1), 59-69.

Bandaogo, A., Bidjokazo, F., Youl, S., Safo, E., Abaidoo, R., & 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.

Bharati, K., Mohanty, S., Padmavathi, P., Rao, V., & Adhya, T. (2000). Influence of six nitrification inhibitors on methane production in a flooded alluvial soil. *Nutrient cycling in agroecosystems, 58*(1-3), 389-394.

Bolan, N. S., &Hedley, M. J., (2003). Role of carbon, nitrogen, and sulfur cycles in soil acidification. In *Handbook of soil acidity* (pp. 43-70). CRC Press.

Brady, N., & Weil, R. (1999). The Nature and Properties of Soils., 12th edn.(Prentice-Hall: Upper Saddle River, NJ.).

Breimer, T. Environmental factors and cultural measures affecting the nitrate content in spinach. Fertilizer Research, 3(3):191–292

Bruulsema, T. W., Fixen, P. E., & Sulewski, G. D. (2016). *4R plant nutrition: a manual for improving the management of plant nutrition*: International Plant Nutrition Institute.

Cassman, K., Gines, G., Dizon, M., Samson, M., & Alcantara, J. (1996). Nitrogen-use efficiency in tropical lowland rice systems: contributions from indigenous and applied nitrogen. *Field Crops Research, 47*(1), 1-12.

Chapman, H. D. Cation-Exchange Capacity. In: Black, C. A (Ed.), Methods of soil analysis Part II. American Society of Agronomy, Inc., Publisher, Madison, Wisconsin, USA. pp. 89–901

Chaturvedi, I. (2005). Effect of nitrogen fertilizers on growth, yield and quality of hybrid rice (Oryza sativa). *Journal of Central European Agriculture, 6*(4), 611-618.

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

Clay, D., Malzer, G., & Anderson, J. (1990). Ammonia volatilization from urea as influenced by soil temperature, soil water content, and nitrification and hydrolysis inhibitors. *Soil Science Society of America Journal, 54*(1), 263-266.

Craswell, E., & Vlek, P. (1983). Fate of fertilizer nitrogen applied to wetland rice *Gaseous loss of nitrogen from plant-soil systems* (pp. 237-264): Springer.

Dawe, D. (2002). The changing structure of the world rice market, 1950–2000. *Food Policy, 27*(4), 355-370.

Day, P. R. Particle fraction and particle size analysis. In: Black, C. A. (Ed.), Methods of Soil Analysis Part I. American Society of Agronomy, Inc., Publisher, Madison, Wisconsin, USA. pp. 545–562

De Datta, S. (1986). Improving nitrogen fertilizer efficiency in lowland rice in tropical Asia *Nitrogen economy of flooded rice soils* (pp. 171-186): Springer.

De Datta, S., Samson, M., Obcemea, W., Real, J., & Buresh, R. (1991). Direct measurement of ammonia and denitrification fluxes from urea applied to rice. *Soil Science Society of America Journal, 55*(2), 543-548.

Dempsey, R. (2015). Rice Grain Yield and Nitrogen Uptake and Ammonia Volatilization from Urea as Affected by Urea Amendment and Simulated Rainfall.

Denning, G., Baroang, K., & Sandar, T. M. (2013). Background paper No. 2 rice productivity improvement in Myanmar. *Retrieved May, 30*, 2014.

Dobermann, A., & Cassman, K. G. (2004). Environmental dimensions of fertilizer nitrogen: What can be done to increase nitrogen use efficiency and ensure global food security. *Agriculture and the nitrogen cycle: Assessing the Impacts of Fertilizer use on Food Production and the Environment*, 261-278.

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

Dobermann, A., Witt, C., & Dawe, D. (2004). *Increasing productivity of intensive rice systems through site-specific nutrient management*: IRRI; Science Publishers, Inc.

Dobermann, A. R. (2005). Nitrogen use efficiency-state of the art. *Agronomy--Faculty Publications*, 316.

Duan, Y., Zhang, Y., Ye, L., Fan, X., Xu, G., & Shen, Q. (2007). Responses of rice cultivars with different nitrogen use efficiency to partial nitrate nutrition. *Annals of Botany, 99*(6), 1153-1160.

Ernst, J., & Massey, H. (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. (2002). Soil quality vs. environmentally-based agricultural management practices. *Communications in Soil Science and Plant Analysis, 33*(13-14), 2301-2329.

Fageria, N., & Baligar, V. (2001). Lowland rice response to nitrogen fertilization. *Communications in Soil Science and Plant Analysis, 32*(9-10), 1405-1429.

