2020-10-21

EFFECTS OF SOURCES, RATES AND TIME OF APPLICATION OF NITROGEN FERTILIZER ON YIELD AND YIELD RELATED COMPONENTS OF UPLAND RICE (Oryza sativa L.) IN FOGERA DISTRICT, NORTHWESTERN ETHIOPIA

Tadesse, Tilahun

http://hdl.handle.net/123456789/11448

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M. Sc. Thesis

By:

Tadesse Tilahun Tawuye

August 2020

Bahir Dar, Ethiopia

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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN AGRONOMY

August 2020

Bahir Dar, Ethiopia

THESIS APPROVAL SHEET

As members of the Board of Examining of the Master of Science (MSc.) thesis open defense examination, we have read and evaluated this thesis prepared by **Mr. Tadesse Tilahun Tawuye** entitled **“Effects of Sources, Rates and Application Time of Nitrogen Fertilizer on Yield and Yield Related Components of Upland Rice (*Oryza sativa* L.) in Fogera District, Northwestern Ethiopia**”. We hereby certify that; the thesis is accepted for fulfilling the requirement for the award of the degree of Master of Science (MSc.) in Agronomy.

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DECLARATION

This is to certify that this thesis entitled “**Effects of Sources, Rates and Application Time of Nitrogen Fertilizer on Yield and Yield Related Components of Upland Rice (***Oryza sativa* **L.) in Fogera District, Northwestern Ethiopia**” submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in “**Agronomy**” to the Graduate Program of College of Agriculture and Environmental Sciences, Bahir Dar University by Mr. **Tadesse Tilahun Tawuye** (ID. No. BDU 0805575) is an authentic work carried out by him under our guidance. The matter embodied in this thesis work has not been submitted earlier for award of any degree or diploma to the best of our knowledge and belief.

Name of the Student
Tadesse Tilahun Tawuye

Signature ------------------------------ Date -------------- 2020

Name of the Advisors

1) Dr. Tilahun Tadesse (Major Advisor)

Signature ------------------------------ Date -------------- 2020

2) Dr. Getachew Alemayehu (Co-Advisor)

Signature ------------------------------ Date -------------- 2020

ACKNOWLEDGEMENTS

Right from the outset, I would like to thank the supreme Almighty **God** for providing me the patience and endurance to complete the study.

I wish to express my most sincere appreciation and gratitude to my major research advisor, Dr. Tilahun Tadesse, for his encouragement, constructive suggestions, practical guidance and assistance from the very beginning with the completion of this thesis write-up. My gratitude also goes to Ethiopian Agricultural Research Institute (EIAR), Fogera National Rice Research and Training Centre (FNRRTC), for permission of the work. My deepest gratitude goes to my co-advisor, Dr. Getachew Alemayehu for his technical advices, material support, frequent supervision with genuine comments, reviewing the thesis and facilitating better working environment and encouragement.

My very special thanks and appreciation also goes to Mr. Zelalem Tadesse, Agronomy Research Division of the FNRRTC, for his unreserved help and coordinating the logistics to this thesis work starting from the inception through to completion. I also wish to thank Mr. Eyaya and Demeke, field experts in the division, for their assistance in the collections of the data.

My special gratitude goes to my wife W/o. Wudset Demelash, for her constant encouragements over and above the total burden of family responsibilities throughout my graduate work. My indebtedness goes to my friend Mr. Getachew Engdayehu for his moral support and encouragement. I wish also to express my greatest thanks to Mr. Mucheye Adugna, Mr. Chalachew Baye, and Mr. Alemzewud Melsew for their direct and indirect contributions in the study. I extend my wordless thanks to my father for training me and paying all the sacrifice where need be. My sincere gratitude also goes to my dear brothers and sister for their huge and endless love and support.

I acknowledge to all my friends, fellows and individuals who have not been mentioned here, but contributed directly or indirectly to the successful completion of my research.

ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
BNF	Biological Nitrogen Fixation
CIMMYT	Centro International de Mejoramiento de Maiz y Trigo/International Wheat and Maize Improvement Centre
CSA	Central Statistical Agency
DHAOGTR	Department of Health and Ageing Office of the Gene Technology Regulator
EIAR	Ethiopian Institute Agricultural Research
FAO	Food and Agricultural Organization
FNRRTC	Fogera National Rice Research and Training Centre
FWOA	Fogera Woreda Office of Agriculture
FYM	Farm Yard Manure
GLM	General Linear Model
GM	Green Manure
ICARDA	International Centre for Agricultural Research in the Dry Areas
IPMS	Improving Productivity and Market Success
MoARD	Ministry of Agriculture and Rural Development
NERICA	New Rice for Africa
RH	Relative humidity
SAS	Statistical Analysis Software
SNNPR	Southern Nation, Nationalities and Peoples Region
SOM	Soil Organic Matter
SSA	Sub-Saharan Africa
USDA	United States Department of Agriculture
WARDA	West Africa Rice Development Association

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDIX TABLES

Appendix Table Page

LIST OF APPENDIX FIGURES

Effects of Sources, Rates and Application Times of Nitrogen Fertilizer on Yield and Yield Related Components of Upland Rice (*Oryza sativa* L.) in *Fogera* District, Northwestern Ethiopia

By:

Tadesse Tilahun Tawuye

Advisors: Dr. Tilahun Tadesse and Dr. Getachew Alemayehu

ABSTRACT

Upland rice (NERICA-4) is a highly valued crop in Northwestern Ethiopia. However, its productivity is very low due to insufficient nitrogen supply, inappropriate sources and nitrogen application time. Therefore, a field experiment was conducted on farmers' field at Fogera District in Northwestern Ethiopia during 2018 cropping season to determine the right sources, rates and timing of Nitrogen application to maximize the productivity of upland rice. A factorial combination of three nitrogen rates (69, 103.5, and 138 kg N ha^{-1}), three N application times (T1=1/3 at planting, 1/3 at tillering and 1/3 at PI (panicle initiation), T2= 1/3 15 DAS (days after sowing), 1/3 at PI and 1/3 at Heading, and T3= 1/3 15 DAS and 2/3 at PI (NTA3)) and two N fertilizer sources, urea stable (US) (46% N) and common urea (CU) (46% N)) were laid out in randomized complete block design with three replications. Phenological, growth and yield related data were collected and analyzed using SAS V 9.0. The ANOVA result of this experiment showed that dry biomass and grain yield were significantly affected by the main effects of nitrogen source, rates and time of application. Whereas most yield and yield related components of upland rice were influenced by interaction effects of N sources, rates and application times. The highest grain yield (6.16 t ha^{-1}) was recorded in common urea (CU) Nitrogen source, at a rate of 69 kg N ha $^{-1}$, and when the N was applied at 1/3 at 15 DAS + 2/3 at PI (NTA3). The partial budget analysis revealed that the combination of common urea (CU), at a rate of 69 kg N ha $^{-1}$, and when the N was applied at 1/3 at 15 DAS + 2/3 at PI (NTA3) is economically feasible with maximum net benefit of 93,393.53 ha^{-1} ETB as compared to others. Therefore, it can be concluded that this treatment is recommended for enhancing NERICA-4 rice productivity in the study area, Fogera district. However, it needs to repeat the research in a number of sites and seasons to come up with strong recommendations.

Key words: Biomass yield, Common urea, NERICA-4, Stable urea, Total tillers

Chapter 1. INTRODUCTION

1.1. Background and Justification

Rice has become a highly strategic and priority commodity for food security in Africa. Consumption is growing faster than that of any other major staple on the continent because of high population growth, rapid urbanization, and changes in eating habits (Seck *et al.,* 2013). It is the single most important source of dietary energy in West Africa and the third most important for Africa as a whole. Although local rice production increased rapidly after the 2007-2008 food crisis, a key problem facing the rice sector in Africa in general is that local production has never caught up with demand. The continent therefore continues to rely on importation to meet its increasing demand for rice (Afework Hagos and Lemma Zemedu, 2015).

Rice is the most rapidly expanding food commodity both in consumption and production in sub-Saharan Africa (SSA). Rice consumption (milled grain) was more than tripled from 9.2 Mt to 31.5 Mt during the period of 1990 to date in SSA (USDA, 2018). However, the average rice yield in SSA is still around 2.1 t ha^{-1}, and a recent database showed that yield growth tended to become stagnant again in the period of 2012 up to 2018 (USDA, 2018).

Rice has become a commodity of strategic significance in Ethiopia for domestic consumption as well as export market for economic development (Hegde and Hegde, 2013). It is regarded as a strategic crop for food security and income generation in line with the poverty eradication strategy. Amongst of the target commodities that have received due emphasis on the promotion of agricultural production, rice is considered as "the new Millennium crop of Ethiopia" expected to contribute to ensuring food security in the country (MoARD, 2010). Even though, it is a recent introduction to the country, rice has shown promise as to be among the major crops that can immensely contribute towards ensuring food security in Ethiopia. At the *Fogera* plain, rice plays an important role in relaxing the problem of food-insecurity of the farming community (Berhanu Gebremedhin and Dirk, 2007).

Nitrogen is the most important mineral nutrient that plants take up from the soil in different growth stages. Nitrogen is the main scarce nutrient in crop production. Therefore, most non legume cropping systems need more nitrogen inputs. Several nitrogen sources are available for use in supplying nitrogen to crops (Ghaly and Ramakrishnan, 2015). Nitrogen availability to crop is one of the major limiting factors in the productivity of major crops such as cereals (Glass, 2003). The increase in the use of nitrogen (N) fertilizers for enhancing the agricultural production has been under consideration for the last fifty years (Hirel *et al.,* 2007). For economic and environmental reasons, nitrogen fertilizers should be utilized more efficiently as much as possible in agriculture production.

1.2 Statement of the Problem

Despite the potential of rice in poverty reduction and enhancement of food security, its production and productivity of the crop under farmers' field conditions in the country in general and in the *Fogera* District in particular is low compared to other parts of the world. The profitability of rice production system depends on solving of its constraints such as, low fertility of soil, low adaptation of improved technology, low of fertilizer consumption and lack of adopted varieties. In addition, lack of suitable fertilizer recommendations coupled with high fertilizer costs are two major reasons for the poor nutrient management in rice fields (Tilahun Tadesse, 2020).

Weeds, pests, soil nutrient deficiencies and terminal moisture stress are the major causes of low rice productivity in Ethiopia (Kiros Habtegebrial *et al*., 2013). Poor soil fertility is among the major factors limiting rice production in Ethiopia. Appropriate fertilizer application is an important management practice to improve soil fertility and production of rice (Alem Reda *et al*., 2018).

Since fertilizer is an expensive and precious input, determination of an appropriate dosage of application that would be both economical and appropriate to enhance productivity is important. The application of nitrogen fertilizer either in excess or less than optimum rate affects both yield and quality of rice to a remarkable extent, hence proper management of crop nutrition is of immense importance. Even when the fertilizer supply is satisfactory, the importance of increasing its use efficiency cannot be underestimated. Utmost care should also be bestowed in selecting the type of fertilizer as well as the timing of fertilizer application. Therefore, availability of nitrogen at various plant growth stages is important to reduce nitrogen loss and increase rice. Increasing the fertilizer use efficiency is very important, particularly in developing countries where the cost of fertilizer is rather very high and increasing. The judicious use of fertilizers contributes a lot towards improving the yield and quality of grain (Aamer *et al.*, 2000). Nitrogen fertilizer management technologies are so important for enhancing resource or input use efficiency.

Though rice production at the *Fogera* plain is expanding rapidly from year to year because of its wider adoption from farmers' social, economic, and environmental perspectives, the production and productivity of the rice crop under farmers' field conditions is low, about 2.844 t ha^{-1} (CSA, 2018). As these consequences, rice production in the study area is not as expected as its potential compared with the other part of the world, which was 4.6 t ha^{-1} (FAOSTAT, 2018). Hence, to enhance the profit of the grower under given situation, it needs intensive study. Therefore, on account of these and given the importance of N fertilization on rice yield, it is necessary to determine the best N source, rates and fertilizer application time as well as their influence on yield and yield related parameters of upland rice in *Fogera* District.

1.3 Objectives

1.3.1 General objective

The general objective of the research was to determine the appropriate sources, rates and Nitrogen fertilizer application time for enhanced production of upland rice (NERICA-4) in *Fogera* District.

1.3.2 The specific objectives

This research was conducted to accomplish the following specific objectives:

- ✓ To evaluate the effect of different sources, rates, and time of N fertilizer application on yield and yield related components of upland rice (NERICA-4) in *Fogera* District;
- ✓ To estimate the efficient and economical use of upland rice to N fertilizer input in the study area; and
- ✓ To identify and suggest the optimum combinations of N sources, rate and time of application that would be maximizing the yield and yield related components of upland rice (NERICA-4) in the study area.

Chapter 2. LITERATURE REVIEW

2.1 Origin and Distribution of Rice

Rice (*Oryza sativa* L.) which is the seed grain of the monocot plants (Asian rice) or *Oryza glaberrima* (African rice). Rice is the most important staple food for the large areas of the world population and is the second highest in production and consumption in the global (FAO, 2009). Rice has been cultivated in China since ancient times and was introduced to India before the time of the Greeks. Chinese records of rice cultivation go back 4 000 years. In classical Chinese literature the words for agriculture and for rice culture are synonymous, signifying that it was already a staple crop at the time the language was taking form. In several Asian languages, the words for rice and food are identical. Many ceremonies have arisen in connection with planting and harvesting rice, and the grain and the plant are traditional motifs in Oriental art. Thousands of rice strains are now known, both cultivated and escaped, and the original form is unknown (Yoshida, 1981). Rice grown in Asia is classified into three sub species known as Indica, Joponica and Javanica (Gupta and O'Toole, 1986).

Cultivation of crop has been carried into all regions having the necessary warmth and abundant moisture favorable to its growth, mainly subtropical rather than hot or cold. The crop was common in West Africa by the end of the 17th century. It is thought that slaves from that area were transported to the Carolinas in the mid–18th century (FAO, 2009).

2.2 Description of Rice

Rice belongs to family Poaceae and genus *Oryza*, and most probably originated in India or Southeastern Asia. The tribe *Oryza* is an isolated group in the family *Poaceae* and is characterized by an aquatic mode of life. There are 27 species of *Oryza* till date of 2005. Of 27, only two species, namely Asian rice (*Oryza sativa* L.) and the African rice, (*Oryza glaberrima* Steud), are cultivated in the world (DHAOGTR, 2005).

Rice is a self–pollinated, short day crop and is a semi–aquatic plant which consist arenchymatic tissues. Arechymatic cells of leaf culm and root give out oxygen from aerial parts downward the roots which allow the crops adaptation to waterlogged conditions. A rice plant possesses a fibrous root system which consists of, rootlets and root hairs; and seminal roots developing from the seed. The plant has adventitious roots which are real functional roots develop from the lower nodes of the culm (Yoshida, 1981). Plant height can be 1-1.8 m, rarely more or less of this depending on the cultivated variety and fertility status of the given soil. Leaves are slender, 50 to 100 cm long while width is 2-2.5 cm. Rice produces tillers and flowers in branched arching to inflorescence, 30-50 cm long with the grain length ranging from 5-12 mm (FAO, 2009).

2.3 Ecological Requirements of Rice

Rice is primarily a tropical and subtropical crop. However, some temperate regions in the world like Japan, Korea and Italy produce good grain yield of the crop. The climatic conditions like temperature, rainfall, relative humidity, solar radiation; soil types and nutrient status may affect the crop development and performance (FAO, 2009). Rice requires a hot and high humidity climate. High altitude and low temperature delay its flowering and maturity. Temperature ranging from 25℃ to 35℃ throughout the life cycle is conducive to its growth and development (Reyes, *et al*., 2003). Except Antarctica, every continent in the world produces rice. It is grown from the equator to latitudes of 53ºN (in China) and 40º S and elevations (in tropical regions) as high as 3000 meters above sea (m.a.s.l) (FAO, 2013). Amgain *et al*. (2006) reported that on decreasing of both maximum and minimum temperature by 4℃ and increasing solar radiation by 1MJ/m^2/day, increased the rice grain yield by 18% and growth duration by 24 days showing the interactive effect of temperature and solar radiation. They further reported that temperature, solar radiation, and water directly affect the physiological processes involved in grain development and indirectly affect grain yield through influencing the incidence of diseases and insects. According to Tunde *et al*. (2011) yield of rice is directly related to the solar radiation at reproductive and ripening phase.

Relative humidity (RH) directly influences the water relations of rice plant and indirectly affects leaf growth, photosynthesis, pollination, occurrence of fungal diseases such as rice blast and leaf blast and finally economic yield. The dryness of the atmosphere as represented by saturation deficit (100 – RH) reduces dry matter production in rice plant through stomatal control and leaf water potential. Reduced transpiration influences translocation of food materials and nutrients, moderately high RH of 60 - 70% is beneficial to rice crop development and performance (FAO, 2002).

Rice is cultivated on a wide range of soils from sandy loam to heavy clay soils. It is well recognized that heavy soils with characteristics of river valley are more preferred than lighter soils in rice cultivation. The best soil for rice should have fine fractions of silt and clay, while a difference in yield from one place to another may be due to greater variation in soil conditions and extension of rice cultivation to unsuitable soils. The optimum soil pH for rice growth in dry conditions is 5.5 - 6.5. It may rise from 7.0 - 7.2 under flooded conditions (WARDA, 2008).

In upland rice, soil structure and fertility are major yield determinants because the amount of mineral fertilizer used is often small while in irrigated rice, soil structure is deliberately destroyed during land preparation. The effect of flooding generally improves nutrient availability and reduces the effects of very alkaline or acid soil conditions on plant growth that occurs under aerobic conditions (Nwilene *et al*., 2008). In high rice yielding environments where improved varieties are used, the difference between the soil's indigenous nutrient supply and crop nutrient demand must be provided in the form of mineral fertilizer.

The dominant ecological factor that distinguishes different kinds of rice cultures is the surface hydrology of rice fields (Sharma *et al*., 1994). There are five rice ecosystems: irrigated, rain-fed lowland, upland, deep-water and tidal wetlands (Singh and Singh, 2000). Irrigated rice accounts for 55% of the world's rice area and about 75% of world's production. Rain-fed lowland and upland rice ecosystems are associated with position in topo-sequences and are defined by the water regime encountered (Buresh, 2002). Rain-fed lowland rice grows in bunded fields that are flooded for at least part of the season (Oberthuer and Kam, 2000). Upland rice is grown under rain-fed conditions on both and sloping fields with naturally well-drained soil and without surface water accumulation (Sharma *et al*., 1994). Upland rice is usually produced under aerobic conditions without irrigation or paddling. The crop can be found in a range of environments from low–lying valley bottom to steep sloping land with high runoff, where land preparation and sowing is done under dry conditions as direct sowing. This rice is also grown either as a monocrop or as mixture with other food crops normally without any fertilizer use (FAO, 2009). This type of rice can be grown on wide range of soils varying from moderately drained to well drained soils such as sandy loam to sandy clay, respectively. The optimum soil pH for rice growth in dry conditions is 5.5 to 6.5. It may rise from 7.0 to 7.2 under flooded conditions (Somado *et al.,* 2008).