Fageria, N., Slaton, N., & Baligar, V. (2003). Nutrient management for improving lowland rice productivity and sustainability. *Advances in agronomy, 80*(1), 63-152.

Fageria, N. K. (2016). *The use of nutrients in crop plants*: CRC press.

FAO. (2002). *Nuclear techniques in integrated plant nutrient, water and soil management. Proceedings Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture*.

Fillery, I., Simpson, J., & De Datta, S. (1984). Influence of Field Environment and Fertilizer Management on Ammonia Loss from Flooded Rice 1. *Soil Science Society of America Journal, 48*(4), 914-920.

Garcia, Y. T., Garcia, A. G., Oo, M., & Hossain, M. (2000). Income distribution and poverty in irrigated and rainfed ecosystems: The Myanmar case. *Economic and Political Weekly*, 4670-4676.

Giller, K. E., Chalk, P., Dobermann, A., Hammond, L., Heffer, P., Ladha, J. K., . . . Freney, J. (2004). Emerging technologies to increase the efficiency of use of fertilizer nitrogen *Agriculture and the nitrogen cycle: Assessing the Impacts of Fertilizer use on Food Production and the Environment* (pp. 35-51): Washington DC: Island Press.

Good, A. G., & Beatty, P. H. (2011). Fertilizing nature: a tragedy of excess in the commons. *PLoS biology, 9*(8), e1001124.

Guo, J. H., Liu, X. J., Zhang, Y., Shen, J., Han, W., Zhang, W., . . . Zhang, F. (2010). Significant acidification in major Chinese croplands. *science, 327*(5968), 1008-1010.

Han, M., Okamoto, M., Beatty, P. H., Rothstein, S. J., & Good, A. G. (2015). The genetics of nitrogen use efficiency in crop plants. *Annual Review of Genetics, 49*, 269-289.

Hardy, B. (2002). *Rice almanac: Source book for the most important economic activity on earth*: Int. Rice Res. Inst.

Hasanuzzaman, M., Ali, M., Karim, M., Masum, S., & Mahamud, J. (2011). Influence of prilled urea and urea super granules on the growth and yield of hybrid rice. *Bangladesh of Bioscience Association, 4*(1), 1-8.

Hasanuzzaman, M., Nahar, K., Alam, M., Hossain, M., & Islam, M. (2009). Response of transplanted rice to different application methods of urea fertilizer. *growth, 5*, 6.

He, Z., Alva, A., Calvert, D., & Banks, D. (1999). Ammonia Volatilization from Different Fertilizer Sources and Effects of Temperature and Soil pH1. *Soil science, 164*(10), 750-758.

Hedley, M. J., & Bolan, N. S. (2003). Role of carbon, nitrogen, and sulfur cycles in soil acidification *Handbook of soil acidity* (pp. 43-70): CRC Press.

Hirzel, J., & 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.

Huda, A., Gaihre, Y. K., Islam, M., Singh, U., Islam, M. R., Sanabria, J., . . . Jahiruddin, M. (2016). Floodwater ammonium, nitrogen use efficiency and rice yields with fertilizer deep placement and alternate wetting and drying under triple rice cropping systems. *Nutrient cycling in agroecosystems, 104*(1), 53-66.

Huke, R. E. (1982). *Rice area by type of culture: South, Southeast, and East Asia*: Int. Rice Res. Inst.

Humphreys, E., Muirhead, W., Melhuish, F., & White, R. (1987). Effects of time of urea application on combine-sown Calrose rice in south-east Australia. I. Crop response and N uptake. *Australian journal of agricultural research, 38*(1), 101-112.

Hutchinson, C., Simonne, E., Solano, P., Meldrum, J., & Livingston-Way, P. (2002). Testing of controlled release fertilizer programs for seep irrigated Irish potato production. *Journal of plant nutrition, 26*(9), 1709-1723.

IFDC Available @ http://www.ifdc.org/getattachment/1c7e9b2e-37b3-4ea4-93c1-318013dc3ce9/FDP.pdf/ [November 02. (2013.). Fertilizer-Deep-Placement technology.

IRRI. (2002). *the most important economic activity on earth Rice Almanac(International Rice Research Institute)*. International Rice Research Institute, Manila, The Philippines

IRRI. (2010). IRRI (International Rice Research Institute). 2010. http://www.irri.org/about rice/ rice_facts/what is rice?

IRRI. (2017). International Rice Research Institute IRRI knowledge bank online resourse:http://www.knowledgebank.irri.org/step-by-step-production/growth/soil-fertility(Accessed 14 august 2017).