Most smallholder upland rice farmers do rarely use inorganic fertilizers and/or manure. This situation is attributed by financial constraints, availability of fertilizer, high price of fertilizers, availability of inadequate manure, transportation problems due to bulkiness of FYM required per unit area and in some area's ignorance among farmers on an importance of FYM is also another factor (Kajiru, 2006).

2.4 Rice Production in the World

Globally, annual paddy rice production covers an area of 167.2 million ha with 769.9 million t of grains (FAOSTAT, 2018). According to FAOSTAT (2018), the production share of paddy rice in the world was 90% in Asia, 5.2% in America, 3.5% in Africa, 0.6% in Europe and 0.1% in Oceania. Rice is the most rapidly expanding food commodity both in consumption and production in sub-Saharan Africa (SSA). Currently in SSA, rice is the second largest source of caloric intake after maize, and it is anticipated that rice demand will increase continuously given the high rate of population growth and rapid urbanization in the region, which has resulted in a shift in consumer preference in favour of rice (Balasubramanian *et al*., 2007; van Oort *et al*., 2015). In response to this growing demand, total rice production in SSA has gradually increased. In the past, this increase was mainly attributed to the expansion of harvested areas (Otsuka & Kalirajan, 2006), although recently it has been attributed to increased yield (Seck *et al*., 2013).

2.5 History of Rice Production in Ethiopia

The cultivation of rice in Ethiopia is of more recent history than its utilization as a food crop. Some studies (e.g. Tilahun Gebey *et al*., 2012) discussed the history of rice (*Orya sativa*) production in Ethiopia. These documents identify two sources of rice species in Ethiopia. The first is a wild rice in *Fogera* plain in the 1970s as a basis for the introduction of rice. Whereas the second discusses that rice came to Ethiopia with the technical support of North Korean experts at the end of 1970s and with the support of those experts' research on rice was initiated at *Jigna* in *Dera* sub-district and *Shega* in *Fogera* cooperatives. This discontinued after 1991 with the change of government and collapse of cooperatives. After this an expert collected seeds from *Jigna kebeles* and multiplied and distributed to farmers. Following this effort, the *Adet* Agricultural Research center released three other rice varieties called *Gumera, Kokit* and *Tigabe*, and rice extension service was given attention in the 1990s within six *kebeles* (Tilahun Gebey *et al*. 2012) and the extension system was promoting rice production. Gradually, the farmers in the six *kebeles* started to produce and consume rice with increasing taste and preferences. Note that whereas this is how rice was started in northern Ethiopia, rice production in *Chewaka* in southern Ethiopia was started differently. In *Chewaka* a farmer who settled from *Hararge* started to produce rice by using the seed he brought from *Hararge*. In the year following, other farmers followed his experience and adopted to produce rice. After looking at the good start of farmers, agricultural experts, researchers (e.g. Bako Agricultural Research Centre) and other stakeholders (e.g. Sasakawa Global 2000) contributed to the expansion of rice production in *Chewaka* and other Zones of *Oromia* and in SNNPR. Currently, the Amhara, *Oromia*, *Benishangul-Gumuz,* Southern nations and Nationalities and *Gambela* regions are developing into major rice-producing areas in Ethiopia (Tilahun Tadesse, 2020).

2.6 Potential and Actual Rice Production in Ethiopia

Ethiopia has a huge potential in both rain-fed and irrigation areas for rice production. It is estimated that a potential of about thirty million ha (5.6 million ha highly suitable and about 25 million ha land suitable) land is available in the country for rain-fed rice production (MoARD, 2010; CSA, 2012; Dawit Alemu, 2015). The country is also endowed with huge irrigation potential for rice crop which accounts about 3.7 million ha of land (Dawit Alemu, 2015). The possibility of growing rice in both rainfed and irrigated agro-eco-systems of both lowland and intermediate areas demonstrates the opportunity the crop creates for poverty reduction in these target ecologies.

Ethiopian government recognized that rice can significantly contribute to improving food security and poverty reduction. As Dawit Alemu (2015) discussed that rice could suitably grow in many parts of the country, the predominant potential areas are:-West central highlands of Amhara Region (*Fogera*, *Gonder Zuria*, *Dembia*, *Takusa* and *Achefer*); North West lowland areas of Amhara and Benshangul Regions (*Jawi*, *Pawi*, *Metema* and *Dangur*); Gameblla regional state (*Abobo* and *Etang* Districts); South and South West Lowlands of SNNPR (*Beralee*, *Weyito*, *Omorate*, *Gura Ferda* and *Menit*); Somali Region (*Gode*); South-Western Highlands of Oromia Region (*Illuababora*, East and West *Wellega* and *Jimma* Zones).

Nearly all the rice varieties grown until recently in Ethiopia were the Asian types that have poor adaptation to upland conditions. However, to meet the vast potential of the upland environment to grow rice, the upland rice variety NERICA (New Rice for Africa) has been recently introduced and grown in the different parts of the country (Zenna *et al*., 2008). Since 1998 when the first rice variety was released in the country 35 improved varieties have been released, of which 15 are rainfed upland, 11 rainfed lowland and the rest 9 are irrigated type varieties (Tilahun Tadesse, 2020). The trend in the use of improved varieties showed a considerable increased since to 2007 and their use varies over the years.

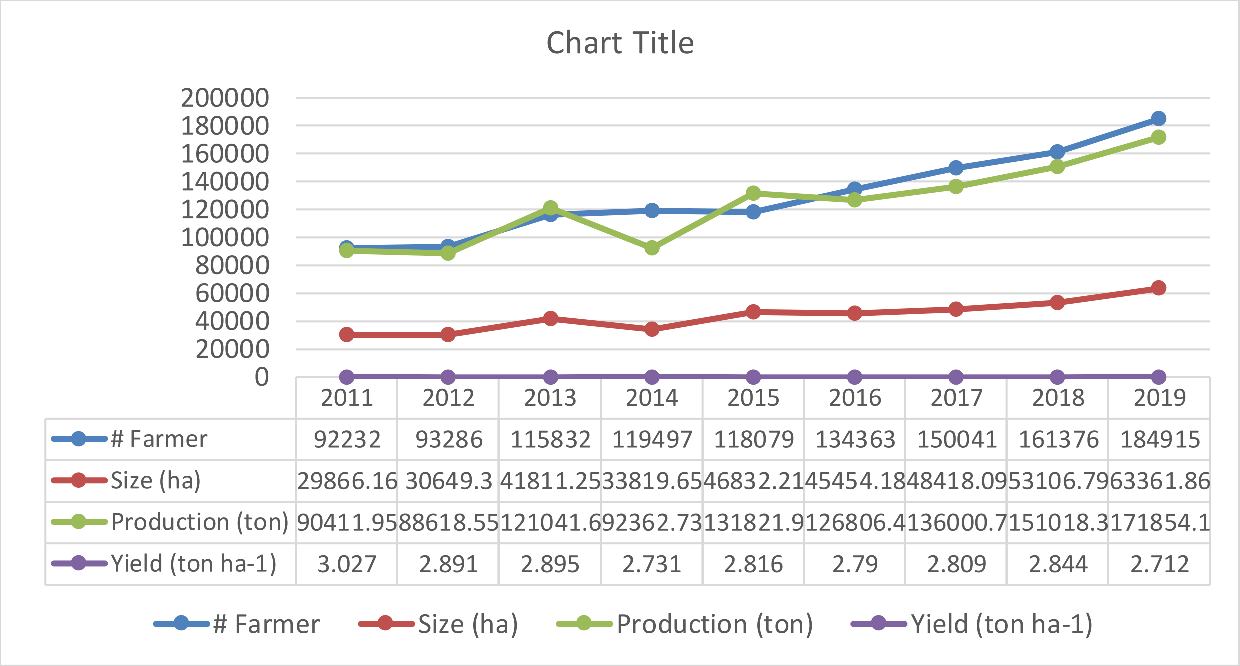
Rice production in Ethiopia has started a few decades ago and now the country is proved to have reasonable potential to grow different rice types for rain fed lowland, upland, and irrigated ecosystems. Rice is currently considered as a strategic food security crop and its use as a food crop, income source, employment opportunity and animal feed has been well recognized in Ethiopia (Teshome Negussie and Dawit Alemu, 2011).

Rice remains as a minor crop in Ethiopian Agriculture though the demand for improved rice technologies is increasing from time to time from different stakeholders. As the figure below

(Figure 1) indicated the previous nine years the total cultivated area at the national has increased from 29,866 in 2010/2011 to 63,361 hectares in 2018 / 2019. The cultivated area has increased from 2018/19 as compared to 2010/11 by about 112.15% which is doubled nationally. Accordingly, rice production has increased from a total of 90.411t, from 2010/11 to 171,854.09 t in 2018/19. While productivity in t ha^{-1} has decreased from 3.027 in 2010 to 2.712 in 2018 and the number of participating farmers increased from 92,232 in 2010 to 184,915 in 2018 cropping season (CSA, 2010; CSA, 2011 and CSA, 2019). However, rice remains as a minor crop in Ethiopia both in area coverage and production compared to a large area and favorable agro-climatic conditions, the country has immense potential for expanding rice production.

The demand for improved rice technologies is increasing from time to time from different stakeholders. Whereas the previous nine years the total cultivated area at the national has increased from 29,866 in 2010/2011 to 63,361 hectares in 2018 / 2019. The cultivated area has increased from 2018/19 as compared to 2010/11 by about 112.15% which is doubled nationally. Accordingly, rice production has increased from a total of 90.411t, from 2010/11 to 171,854.09 t in 2018/19. While productivity in t ha^{-1} has decreased from 3.027 in 2010 to 2.712 in 2018, due to continuous monocropping and the number of participating farmers increased from 92,232 in 2010 to 184,915 in 2018 cropping season (CSA, 2019; Tilahun Tadesse, 2020). However, rice remains as a minor crop in Ethiopia both in area coverage and production compared to a large area and favorable agro-climatic conditions, the country has immense potential for expanding rice production.