Islam, S. M., Gaihre, Y. K., Shah, A., Singh, U., Sarkar, M. I. U., Satter, M. A., . . . Biswas, J. C. (2016). Rice yields and nitrogen use efficiency with different fertilizers and water management under intensive lowland rice cropping systems in Bangladesh. *Nutrient cycling in agroecosystems, 106*(2), 143-156.

Jena, D., Misra, C., & Bandyopadhyay, K. (2003). Effect of prilled urea and urea super granules on dynamics of ammonia volatilisation and nitrogen use efficiency of rice. *Journal of the Indian Society of Soil Science (India)*.

Jiang, L., Cao, W., Gan, X., Wei, S., Xu, J., Dong, D., . . . Qin, H. (2004). Nitrogen uptake and utilization under different nitrogen management and influence on grain yield and quality in rice. *Zhongguo nongye kexue, 34*(4), 490-496.

Johnston, A., & Bruulsema, T. (2014). 4R nutrient stewardship for improved nutrient use efficiency. *Procedia Engineering, 83,* 365-370.

Jokela, W., & Randall, G. (1989). Corn yield and residual soil nitrate as affected by time and rate of nitrogen application. *Agronomy Journal, 81*(5), 720-726.

Kapoor, V., Singh, U., Patil, S., Magre, H., Shrivastava, L., Mishra, V., . . . Diamond, R. (2008). Rice growth, grain yield, and floodwater nutrient dynamics as affected by nutrient placement method and rate. *Agronomy Journal, 100*(3), 526-536.

Khan, P., Aslam, M., Memon, M. Y., Imtiaz, M., Shah, J. A., & Depar, N. (2010). Determining the nutritional requirements of rice genotype JAJAI 25/A evolved at NIA, Tandojam, Pakistan. *Pak. J. Bot, 42*(5), 3257-3263.

Kirda, C., Derici, M., & Schepers, J. (2001). Yield response and N-fertiliser recovery of rainfed wheat growing in the Mediterranean region. *Field Crops Research, 71*(2), 113-122.

Keeney and Sahrawat KL (1986). *DR and Sahrawat KL.(1986).Nitrogen transformations in flooded rice soils.Advances in soil science book series.(soil,volume 4)Conference proceedings. .*

Koudjega, K. (2018). *Management of Urea Supergranule (USG) Application to Improve Growth and Yield of Rice (Oryza Sativa L) In Some Paddy Soils of Togo and Ghana.* University of Ghana.

Koyama, T. 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 Sci. Plant. Nutr., 17, 210-220

Kromdijk, J., & Long, S. P. (2016). One crop breeding cycle from starvation? How engineering crop photosynthesis for rising CO2 and temperature could be one important route to alleviation. *Proceedings of the Royal Society B: Biological Sciences, 283*(1826), 20152578.

Ladha, J., Dawe, D., Pathak, H., Padre, A., Yadav, R., Singh, B., . . . Kundu, A. (2003). How extensive are yield declines in long-term rice–wheat experiments in Asia? *Field Crops Research, 81*(2-3), 159-180.

Lal, R., & Stewart, B. A. (2014). *Soil management of smallholder agriculture*: CRC Press.

Leghari, S. J., Wahocho, N. A., Laghari, G. M., HafeezLaghari, A., MustafaBhabhan, G., HussainTalpur, K., . . . Lashari, A. A. (2016). Role of nitrogen for plant growth and development: A review. *Advances in Environmental Biology, 10*(9), 209-219.

Leroy E. & -Arthur S. ((1950)). *Nitrogen Fertilizers.Federal Cooperative Extension Service Oregon State College Corvallis Extension Bulletin 699*

Lin, X., Zhu, D., Chen, H., Cheng, S., & Uphoff, N. (2009). Effect of plant density and nitrogen fertilizer rates on grain yield and nitrogen uptake of hybrid rice (Oryza sativa L.). *Journal of Agricultural Biotechnology and Sustainable Development, 1*(2), 44-53.

Liu, X., Wang, H., Zhou, J., Hu, F., Zhu, D., Chen, Z., & Liu, Y. (2016). Effect of N fertilization pattern on rice yield, N use efficiency and fertilizer–N fate in the Yangtze River Basin, China. *PloS one, 11*(11), e0166002.

Lwin, H. Y., Myint, T., Than, S., Aung, N. M., San, C. C., & Htut, T. (2015). Role of fertilizer policy in transforming agriculture of Myanmar.

Manning, G., Fuller, L., Eilers, R., & Florinsky, I. (2001). Soil moisture and nutrient variation within an undulating Manitoba landscape. *Canadian journal of soil science, 81*(4), 449-458.

Mary, B., & Recous, S. (1994). Measurement of nitrogen mineralization and immobilization fluxes in soil as a means of predicting net mineralization. *European journal of agronomy, 3*(4), 291-300.

McBratney, A. B., Minasny, B., & Whelan, B. M. (2005). Obtaining 'useful'high-resolution soil data from proximally-sensed electrical conductivity/resistivity (PSEC/R) surveys. *Precision agriculture, 5*, 503-510.

McLeod, S. Studies on wet oxidation procedures for the determination of organic carbon in soils. CSIRO Division of Soils, Notes on Soil Techniques, pp. 73-79.

Meyer, R., Olson, R., & Rhoades, H. (1961). Ammonia Losses from Fertilized Nebraska Soils 1. *Agronomy Journal, 53*(4), 241-244.

Min Thiha, Soe Lin Aung,,Tint Lwin,,Su Su Win ., & Hla Tin. (2010). *Rice and legume yield as affected by late foliar fertilization of nitrogen and boron.* Paper presented at the the Annual Research Conference of the Myanmar Academy of Agricultural,Forestry,Livestock, and Fishery Sciences held at Yezin Agricultural University Pp 99-124

Mishra, B., Das, A., Dash, A., Jena, D., & Swain, S. (1999). Evaluation of placement methods for urea supergranules in wetland rice (Oryza sativa) soil. *Indian Journal of Agronomy, 44*(4), 710-716.

Murrell, T., Lafond, G., & Vyn, T. (2009). Know your fertilizer rights: right place. *Crops & Soils. March-April*, 29-33.

Nguu, N., & De Datta, S. (1979). Increasing efficiency of fertilizer nitrogen in wetland rice by manipulation of plant density and plant geometry. *Field Crops Research, 2*, 19-34.

Nguyen, M. (2014). International Symposium on Managing Soils for Food Security and Climate Change Adaptation and Mitigation.

Norman, R., Helms, R., & Wells, B. (1992). Influence of delaying flood and preflood nitrogen application on dry-seeded rice. *Fertilizer research, 32*(1), 55-59.

Norman, R., Wolf, D., Wells, B., Helms, R., & Slaton, N. (1991). Influence of application time and soil moisture condition on yield and recovery of fertilizer nitrogen-15 in dry-seeded rice. *Arkansas rice research studies*, 7-10.

Ohyama, T., M. Ito, K. Kobayashi, S. Araki, S. Yasuyoshi, O. Sasaki, T. Yamazaki, K. Soyama, R. Tanemura, Y. Mizuno, and T. Ikarashi. 1991. . Analytical procedures of N, P, K contents in plant and manure materials using H2SO4-H2O2Kjeldahl Digestion Method.

Okamoto, I. (2004). Agricultural Marketing Reform and Rural Economy in Myanmar The Successful Side of the Reform. *World, 5*(11.4), 1.1.

Olesen, J., Sørensen, P., Thomsen, I., Eriksen, J., Thomsen, A., & Berntsen, J. (2004). Integrated nitrogen input systems in Denmark. *Agriculture and the nitrogen cycle: Assessing the Impacts of Fertilizer use on Food Production and the Environment, 65*, 129-140.

Olsen, S. R. a. L. A. D. Phosphorus. In: Black, C. A. (Ed.), Methods of Soil Analysis Part II. American Society of Agronomy, Inc., Publisher, Madison, Wisconsin, USA. pp. 1035–1049.

CSO (2018). *Myanmar statistical yearbook Central Statistical Organization.The Government of the Republic of the Union of Myanmar.Ministry of Planning and Finance.p 272* Central Statistical Organization.The Government of the Republic of the Union of Myanmar.Ministry of Planning and Finance

Pandey, A., Suter, H., He, J.-Z., Hu, H.-W., & Chen, D. (2019). Dissimilatory nitrate reduction to ammonium dominates nitrate reduction in long-term low nitrogen fertilized rice paddies. *Soil Biology and Biochemistry, 131*, 149-156.

Pathak, H., Aggarwal, P., Roetter, R., Kalra, N., Bandyopadhaya, S., Prasad, S., & Van Keulen, H. (2003). Modelling the quantitative evaluation of soil nutrient supply, nutrient use efficiency, and fertilizer requirements of wheat in India. *Nutrient cycling in agroecosystems*, *65*(2), 105-113.

Peng, S., Garcia, F., Laza, R., Sanico, A., Visperas, R., & Cassman, K. (1996). Increased N-use efficiency using a chlorophyll meter on high-yielding irrigated rice. *Field Crops Research, 47*(2-3), 243-252.