Though the productivity of rice in Ethiopia is better than many African countries, it is lowered compared to the world average productivity. Estimated yields for 2018/2019 was 2.712 t ha^{-1} (CSA, 2019) and is lower compared to 5.80 t ha^{-1} in Europe, 4.93 t ha^{-1} in the Americas and 4.22 t ha^{-1} in Asia in 2006 (Sreepada and Vijayalaxmi, 2013).



	2011	2012	2013	2014	2015	2016	2017	2018	2019
# Farmer	92232	93286	115832	119497	118079	134363	150041	161376	184915
Size (ha)	29866.16	30649.3	41811.25	33819.65	46832.21	45454.18	48418.09	53106.79	63361.86
Production (ton)	90411.95	88618.55	121041.6	92362.73	131821.9	126806.4	136000.7	151018.3	171854.1
Yield (ton ha-1)	3.027	2.891	2.895	2.731	2.816	2.79	2.809	2.844	2.712

Figure 2.1: Rice production trend in Ethiopia

2.7 Constraints of Rice Production in Ethiopia

The average rice productivity in Ethiopia is estimated at 2.712 t ha^{-1} (CSA, 2019), which is much lower than the World's average of 4.4 t ha-1 (Sreepada and Vijayalaxmi, 2013). Weeds, pests, soil nutrient deficiencies and terminal moisture stress are the major causes of low rice productivity in Ethiopia (Kiros Habtegebrial *et al*., 2013; Alem Reda, 2018; Tilahun Tadesse, 2020). Poor soil fertility is among the major factors limiting rice production in Ethiopia. Appropriate fertilizer application is an important management practice to improve soil fertility and production of rice. Productivity increments were observed in various experiments conducted on soil nutrient management for rice production in Ethiopia (Tilahun Tadesse and Zelalem Tadesse, 2019).

2.8 Rice Production in the Study Area (*Fogera* District)

Rice is one of the important crops that is grown in *Fogera* Plain of Ethiopia (Tesfaye, Befekadu, and Aklilu, 2005). *Fogera* plain is one of the main producers of rice which contributes 58% of the region and 28% of the national production of rice. In the plain, rice is one of the food crops produced by many of the farmers, after teff, maize and finger millet. Study conducted by Berhanu Gebremedhin and Dirk (2007) indicated that 72% of the households are producers of rice and about 50% of the farmers sell rice in the area. The District has 33 rural *kebele* administrations, of which 28 *kebeles* produce rice. From those *kebeles,* 21 *kebeles* produce lowland rice and six *kebeles* produce upland rice. The possibility of growing rice in both rainfed and irrigated agro-eco-systems of both lowland and intermediate areas demonstrates the opportunity the crop creates for poverty reduction in these target ecologies. Although the rice production in the district is increased time to time

2.9 Sources of Nitrogen

Nitrogen exists naturally in our environment and is constantly being converted from organic to an inorganic form and vice versa. Production of fertilizer adds up to the natural source of nitrogen (Smil, 2001). In general, source of Nitrogen nutrient may either organic or inorganic form. Nitrogen is available for plants from many different sources such as industrial N fixation, atmospheric N fixation, biological N fixation and from organic resources.

2.9.1 Organic sources of N

Plants may get N from organic sources such as, biological N fixation, atmospheric N fixation, and other organic resources. Leguminous crops can improve soil fertility through nitrogen fixation, such as, grass pea and check pea which are used as intercropping in the study area. Various cropping systems have shown good impact is soil nutrients amendment like improving of N, P and K (Prasad *et al*., 2011). In addition, a small amount of nitrogen is also contributed by rainfall in the form of nitric acid (HNO_3) through atmospheric N fixation, which when dissolved in the soil water disassociates into hydrogen and nitrate ions. The nitric acid is formed when nitrogen and oxygen gases are combined with water by the intense heat of a lightning bolt during a thunderstorm. Moreover, there are various types of organic manures contains nitrogen. They are bulky organic manures includes farmyard manures (FYM) (0.5% N), poultry manure (3.03% N), compost including Farm (0.5% N) and refuse of town (1.4% N) and green manure (G.M) (Alagappan, 2016) etc. FYM have traditionally been used by rice farmers (Satyanarayana *et al*., 2002). FYM application has been reported to improve crop growth by supplying plant nutrients including micronutrients as well as improving soil physical, chemical, and biological properties (Dejene Mengistu and Lemlem Mekonnen, 2012). Poultry manure and other animal waste products (e.g., cow dung) were used as a source of supplemental nitrogen long before inorganic nitrogen fertilizer came into popular use. The doses of chemical fertilizer may be reduced by 33% for both dry and wet season by using cow dung and ash in the dry season (Saleque *et al*., 2004). Composted plant residues, legumes plowed under as green manure, and animal wastes continue to be used today, especially by organic crop producers, as a source of nitrogen. From the plant origin there are also concentrated organic manures, such as, oil cakes of castor, cotton, safflower, coconut, groundnut, linseed, rapeseed, safflower, sesamum etc. While from animals, they are blood meal, fish meal, raw bone meal, horn and hoof meal etc. Concentrated organic manures contain relatively maximum amount of N compares to bulky organic manures (Khalil, 2015).

2.9.2 Inorganic source of N

Artificial Fertilizers, on the other hand, contain one or more plant nutrients in concentrated readily available forms. They can be so applied as to supply the nutrients needed by plants and thereby increase crop growth and yield (Panda, 2006). Until 2013, urea and DAP (di-ammonium phosphate) fertilizers have been the only fertilizer sources that have been in use in the Ethiopian agriculture for more than four decades since 1960s. None of these are locally produced and should be supplied by imports to meet the demand. Now adays DAP is being gradually substituted by NPS starting from 2014/15 to meet the sulfur demand of most of Ethiopian soils. The other blended type of those recently introduced fertilizers are NPSZn and NPSB (ATA, 2016).

2.10 Loss of Nitrogen in Rice Crop Field

Compared with other nutrients, nitrogen is highly soluble and may be lost by leaching, denitrification, volatilization and erosion (Tilahun Geleto *et al*., 1996). Substantial quantities of nitrogen may also be immobilized into organic forms that are not readily available to crops (Anderson, 1985).

Both ammonium and nitrate forms of nitrogen are lost through leaching. However, nitrate form is lost easily due to its negative charge while the positively charged ammonium form is usually adsorbed to the negatively charged soil clay lattice. Marko *et al*. (2002) reported that more than 98% of the leached N was in the form of NO_3-N in soybean cultivation.

Denitrification occurs in the flooded rice soils following the nitrification of ammonium into nitrate (NO_3). Nitrification occurs at depth of 0-2mm from root surface while denitrification occurs at a depth of 1.5-5.0mm. (Arth and Frenzel, 2000).

Water erosion from soil is influenced by the rain, soil type, topography, soil cover and management, and by conservation practices. Soil erosion leads to nutrient losses (Guadagnin *et al.*, 2005), with potentially negative impacts on water quality of surface and ground water sources, as well as on the air.

2.11 Effects of Nitrogen Fertilizer Sources on Rice

2.11.1 Phenological effect

According to Zhou *et al*. (2011) and Shiferaw Nesgea *et al*. (2016) suggested that sources of N were not found significantly ($P > 0.05$) affected on days to flowering of rice. Similarly, Nitrogen application timing did not affect seedling emergency (Workneh *et al*., 2014).

2.11.2 Effect on growth parameters

The nitrogen source had little effect on growth parameters (Zhou *et al.*, 2011). In addition some other researchers, like, Chaturvedi (2005) reported that due to source of nitrogen there was a significant variation in plant growth and dry matter accumulation, but maximum plant height (128.6 cm) was obtained in plots where the Super Net was applied and the lowest plant height

(110.2 cm) was recorded for urea. According to the author, the increase in plant height in response to application of N fertilizers is probably due to enhanced availability of nitrogen which enhanced more leaf area resulting in higher photo assimilates and thereby resulted in more dry matter accumulation. Fageria *et al*. (2011) also shows that response of root growth and shoot dry weight to N sources was different, Ammonium sulfate produced much higher root growth at the lower N rate and overall, ammonium sulfate produced 4% higher shoot dry weight compared to urea fertilization.

2.11.3 Effect on yield and yield related parameters

One of the variations to rice crop yield is that source of N (Fageria *et al*., 2011). Faberia (2007) also reported that N is one of the most important nutrients in increasing yield component of rice, including 1000 grain weight. Another component of yield, panicle number response to N fertilization was similar for both ammonium sulfate and urea N sources; however, magnitude of response was higher in case of ammonium sulfate (Fageria *et al.*, 2011). According to Assefa Menna *et al*. (2009), di-ammonium phosphate could be chosen as an appropriate inorganic N fertilizer source followed by $(NH_4)_2SO_4$ for better grain yield of rice. Fageria (2009) also reported that ammonium sulfate produced greater grain yield of upland as well as lowland rice compared to urea.

2.12 Effect of N Fertilizer Rates on Rice

2.12.1 Phenological effect

In *Fogera* plains, higher nitrogen rates promoted early maturity in the rice crop than the plot receiving no nitrogen fertilizer (Zewdie Gebre Tsadik, 2004). Excessive nitrogen supply causes higher photosynthetic activity, vigorous growth weak stem resulting in crop lodging, delayed in maturity and increase in susceptibility to insect pest diseases (Brady and Weil, 2002).