Phongpan, S., Vacharotayan, S., & Kumazawa, K. (1988). Fate and efficiency of urea fertilizer in wetland rice soil. *Soil Science and plant nutrition, 34*(1), 117-126.

Prasad, R., & De Datta, S. (1978). *Increasing fertilizer nitrogen efficiency in wetland rice [in tropical Asia]*. Paper presented at the Nitrogen and Rice Symposium. College, Laguna (Philippines). 18-21 Sep 1978.

Pratt, P. F. Potassium. In: Black, A. (Ed.), Methods of soil analysis part II. American Society of Agronomy, Inc., Publisher, Madison, Wisconsin, USA. pp. 1025–1027.

Qurashi, T., Salam, M., Jannat, M., & Rabbani, M. (2013). Evaluation of urea super granule as a source of nitrogen in transplant aman rice. *Progressive Agriculture*, *24*(1-2), 29-37.

Raun, W. R., & Johnson, G. V. (1999). Improving nitrogen use efficiency for cereal production. *Agronomy Journal*, *91*(3), 357-363.

Reynolds, C., & Wolf, D. (1987). Effect of soil moisture and air relative humidity on ammonia volatilization from surface-applied urea. *Soil science, 143*(2), 144-152.

Robert Edis, I. W., Bob Farquharson,& Deli Chen. (2014). *Management of nutrients for improved profitability and sustainability of crop production in central Burma*. Retrieved from

Robertson, G. P., & Vitousek, P. M. (2009). Nitrogen in agriculture: balancing the cost of an essential resource. *Annual review of environment and resources, 34*, 97-125.

Roy, A. H., Hammond, L. L., Mosier, A., Syers, K., & Freney, J. (2004). Challenges and opportunities for the fertilizer industry. *About Island Press*, 233.

Roy, B. (1985). Nitrogen use efficiency in transplanted rice with point placement method. *Oryza (India).*

Federal Cooperative Extension Service Oregon State College Corvallis

Salman, D., Morteza, S., Dariush, Z., Abbas, G. M., Reza, Y., Ehsan, G. D., & Reza, N. A. (2012). Application of nitrogen and silicon rates on morphological and chemical lodging related characteristics in rice (Oryza sativa L.) at North of Iran. *Journal of agricultural science, 4*(6), 12.

Sarkar, M. A. R., Zobaida, M. R., Yeasmin, S., & Islam, A. M. (2016). Fundamental and Applied Agriculture.

Savant, N., Ongkingco, P., Zarate, I., Torrizo, F., & Stangel, P. (1991). Urea briquette applicator for transplanted rice. *Fertilizer research, 28*(3), 323-331.

Schroder, J., Neeteson, J., Oenema, O., & Struik, P. (2000). Does the crop or the soil indicate how to save nitrogen in maize production? Reviewing the state of the art.[Erratum: Sept 29, 2000, v. 68 (1), p. 85.]. *Field Crops Research, 66*(2), 151-164.

Segda, Z. (2006). *Gestion de la fertilité du sol pour une production améliorée et durable du riz (Oriza sativa L.) au Burkina Faso. Cas de la plaine irrigué de Bagré.* Thèse présenté à l'UFR/SVT. Thèse doctorat UO. BF, 202p+ publications.

T. C. S. (2001). Use of isotope and radiation methods in soil and water management and crop nutrition.

Sharma, P., Abrol, V., & Sharma, R. (2011). Impact of tillage and mulch management on economics, energy requirement and crop performance in maize–wheat rotation in rainfed subhumid inceptisols, India. *European journal of agronomy, 34*(1), 46-51.

Shivay, Y., Prasad, R., Singh, S., & Sharma, S. (2001). Coating of prilled urea with neem (Azadirachta indica) for efficient nitrogen use in lowland transplanted rice (Oryza sativa). *Indian Journal of Agronomy, 46*(3), 453-457.

Smil, V. (1999). Nitrogen in crop production: An account of global flows. *Global biogeochemical cycles, 13*(2), 647-662.

Spoorenberg, T. (2015). Provisional results of the 2014 census of Myanmar: The surprise that wasn't. *Asian Population Studies, 11*(1), 4-6.

Swain, D. K., Bhaskar, B. C., Krishnan, P., Rao, K. S., Nayak, S. K., & Dash, R. N. (2006). Variation in yield, N uptake and N use efficiency of medium and late duration rice varieties. *The Journal of Agricultural Science, 144*(1), 69-83.

Thind, H., Kumar, A., Gupta, R., Kaul, A., & Vashistha, M. (2012). Fixed-time adjustable dose site-specific fertilizer nitrogen management in transplanted irrigated rice (Oryza sativa L.) in South Asia. *Field Crops Research, 126*, 63-69.

Thwe, H. M., Kristiansen, P., & Herridge, D. F. (2019). Benchmarks for improved productivity and profitability of monsoon rice in lower Myanmar. *Field Crops Research, 233*, 59-69.

Turner, F., & Jund, M. (1994). Assessing the nitrogen requirements of rice crops with a chlorophyll meter. *Australian Journal of Experimental Agriculture*, *34*(7), 1001-1005.

Van Hach, C., & Nam, N. (2006). Responses of some promising high-yielding rice varieties to nitrogen fertilizer. *Omonrice, 14*, 78-91.

Vitousek, P. M., Naylor, R., Crews, T., David, M. B., Drinkwater, L., Holland, E., . . . Matson, P. (2009). Nutrient imbalances in agricultural development. *science, 324*(5934), 1519-1520.

Vlek, P., & Craswell, E. (1979). Effect of Nitrogen Source and Management on Ammonia Volatilization Losses from Flooded Rice-Soil Systems 1. *Soil Science Society of America Journal, 43*(2), 352-358.

Vyn, T. J., Faber, J. G., Janovicek, K. J., & Beauchamp, E. G. (2000). Cover crop effects on nitrogen availability to corn following wheat. *Agronomy Journal, 92*(5), 915-924.

Wang, G., Dobermann, A., Witt, C., Sun, Q., & Fu, R. (2001). Performance of site-specific nutrient management for irrigated rice in southeast China. *Agronomy Journal, 93*(4), 869-878.

Wang, Y., Lu, J., Ren, T., Hussain, S., Guo, C., Wang, S., . . . Li, X. (2017). Effects of nitrogen and tiller type on grain yield and physiological responses in rice. *AoB Plants, 9*(2).

Waqar, A., Hira, K., Ullah, B., Khan, A., Shah, Z., Khan, F., & Naz, R. (2014). Role of nitrogen fertilizer in crop productivity and environmental pollution.International Journal of Agriculture and Forestry.Volume 4(3).Pages 201-206 *International Journal of Agriculture and Forestry, 4*(3), 201-206.

Wilson, C., Wells, B., & Norman, R. (1989). Seasonal uptake patterns of fertilizer nitrogen applied in split applications to rice. *Soil Science Society of America Journal, 53*(6), 1884-1887.

Wilson, C., Wells, B., & Norman, R. (1994). Fertilizer nitrogen uptake by rice from urea-ammonium nitrate solution vs. granular urea. *Soil Science Society of America Journal*, *58*(6), 1825-1828.

Wit, C. d. (1992). Resource use efficiency in agriculture. *Agricultural systems, 40*(1-3), 125-151.

Xu, G., Fan, X., & Miller, A. J. (2012). Plant nitrogen assimilation and use efficiency. *Annual review of plant biology, 63,* 153-182.

Xue, L., Cao, W., Luo, W., Dai, T., & Zhu, Y. (2004). Monitoring leaf nitrogen status in rice with canopy spectral reflectance. *Agronomy Journal, 96*(1), 135-142.

Yadav, M., Kumar, R., Parihar, C., Yadav, R., Jat, S., Ram, H., . . . Kumar, U. (2017). Strategies for improving nitrogen use efficiency: A review. *Agricultural Reviews, 38*(1).

Yana, C., Dua, T., Yana, S., Donga, S., Gonga, Z., & Zhangb, Z. (2018). Changes in the inorganic nitrogen content of the soil solution with rice straw retention in northeast China. *DESALINATION AND WATER TREATMENT, 110*, 337-348.

Yoshida, S. (1981). Fundamentals of Rice Crop Science, International Rice Research Institute, Los Baños.

APPENDICES

Appendix 1. Plant height (cm) of Yadanar Toe grown as summer at YAU research farm in 2017

Treatment	Days After Transplanting (DAT)										
	7 DAT	14 DAT	21 DAT	28 DAT	35 DAT	42 DAT	49 DAT	56 DAT	63 DAT	70 DAT	77 DAT
T1	46.6	58.4	71.6	78.2	85.3	95.9	102.7	117.8	124.2	126.3	126.1
T2	45.8	55.9	67.6	76.4	85.1	98.2	106.3	117.8	125.9	126.9	126.6
T3	50.9	59.3	71.3	78.4	85.5	94.7	110.4	121.6	125.4	126.2	125.9
T4	48.1	58.4	70.1	78.5	84.2	96.8	110.9	120.5	128.1	127.3	128.3
T5	51.5	61	74.6	80.8	86.9	97.9	113.5	120.6	125.7	125.5	124.4
T6	50.1	59.8	72.7	80.3	86.3	97.1	112.1	118.7	124.7	124.6	125.0
T7	50.7	62.8	75.2	82.4	88.9	98.9	115.2	122.3	128	128.1	127.5
T8	49.6	63.8	76.8	86.6	92.2	102.9	112.7	120.8	130.8	131.7	130.7
CV%	8.2	7.6	4.6	3.72	3.31	2.53	6.48	3.74	2.86	3.2	3.2
F test	ns	ns	ns	*	ns	*	ns	ns	ns	ns	ns
$LSD_{(0.05)}$	-	-	-	5.2	-	4.3	-	-	-	-	-