2.12.2 Effects on growth parameters

Nitrogen is a major contributor to crop growth, size, and total dry matter production. Plant height might be increased due to enhanced vegetative growth with more N supply to plant that increase in plant height with increased application of N. The increment in plant height was in congruence with increasing N fertilizer application (Kumar *et al*., 2015). Since nitrogen is present in many essential compounds, it is not surprising that growth without added nitrogen is slow in most crops (Chaturvedi, 2005). An optimum supply of nitrogen to the plant stimulates root growth and development as well as uptake of other nutrients (Brady and Weil, 2002). Dry matter accumulation also effected by rate of N fertilizer with a corresponding increase in total dry matter production with increasing rates of N (Fegeria and Baligar, 2001; Buri *et al*., 2015; Haque and Haque, 2016).

2.12.3 Effects on yield and yield related parameters

Rice yield and yield related parameters are highly affected due to the variation of N rate. Tiller number was significant in response to different N doses (Zewdie Gebre Tsadik 2004; Kumar *et al*., 2015; Haque and Haque, 2016). Tiller number increased with increasing N rates but the increased was more pronounced (Galloway *et al*., 2008: Buri *et al*., 2015). Nitrogen fertilization increased the number of stems and panicles per square meter and the total number of spikelets, reflecting on grain productivity (Dastan *et al*., 2012).

Haque and Haque (2016) also showed the same result on the number of panicles per hill of rice. Nitrogen promotes the grain filling and increases the protein content of both seeds and foliage (Brady and Weil, 2002). Fageria *et al*. (2011) also reported that grain yield increased significantly when N rate was increased.

1000 grain of rice also affected due to different rate of N. Biswajit *et al*. (2017) stated that 1000 grain weight had direct relation with the rates of fertilizer significantly. This was probably due to higher uptake of applied nitrogen and greater availability of soil nutrients. Rice straw yield also one of the yield components which is consistently increase due to excessive increase in nitrogen rates (Zewdie Gebre Tsadik, 2004).

2.13 Effect of Time of N Fertilizer Application on Rice

2.13.1 Phenological effect

Different researchers stated that timing of N application made difference on the phenology of rice crop. Nitrogen use efficiency can be increased by split application of optimum dose of nitrogen that brings phenological changes (Pal, 2004). According to Tsedalu Jemberu *et al*. (2015) result, there was no significance difference on seedling establishment due to varies timing of nitrogen application while it showed significance difference on heading and maturity days ($P<0.05$). The shortest days obtained from application of nitrogen fertilizer ½ at sowing + ½ at early tillering and ½ at sowing + ½ at active tillering stage (90 days for heading and 126 days for maturity). The late application time of N fertilizer may extend the photosynthesis period of the plant and this leads to extend the date of heading and maturity. However, according to Gebrelibanos Gebremariam and Fisseha Baraki (2016), days to emergence, panicle initiation and days to 50% of heading showed that timings of nitrogen application had no significant effect.

2.13.2 Effect on growth parameters

According to Tsedalu Jemberu *et al*. (2015) result, there was significance difference on the time of nitrogen fertilizer application starting from 51 days after sowing on plant length. It was as expected since vegetative growth resulting from higher photosynthetic activities is well known to be influenced by nitrogen (Reddy, 2000). In general, dry matter accumulation increased at slow rate up to 30 days after transplanting and thereafter increased at faster rate up to harvest. The higher dry mass of nitrogen treated plants could relate to the positive effect of nitrogen in some important physiological processes. These differences were statistically significant. Another authors, Bah *et al*. (2009), the highest plant dry weight might be attributed to application of N at critical growth stages such as 50 and 55. This experiment confirms the observation made by Dobermann *et al*. (2000) that N uptake at mid tillering and panicle initiation stage tends to increase the biomass of plants' leaves, stems and panicles.

2.13.3 Effect on yield and yield related parameters

The highest number of total tillers/hills were noted when N was applied in three equal splits, (Islam *et al*., 2009; Hirzel *et al*., 2011; Kamruzzaman *et al*., 2013). This is also in agreement with the findings of Kaushal *et al*. (2010) who found highest productive tillers/m^{-2}, from three splits of N viz., ½ basal, ¼ at tillering, and ¼ at panicle initiation. Djaman *et al*. (2018) stated that the total number of tillers was not affected by time of application/split application of fertilizer. Split application of nitrogen fertilizer also showed significance difference on number of panicles m^{-2}, and number of spikelets/panicle. According to Fageria (2007) and Fageria (2009), obtained highly significant relation between grain yield and panicle number. Hence application of nitrogen at active tillering and panicle differentiation stage may make the plant to develop strong and active panicles which helps to take the assimilation from leaf and or stem to panicle. Finally, it leads to the high 1000 seed weight. Djaman *et al*. (2018) stated that the panicles were not affected by time of application/split application of fertilizer.

Nitrogen use efficiency can be increased by split application of optimum dose of nitrogen considering the nitrogen demand for infrastructure development of plant and maintenance of infrastructure and phonological changes leading to the development of sink or grains (Pal, 2004). Results shown in Bah *et al*. (2009), that application of N fertilizer at 55 DAS during the PI stage increased the percentage of filled grains and total grain yield. The increase in yield could be due to efficient N uptake by the plants that led to better photosynthetic rate. The results suggest that delaying application of N at PI stage may drastically reduce paddy yield (Kaushal *et al*., 2010) who found highest grain yield, from three splits of N viz., ½ basal, ¼ at tillering, and ¼ at panicle initiation which is agreed with this result.

As Tsedalu Jemberu *et al*. (2015) resulted; split application of nitrogen fertilizer showed significance difference on thousand seed weight. Application of N fertilizer at 55 DAS during the PI stage increased the percentage of filled grains and 1000-grain weight (Bah *et al*., 2009).

Besides, Djaman *et al*. (2018) revealed that the filled grain weight per panicle was higher under 4 split N treatment. In the same way, Merkebu Getachew and Amsalu Nebiyu (2018) stated that although the effect is controlled by mainly due to genetic characteristics, the time of application was made significant different on the 1000-grain weight of rice crop.

2.14 Interaction Effect of N Sources, Rates, and Time of N Fertilizer Application

2.14.1 Phenological effect

Days to 50% heading and 90% physiological maturity of the crop did not affect between the interaction effect of timing of N application by rate (Merkebu Getachew and Techale Birhan, 2015). Days to flowering was also not significantly ($P > 0.05$) affected by the interactions between sources of N by application time (Shiferaw Nesgea *et al*., 2012).

2.14.2 Effects on growth Parameters

The interaction effect of source by rate of N fertilizer is a one factor for variation of rice plant height, as Fageria *et al*. (2011) reported; maximum plant height was increased with increasing rate in a quadratic fashion in both Ammonium salphate and urea nitrogen sources. Assefa Menna *et al.* (2009) found similar result on rice plant height using urea, ammonium nitrate, ammonium sulfate, di-ammonium phosphate and calcium ammonium nitrate each at 120 kg N ha-1 as a source of N in the hot-humid North-western part of Ethiopia. Rice plant height, however, did not show significant ($P > 0.05$) differences with sources of N by application time (Shiferaw Nesgea *et al*., 2012). Moreover, these authors stated that the panicle length was not varied significantly ($P > 0.05$) because of interactions of N sources by application time and year by N sources by application time.

Shoot dry weight was significantly affected in a quadratic fashion with increasing N rate in the range of 0 to 400 mg kg^{-1} of soil by both the sources of N (Fageria *et al*., 2011). These findings are also in accordance with the increase in upland rice growth and yield components (Fageria, 2000b; Fageria *et al*., 2006; Fageria, 2009).

2.14.3 Effects on yield and yield related parameters

Total tillers hill^{-1} was significantly affected by both the nitrogen application at different growth stage and the amount of nitrogen applied at all dates of sampling (At 45 DAT, At 60 DAT and 75 DAT) when N applied at maximum tillering and panicle initiation stage (Tsedalu Jemberu *et al*., 2015). Singh and Singh (2002) reported that interaction effect of application of N with different growth stages and different rates of N were not significantly affected by total tillers hill^{-1} for all sampling dates.

Maximum number of panicles were produced at 429 mg N kg^{-1} applied by ammonium sulfate and at 250 kg N applied by urea (Fageria *et al*., 2011). This important component of grain production was quite influenced by treatments. The control and lowest preplant N dose significantly reduced the number of panicles per m^2. This parameter, as it was expected, has influenced rice yield quite in connection with fertilizer treatments. In fact, the lowest fertile panicles number was recorded for the unfertilized control.

Result of Fageria *et al*. (2011) observed that grain yield increased significantly in a quadratic fashion, when N rate was increased in the range of 0 to 400 mg kg^{-1} of soil, using ammonium sulfate and urea sources of N. According to Fageria *et al*. (2006), the maximum grain yield of upland rice was obtained with the application of 400 mg N kg^{-1} of soil through ammonium sulfate. The author also concluded that across the six N rates, ammonium sulfate produced 12% higher grain yield compared to urea. Grain yield of rice crop also affected by the interaction between rate of N with time of application (Kamruzzaman *et al.*, 2013) stated that the highest grain yield was obtained at the rate of 120 kg N/ha with a splited of ⅓ at 15 DAT + ⅓ at 30 DAT + ⅓ at 45 DAT. The control (0 kg N ha $^{-1}$) gave lowest grain yield with a split application of ½ at 25 DAT+ ½ at 50 DAT.

Of the yield determining component thousand grains weight is an important and reported to be a genetic character that is influenced least by environmental factors (Hailu Tefera, 2010). In line with this study, Fageria *et al*. (2011) N source X N rate interaction for grain harvest index, grain sterility and thousand grain weighs were not significant. According to the author, maximum number of panicles were produced at 429 mg N kg^{-1} applied by ammonium sulfate and at 250 kg N applied by urea. This important component of grain production was quite influenced by treatments. Accordingly, Tsedalu Jemberu *et al*., 2015 reported that N rate by N source interaction significantly influenced N uptake in root, shoot, and grain.