Appendix 2. Plant height (cm) of Sin Thukha grown as monsoon at YAU research farm in 2017

Treatment	Days After Transplanting (DAT)									
	7 DAT	14 DAT	21 DAT	28 DAT	35 DAT	42 DAT	49 DAT	56 DAT	63 DAT	70 DAT
T1	56.4	62.4	75.2	80.6	86.2	97.9	114.4	121.8	121.74	122.5
T2	56.4	66.9	77.5	83.5	88.7	95.1	112.7	122.1	123.2	120.9
T3	59.1	72.3	79.4	86	89.5	102.6	114.9	122.9	122.13	122.9
T4	58.4	73.7	79.8	85.4	87.9	98.2	114.9	122.5	122.03	122.9
T5	59.2	71.9	81.3	86.7	91.8	103.4	122.1	125.4	124.47	124.8
T6	59.7	73.4	84.5	91.1	89.7	106.8	123.1	129.1	129.46	127.3
T7	58	68.8	80.7	86.1	89.3	97.5	113.7	122.4	121.68	120.8
T8	63.1	79.5	90.2	98.4	103	110.4	124.8	134.7	134.24	135.4
CV%	5.0	5.9	4.35	4.27	5.28	5.44	4.41	3.54	3.3	3.2
F test	ns	**	**	**	*	ns	ns	*	*	**
$LSD_{(0.05)}$	-	7.3	6.2	6.5	8.4	-	-	7.7	7.2	6.9

Appendix 3. Tiller Numbers of Yadanar Toe grown as summer at YAU research farm in 2017

Treatment	Days After Transplanting (DAT)										
	7 DAT	14 DAT	21 DAT	28 DAT	35 DAT	42 DAT	49 DAT	56 DAT	63 DAT	70 DAT	7 DAT
T1	15.7	20.1	18.8	18.5	18.5	15.9	15.3	13.7	13.9	14.6	13.5
T2	16.1	20	18.9	16.7	18	16.7	15.8	15	15.6	16	15.5
T3	16.1	19.2	17.1	16.5	16.3	14.7	13.5	12.5	13.1	13.4	13.3
T4	17.3	19.6	18.3	16.9	17.3	15.7	15.1	14.7	14.9	15	15.3
T5	18.4	21.7	20.6	19.7	19.5	17.2	16.5	15.6	15	15.8	16.1
T6	17.3	20.7	21.1	18.3	18.2	16.5	16.3	15.1	15.2	14.9	14.9
T7	18.8	21.2	22.1	19.5	18.9	17.5	16.5	13.6	14.5	15.1	14.7
T8	19.6	21.8	20.2	20.6	20.7	18.3	16.9	16.1	16	15.9	16.1
CV%	22.3	12.86	16.1	14.3	14.2	11.9	10.3	11.95	12.15	10.35	11.3
F test	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
LSD $_{(0.05)}$	-	-	-	-	-	-	-	-	-	-	-

Appendix 4. Tiller Numbers of Sin Thukha grown as monsoon at YAU research farm in 2017

Treatment	Days After Transplanting (DAT)									
	7 DAT	14 DAT	21 DAT	28 DAT	35 DAT	42 DAT	49 DAT	56 DAT	63 DAT	70 DAT
T1	10.7	12.9	12.6	11.3	10.6	7.4	7.9	8.3	8.4	9.1
T2	10.5	15.1	12.7	12	11.3	7.5	8.2	8.2	8.7	8.8
T3	11.3	12.9	13.9	12.3	12.6	8.7	8.5	8.9	9.6	9.7
T4	11.9	15.4	13.7	12.3	12.3	8.9	8.7	8.3	9	9.7
T5	13.4	15.6	13.9	13.1	12.1	8.9	9.3	8.6	9.8	10.7
T6	13.6	15.3	15.9	12.9	12.2	8.9	10.7	9.1	10.1	10.1
T7	12.3	15.3	15	13.2	13.5	9.5	9.5	9.1	10.7	10.6
T8	15.3	17.5	16.5	15.1	15.1	10.2	10.5	9.4	9.6	9.6
CV%	17.6	10.78	16	11.79	10.21	11.54	14.32	10.71	13.77	14.23
F test	ns	ns	ns	ns	*	ns	ns	ns	ns	ns
$LSD_{(0.05)}$	-	-	-	-	2.23	-	-	-	-	-