Chapter 3. MATERIALS AND METHODS

3.1 Description of the Study Area

The experiment was conducted on farmers’ field in Tewa Zkana *Kebele* in *Fogera* District during the rainy season of 2018. The district is located in the South Gondar Zone of Amhara National Regional State (Figure 3.1). The capital of the District is *Woreta* and is located 625 km northwest of Addis Ababa and 55 km from the regional capital, Bahir Dar. Geographically, it is situated at 11º46 to 11º59 latitude North and 37º33” to 37º52” longitudes East. It has a total land area of 117,405 hectares, of which flat lands account for 76%, while the rest are mountains and hills and valley bottoms account for 11% and 13%, respectively.

The study area mean annual rainfall is 1,216.3 mm, with unimodal rainfall pattern. Its altitude ranges from 1,774 up to 2,410 masl allowing a favorable opportunity for wider crop production and better livestock rearing (IPMS, 2005) and is predominantly classified as *Woina-Dega*. Farmers depend on long rainy (*Kremt*) season for crop production. There are altogether 33 rural Keeble’s and 5 urban *Keeble’s* (FWOA, 2017/18). The District comprises of 27 rice producing peasant administrative *(Kebeles)*. Out of which majority of (21 *kebeles*) it is suitable for lowland production of rice and few of (6 *kebeles*) practiced upland rice cultivation. As per population census dated 2005, the population of the District was 224,884 (CSA, 2005).

The land use pattern of the District is characterized by 48% cultivated land, 22% grazing land, 21% water bodies, 2% forest land and 7% for others. Most of the farmland was allocated for annual crops where cereals covered 54,066 ha; pulses cover 1,026 ha; oil seeds 1,940 ha; vegetables 2,531 ha (FWOA, 2017/18).

The major crops include *teff*, maize, finger millet and rice, in order of area coverage are grown predominantly during the wet season, whereas leguminous crops, including grass peas, chickpea and lentil are produced on residual soil moisture as sequential crops during the dry season beginning from September. Vegetables and Horticultural crops also are produced in the

Districts. According to IPMS (2005) and Tilahun Gebey *et al*. (2012), the average land holding was about 1.4 ha with minimum and maximum of 0.5 and 3.0 ha, respectively.

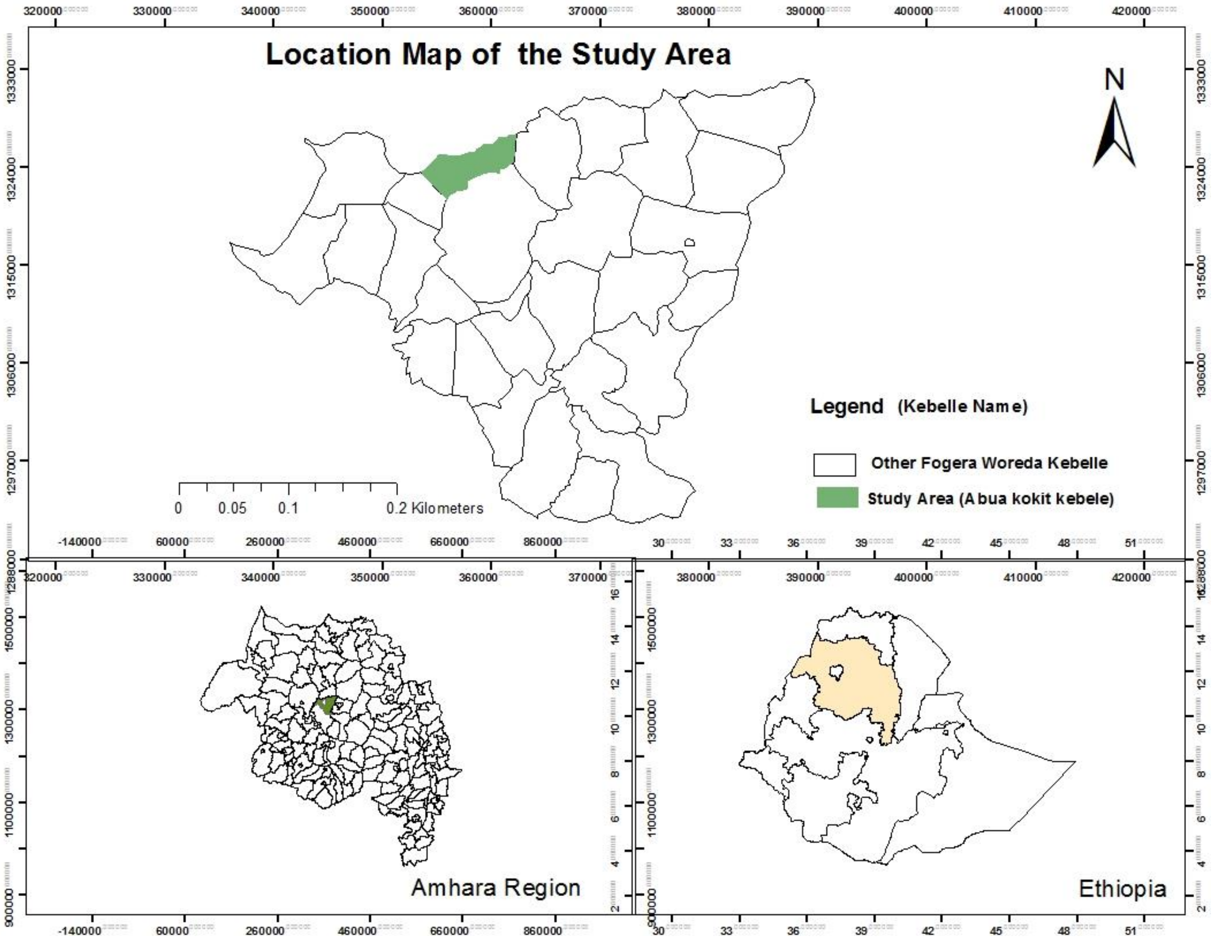


Figure 3.2: Location map of the study area

3.2 Experimental Materials

3.2.1 Planting materials

The recently introduced upland rice variety (NERICA-4), released in 2006 by *Pawe* Agricultural Research Center was used as experimental material for the study. NERICA is derived from the crossing of the African rice (*O. glaberimma* Steud.) and the Asian rice (*O. sativa* L.) by Africa Rice Center. This variety was obtained from the Ethiopian Agricultural Research Center of

Fogera Rice Research and Training Center. This NERICA-4 type variety is adopted in the research area and possess high yield potential, early vigor, short growth cycle, tolerance to abiotic stress such as drought, resistance to pest and diseases such as blast and rice yellow mottle virus, good response to fertilizers, good grain qualities, and non-shattering grains (Mulugeta Syoum *et al*., 2000).

3.2.2 Fertilizer sources

The two types of N sources fertilizer, Urea stable (46% N) (Slow release) – release nutrients at a slower rate and Common Urea (46% N) and Triple Super Phosphate (TSP) (46% P_2O_5) as a source of P were used in the study. Urea stable (Slow release) – release nutrients at a slower rate than conventional fertilizer since it consists of urea coated or polymers. The N containing fertilizer were applied in split according to the time of nitrogen application whereas all the recommended amount of TSP was applied at sowing time.

3.3 Experimental Treatments, Design and Procedures

A factorial combination of three nitrogen rates, three N application times and two N fertilizer sources were tested in randomized complete block design with three replications. The three N rates were 69, 103.5, and 138 kg N ha^{-1}. On the other hand, the three N application times were 1/3 at planting, 1/3 at tillering and 1/3 at panicle initiation (PI) (NTA1), 1/3 15 days after sowing (DAS), 1/3 at PI and 1/3 at heading (NTA2), and 1/3 at 15 DAS and 2/3 at PI (NTA3). Finally, the two N fertilizer sources were Urea stable (US) (46% N) and Common Urea (CU) (46% N). For all plots, the recommended quantity of P (23 kg ha^{-1} P_2O_5) was applied to all the experimental plots at planting time. The NERICA-4 Rice variety was planted at inter row spacing of 20 cm drill row planted at a seeding rate of 100 kg ha^{-1}.

The treatments were arranged in a randomized complete block design replicated three times. In accordance with the specifications of the design, each treatment was assigned randomly to experimental units within a block. Each replication was accommodating 18 treatments which resulted in total of 54 experimental plots. Gross plot size was 3m x 4m accommodating 15 rows of 3m lengths, with spacing between plots and blocks 50 cm and 1m, respectively. The outermost 2 rows on both sides of plots and 0.5 m row lengths at both ends of the plots were considered as borders. Therefore, net plots were constituted the remaining 11 rows of 3 m length with net plot size of 2.2 m x 3 m size for the determination of yield/plot or ha. To control mixing of treatments, experimental plots were bunded manually.

The N fertilizer was side dressed within 5 cm distance from the plant to reduce the burning effect according to the time of nitrogen application. Furthermore, during the different growth stages of the crop, all necessary agronomic practices other than the treatments, in terms of plowing, cultivation and weeding were carried out equally and properly.

3.4 Data Collection

All phenological, vegetative growth and yield and yield related parameters were assessed accordingly within a required time. All Data were collected on plant and plot bases. Harvesting was done through manually using sickle and the harvested crop of each plot was collected in sack separately and tagged properly. Harvested samples were sun dried for a week to measure the above ground biomass. Thereafter, threshing, winnowing, and cleaning were done manually. Sampling, harvesting, data collection, and recording for each phenology, growth and yield and yield components are described as follows:

3.4.1 Phenological parameters

Phenological data, such as, days to 50 % heading and days to 90 % physiological maturity were taken at date when 50% of the panicles emerged from sheath and 50% of the plant headed and physiological maturity were recorded when two-third of the length of panicle axes in 50% of the plant’s population attained yellow coloration, respectively.