Appendix 5. SPAD value of Yadanar Toe grown as summer at YAU research farm in 2017

Treatment	Days After Transplanting (DAT)										
	7 DAT	14 DAT	21 DAT	28 DAT	35 DAT	42 DAT	49 DAT	56 DAT	63 DAT	70 DAT	7 DAT
T1	38.8	41.4	39.1	38.5	33.4	33.2	35.4	35.7	36.7	34.9	32.4
T2	38.3	41.9	38.6	38.3	34.5	33.3	36	36.3	37.1	36.4	35.4
T3	36.6	41	36.4	37.3	34.6	34.2	35.6	34.8	37.5	34.9	33.3
T4	37.1	38	37.6	37.8	35.1	34.1	37.4	38.5	38.1	36.8	37.2
T5	40.7	42.2	38.5	38.4	36.5	36.5	39.8	38	40.3	38.4	38.1
T6	39.3	40.3	37.4	37.3	37	36.9	40.3	38.8	38.3	37.1	38.6
T7	38.6	39.8	37.9	38.4	36.5	37	40	39.7	38.8	38.2	38.7
T8	39.2	42.3	40.9	41.2	35.9	34.6	37.4	37.3	38.5	37.5	38.0
CV%	3.81	6.38	5.53	4.04	4.09	5.88	5.47	3.03	3.64	4.93	6.14
F test	ns	ns	ns	ns	ns	ns	*	**	ns	ns	*
LSD (0.05)	-	-	-	-	-	-	3.61	1.98	-	-	3.9

Appendix 6. SPAD value of Sin Thukha grown as monsoon at YAU research farm in 2017

Treatment	Days After Transplanting (DAT)									
	7 DAT	14 DAT	21 DAT	28 DAT	35 DAT	42 DAT	49 DAT	56 DAT	63 DAT	70 DAT
T1	38.1	37.3	36.9	37	36.3	36.1	41.2	39.1	37.9	34.1
T2	38.7	38.3	38	36.7	35	35.1	40.3	39.5	37.3	37.6
T3	39.6	38.7	38.5	36.6	36.5	38.3	43.1	39.4	38.8	37
T4	40.5	39.8	39.7	37.9	36.1	40.6	43	40.4	39.6	38.9
T5	39.9	38.9	38.5	37.6	35.8	40.6	43.6	40.8	39.7	35.5
T6	40.8	40.4	39.8	38.8	37.2	40.9	42.6	42.9	40.5	37.4
T7	41.3	40.6	40.3	38.7	36.3	40.9	44.1	41.7	40.4	39.1
T8	40.4	40.1	39.5	41.2	39.3	37.9	41.5	42.6	40.5	36.9
CV%	2.62	2.9	3.33	3.93	2.83	2.98	2.45	4.05	2.03	7.83
F test	*	*	ns	*	**	**	**	ns	**	ns
LSD (0.05)	1.83	2	-	2.62	1.81	2.03	1.82	-	1.4	-

Appendix 7. Grain and straw N uptake at harvest of Yadanar Toe in summer season and Sin Thukha in monsoon season at YAU research farm in 2017

Treatment	Yadanar Toe		Sin Thukha	
	Grain N uptake (kg ha^{-1})	**Straw N uptake** (kg ha^{-1})	**Grain N uptake** (kg ha^{-1})	**Straw N uptake** (kg ha^{-1})
T1= Control	90.77	54.33	73.00	95.67
T2= 0 kg N ha^{-1}	73.58	72.67	50.00	95.67
T3= 30 kg N ha^{-1}	98.07	104.00	73.67	108.67
T4= 77.6 kg N ha^{-1}	118.45	117.00	72.67	126.67
T5=100 kg N ha^{-1}	128.23	115.33	77.0	133.67
T6=130 kg N ha^{-1}	133.35	124.33	77.0	117.00
T7=160 kg N ha^{-1}	125.79	114.00	67.67	131.67
T8= USG 77.6 kg N ha^{-1}	112.62	130.00	73.33	126.67
CV%	5.87	28.38	9.56	20.48
Pr>f	**	ns	**	ns
LSD $_{(0.05)}$	51.67	-	11.80	-

Means followed by different letters in the same column are significantly different by LSD test at 5% level.
* **Significant difference at 1% level