3.4.2 Growth parameters

*Plant height***:** It was measured from the base of the main stem to the tip of the panicle in cm and calculated as the average of five randomly taken plants per plot from different rows other than the border row. Then the average plant height per each plot were determined.

Panicle length: It was measured from the node where the first panicle branch starts to the tip of the panicle as the average of five randomly taken panicles per plot at physiological maturity/harvesting time. The average length of panicles in cm in each plot was then determined and used for analysis.

3.4.3 Yield and yield related parameters

Number of total tillers: It was the average number of tillers from 0.5 m row length of randomly sampled plants found at both sides of each net plot and it converted into 1 m. It was taken at harvesting.

Number of fertile panicles per 1-meter row length: It was the average number of fertile panicles from 0.5 m row length of randomly sampled plants found at net plot area and converted in 1 m. It was also taken at harvesting time.

Number of infertile panicles per 1-meter row length: It was the average number of un-fertile panicles from 0.5 m row length of randomly sampled plants found at net plot area and converted in 1 m. It was taken at harvesting.

Number of filled grains per panicles: It was taken as the number of filled grains from the main panicle at harvesting time from average of five randomly taken plants in each net plot area.

Number of unfilled grains per panicles: It was the number of unfilled grains from the main panicle at harvesting time from average of five randomly taken plants in each net plot.

Total Fresh above Ground Biomass per ha (TFBM) (t ha^{-1}): It was measured by weighing the total above ground (straw plus grain) from the net plot area (2.2m x 3m size). It was taken at harvesting.

Above ground dry biomass yield (DBM) (t ha^{-1}): Total above ground dry biomass or biological yield was measured by weighing the sun-dried total above ground plant biomass (straw plus grain) of the net plot area (2.2m x 3m size). The outermost 2 rows on both sides of each sampled plots and 0.5m row lengths at both ends of the plots were not used for calculating DBM, since they are considered as borders. The plants were harvested manually from the ground surface just above the soil and sun-dried for a week until constant weight reached. Then, above ground dry biomass was measured by weighing the total harvested material, consisting of both grain and straw yields from each net plot. The aboveground dry biomass yield obtained from the sample was converted to yield per hectare using the following formula:

$$\text{DBM (ton / ha)} = \frac{\text{ABM (t / ha)} * 10000\ (\text{m}^2)}{\text{Ha}\ (\text{m}^2)}$$

Where:

ABM-Above ground biomass

Ha-Harvest area

Grain yield (t ha^{-1}): The grain yield was measured by taking the weight of the grains from the net plot area and converted to t ha^{-1} at 14% moisture content. The weight of grain from each net plot was recorded. The data on grain yield in each experimental unit was determined by weighing using sensitive balance after sun drying, threshing, and cleaning of grains. The moisture percentage of grains of each net plot was determined by moisture meter and final grain yield was adjusted at 14% moisture. The moisture content of the grain was determined by using Burrows DMC - 500 Moisture Tester 2009 model, three times for each plot.

The moisture correction factor was obtained by the following formula:

$$\text{Mcf} = \frac{100-Y}{100-X}$$

Where:

Mcf - Moisture correction factor

X- Standard moisture content for cereal crops, i.e., 14%.

Y- Actual moisture content measured by moisture tester instrument

Therefore, according to the standard moisture content, 14 % adjusted grain yield was calculated using the following equation:

Agy = Mcf*Gy

Where:

Mcf- Moisture correction factor (decimal)

Agy- Adjusted grain yield

Gy- Grain yield obtained from each sample area in the sun-dried condition

Finally, the grain yield obtained from the sample area was converted to per ha using the following formula:

$$\text{Grain yield (t/ha)} = \frac{\text{Grain yield (t/ha)} * 10{,}000\text{m}^2}{\text{Harvested area (m}^2\text{)}}$$

Thousand grain weight (TGW): The thousand grains weight was expressed in gram (gm). It was recorded in gram of 1000 seeds weight with sensitive balance which was taken from bulked grains of each plot and adjusted to 14% seed moisture.

Straw yield per ha (SY) (t ha^{-1}): Straw yield of each net plot was calculated by subtracting the grain yield from the total above ground dry biomass.

Harvest index (HI): It was calculated as the ratio of grain yield obtained from each plot to the total above ground dry biomass (grain plus straw) per ha expressed in percent. Air drying was made by keeping the harvest in the sun and finally yields until it measures a constant weigh on the plot and ha bases were determined. It indicates the efficiency of plant to assimilate partition to the economic parts (example: rice grain).

3.5 Data Analyses

3.5.1 Analyses of variance

All collected data were subjected to analysis of variance using the general linear model (GLM) procedures of the SAS 9.0 version system (SAS, 2009). Upon obtaining significance difference between treatments, mean separation was computed using Least Significance Difference (LSD) test at <5% and or <1% of probability depending on the ANOVA result.

3.5.2 Economic analyses (partial budget analyses)

To determine the economic feasibility associated with different treatments – source, rates and application timing of N application, the partial budget analysis was carried out for evaluating the cost and benefit which was computed by using the method as described in CIMMYT (1988). The total variable cost (TVC) and the net benefits (NB) of each treatment was calculated. It includes adjusted grain yield and gross field benefits (GFB). The GFB ha^{-1} was obtained as the products of real farmers' price and the average rice grain yield for each treatment. The TVC in the partial budget analysis referred to the sum of costs of fertilizer and labor, whereas the NB ha^{-1} is the difference between the GFB and the TVC. The average grain yield was adjusted downward by 10% to reflect the difference between the experimental yield and the yield farmers could expect from the same treatment without the involvement of researchers before the gross benefit was calculated (CIMMTY, 1988; Shah *et al.*, 2009). To estimate the economic parameters, products were valued based on the nearby local *Woreta* market price collected during the harvesting time November and December 2018 where rice was 16.50 ETB kg^{-1}. Costs related to N source in ETB per 100 kg at the time of the experiment were 15.081 ETB kg^{-1} for Stable Urea (SU) and 13.71 ETB kg^{-1} for Common Urea (CU) and 50 ETB (application cost per day ha^{-1}). Other production costs were assumed to remain the same among the treatments (Appendix Table 4). The dominance analysis procedure, which was used to select potentially profitable treatments, comprised ranking of treatments in order of ascending order. Total cost that varied from the lowest to the highest cost to avoid those treatments costing more but producing a lower NB than the next least cost treatment. The selected and discarded treatments by using this technique were referred to as undominated and dominated treatments, respectively. For each pair of ranked undominated treatments, a marginal rate of return (% MRR) was calculated. The % MRR between any pair of undominated treatments denotes the return per unit of investment in crop managing practices expressed as %age. The % MRR is given by the equation:

$$\%\ \mathrm{MRR} = \frac{\text{Marginal net benefit}}{\text{Marginal cost}} \times 100$$

Marginal net benefit = Net benefit at two - Net benefit at one

Marginal cost = Total variable cost at two - Total variable cost at one

In order to make recommendations from marginal analysis (MRR), the least acceptable rate of return to farmers in the advice domain, was set at 100%. Among the treatments with acceptable MRR values, the one having highest net benefit (NB) was selected as the best profitable treatment.

Chapter 4. RESULTS AND DISCUSSION

4.1 Effect of Sources, Rates and Application Times of N Fertilizer on Phenology of Rice

4.1.1 Days to 50% heading

All main effects of N sources, rates, and application time and among their interactions did not impacted significantly on days to 50% crop heading (Appendix Table 1). This could be due to the fact that only one type of variety was used as planting material. Similarly, Gebrelibanos Gebremariam and Fisseha Baraki, 2016 reported timing of N application had no significant effect on days to emergence, panicle initiation and days to 50% of heading due since they have used a single variety as a planting material. In line with the present findings, Shiferaw Nesgea *et al*., 2012 also suggested that the nitrogen source and time of application and their interaction did not significantly affected the rice crop flowering. In addition, Gebrelibanos Gebremariam and Fisseha Baraki (2016) also showed that timings of nitrogen application had no significant effect on days to 50% of heading. On the contrary, Tsedalu Jemberu *et al*. (2015) illustrated that application times of N fertilizer had significant difference ($P<0.05$) on days to 50% heading of rice crop. According to the authors, this difference comes from the genetic characteristics of the varieties.

4.1.2 Days to 90% physiological maturity

Like days to heading studied in the present experiment, physiological maturity of the rice crop was not significantly affected by the main treatments of N source and its , while effect of N application time was found significant ($P<0.05$). the application time of N the recorded data indicates that the plot received nitrogen fertilizer when 1/3 at planting + 1/3 at tillering + 1/3 at PI (NTA1) took earlier (138.06 days) maturity than others (139.06) (Table 4.1). The rest plots those received N 1/3 at 15 DAS + 2/3 at PI (NTA3) and 1/3 at 15 DAS + 1/3 at PI + 1/3 at heading (NTA2) were need 138.06 and 138.78 days respectively (Table 4.1). As the statistical analysis showed that the application of N at the time of sowing coupled with splitting in to three is important due to the fact that it may made the upland rice crops being stand vigour enough at its critical growth stage which will hasten the physiological maturity. This view is supported by Iqbal *et al*., 2005; Kichey *et al*. (2007) who observed that N fertilizer application time had significant roles in determining uptake of fertilizer and its partition to soil and plant. In harmony with the present result, Tsedalu Jemberu *et al*. *(*2015) recorded that time of nitrogen fertilizer showed significance difference on days to maturity ($P<0.05$). According to them, the shortest days to maturity (126) of rice crop was obtained from a plot where nitrogen fertilizer was applied ½ at sowing + ½ at active tillering stage. According to the authors, the late application time of N fertilizer could extend the photosynthesis period of the plant and this may lead to extend the date of heading and maturity. Contrarily to the present research, Merkebu Getachew and Techale Birhan, 2015 reported that the physiological maturity was not affected significantly because of main effect of timing of N-application difference.

The interactions effect between the sources, rates and timing of N fertilizer application showed that upland rice crop took the shortest mean days to physiological maturity (137.67) from the plots where received combined treatments of urea stable (US), at a of 103.5 kg ha^{-1} applied 1/3 at planting + 1/3 at tillering + 1/3 at PI (NTA1) (Table 4.2). By following this, statistically similar results (138.00 days) were recorded from the plots those received combined treatments of urea stable (US) at a rate of 69 kg ha^{-1} applied 1/3 at planting + 1/3 at tillering + 1/3 at PI (NTA1), from plots where received common urea (CU) at a rate of 103.5 kg ha^{-1} applied 1/3 at planting + 1/3 at tillering + 1/3 at PI (NTA1) and from plots where received common urea (CU) at a rate of 138 kg ha^{-1} when applied 1/3 at planting +1/3 at tillering + 1/3 at PI (NTA1). This result indicated that an optimum supply of N with a slow release fertilizer type – urea stable applied by splitting at different growth stage may made the nutrient available through the crops life when it is needed. Moreover, the result revealed that the appropriate time of N fertilizer found that at a time of 1/3 at planting + 1/3 at tillering + 1/3 at PI (NTA1). This is applied both in the main and interaction treatments. Therefore, in conclusion, for better production of days to 90% physiological maturity of upland rice (NERICA-4), consideration of appropriate application timing of N would be vital. Iqbal *et al*., 2005; Kichey *et al*., 2007 and Jan *et al*., 2010 also support this view that N fertilizer sources, rates and application time had significant roles in determining uptake of fertilizer and its partition to soil and plant. Similarly, Nomura and Kikuzawa, 2003 and Tessier and Raynal, 2003 stated that in some ecosystem's phenology is coupled to N availability, with flushes of plant growth coinciding with pulses of N availability, which leads to maturity.

Table 4.1: Mean main effects of sources, rates and application times of nitrogen fertilizer on phenology of upland rice crop

Treatments	Days to 90 % physiological maturity
N sources	
Stable Urea (SU)	138.59
Common Urea (CU)	138.66
LSD (<5%)	NS
SE±	0.174
Nitrogen Rates, kg ha^{-1}	
69.00	138.78
103.5.0	138.39
138.00	138.72
LSD (<5%)	NS
SE±	0.211
Time of N Fertilizer Application	
NTA1	138.06^{b}
NTA2	139.06^{a}
NTA3	138.78^{a}
LSD (<5%)	0.550*
SE±	0.189
CV (%)	0.586

*Note: Numbers followed by different letters in the same column indicate significant differences at <5% of probability. * and NS = Significant at <0.05 probability and non-significant respectively; NTA1= N application time at 1/3 at planting, 1/3 at tillering, and 1/3 at PI; NTA2 = N application time at 1/3 at 15 DAS, 1/3 at PI and 1/3 at heading; NTA3 = N application time at 1/3 at 15 DAS, and 2/3 at PI; CU = Common Urea and SU = Stable Urea.*

Table 4.2: Mean interaction effects of sources, rates and application times of nitrogen fertilizer on Phenology of upland rice crop

Treatments	Days to 90 % physiological maturity
US × 69 × NTA1	138.00^{bc}
US × 69 × NTA2	138.33^{bac}
US × 69 × NTA3	139.67^{a}
US × 103.5 × NTA1	137.67^{c}
US × 103.5 × NTA2	139.00^{bac}
US × 103.5 × NTA3	138.33^{bac}
US × 138 × NTA1	138.33^{abc}
US × 138 × NTA2	139.67^{a}
US × 138 × NTA3	138.33^{bac}
CU × 69 × NTA1	138.33^{bac}
CU × 69 × NTA2	139.67^{a}
CU × 69 × NTA3	138.67^{bac}
CU × 103.5 × NTA1	138.00^{bc}
CU × 103.5 × NTA2	139.00^{bac}
CU × 103.5 × NTA3	138.33^{bac}
CU × 138 × NTA1	138.00^{bc}
CU × 138 × NTA2	138.667^{bac}
CU × 138 × NTA3	139.333^{ba}
LSD (<5%)	1.347*
SE±	0.122
CV (%)	0.586

*Note: Numbers followed by different letters in the same column indicate significant differences at <0.05 of probability. Where: * and NS = Significant at <0.05 probability and non-significant respectively; NTA1= N application time at 1/3 at planting, 1/3 at tillering, and 1/3 at PI; NTA2 = N application time at 1/3 at 15 DAS, 1/3 at PI and 1/3 at heading; NTA3 = N application time at 1/3 at 15 DAS, and 2/3 at PI; CU = Common Urea and SU = Stable Urea.*

4.2 Effect of N Sources, Rates and Application Times on Growth Parameters

4.2.1 Plant height

Plant height of the rice crop was not significantly affected by the main effects of N source, rates, and application times. However, it was impacted significantly ($P<0.05$) by the interactions of the three factors (Table 4.2 and Table 4.3).

As the data depicted in Table 4.4, the present study shows that there was a significant ($P<0.05$) difference due to the interaction among the factors. Of the combinations treatments studied in this experiment the maximum (78.03 cm) height was obtained from the plots where the combination of common urea (CU) with a rate of 69 kg N ha^{-1} which was applied at 1/3 at planting + 1/3 at tillering + 1/3 at PI (NTA1) which is followed by combinations of urea stable (US) as a source with a of 69 kg ha^{-1} applied at 1/3 at 15 DAS + 2/3 at PI (NTA3) resulted 77.10 cm plant height. The shortest plant height (64.87 cm) were obtained from the plots where the combined treatments of urea stable (US) at a rate of 103.5 kg N ha^{-1} applied 1/3 at planting + 1/3 at tillering + 1/3 at PI (NTA1). Although plant height did not show significant effect by all main effects, it was affected significantly by their interactions, due to the fact that Plant height reveals the overall vegetative growth of the crop in response to various management practices (Chaturvedi, 2005). At par with the present study, Assefa Menna *et al.* (2009) found significant effect on rice plant height using urea, ammonium nitrate, ammonium sulfate, di-ammonium phosphate and calcium ammonium nitrate each at 120 kg N ha^{-1} as a source of N in the hot-humid North-western part of Ethiopia. Contrarily to this study, Shiferaw Nesgea *et al*. (2012), reported that plant height was not affected significantly by the interactions of sources of N by application time.

4.2.2 Panicle length

The analysis of data showed that panicle length of NERICA-4 rice crop was not significantly affected by any treatments that was studied, either main effect of N source, rates and time of application or among their interactions (Appendix Table 2).

4.2.3 Total number of tillers

The data presented in Appendix Table 2 indicate that total tillers per 1-meter plant row length of rice was significantly affected by all the main and interaction effects of N sources, rates and the times of fertilizer applied. The highest number of tillers (87.611 cm) were obtained from the plot received highest rate of nitrogen (138 kg ha^{-1}). It is followed by the plots received from 103.5 kg ha^{-1} and 69 kg ha^{-1} which resulted 73.94 and 70.28 total number of tillers, respectively (Table 4.3).. The number of tillers of upland rice crop increased positively with increasing of N level. More number of tillers m^{-2} in experiment might be due to the more availability of nitrogen that played a vital role in cell division. Number of tillers per unit area is the most important component of yield. More the number of tillers, especially fertile tillers, the more will be the yield. More number of tillers m^{-2} in experiment might be due to the more availability of nitrogen that played a vital role in cell division (Chaturvedi, 2005). In line with the current research, Chaturvedi, 2005; Mandana *et al.*, 2014; Meena *et al.*, 2014 and Buri *et al.*, 2015, noted that the number of total tillers m^{-2} was increased with increased level of nitrogen.

The statistical result had revealed that interaction effect of the three sources of variation: N sources, rates, and time of application, had significant influence ($P<0.001$) on total tiller of the NERICA-4 rice crop. Of the combination effects, common urea (CU) fertilizer at a rate of 138 kg N ha^{-1} applied 1/3 at 15 DAS + 2/3 at PI (NTA3) resulted the maximum number of tillers (99.67. It was followed by the treatments of common urea (CU) at a rate of 138 kg N ha^{-1} applied 1/3 at 15 DAS + 1/3 at PI + 1/3 at heading (NTA2) gave maximum tiller number (98.33) and the treatments of common urea (CU) at a rate of 138 kg N ha^{-1} applied 1/3 at planting + 1/3 at tillering + 1/3 at PI (NTA1) and common urea (CU) at a of 103.5 kg N ha^{-1} applied 1/3 at 15 DAS + 2/3 at PI which had similar result based on statistical analysis. The minimum number of total tillers (56.67) was recorded from the combination of urea stable (US) at a rate of 69 kg N ha^{-1} 1/3 at planting + 1/3 at tillering + 1/3 at PI (NTA1) (Table 4.4). At par of the present study, the study conducted by Alim (2012) also showed that the interaction effect of N sources and doses were significant for number of bearing tillers hill^{-1}. Similarly, according to the findings of Kamruzzaman *et al*. (2013), number of total tillers hill^{-1} was significantly affected by the interactions among the N and its application timing. According to the authors, the highest number of total tillers (18.03) was recorded from the treatments of Contrarily to this research, some studies reported that the number of effective tillers m^{-2} was insignificant to the interactions between N source and application time (Shiferaw Nesgea*et al.*, 2012) (P>0.05).

Table 4.3: Mean main effect of Nitrogen sources, rates and nitrogen fertilizer times of application on vegetative traits of rice crop

Treatments	Total tillers per 1m plant row
N source	
Stable Urea (SU)	70.44^{b}
Common Urea (CU)	84.11^{a}
LSD (<5%)	4.056***
SE±	2.177
Nitrogen Rates, kg/ha	
69.00	70.278^{b}
103.50	73.944^{b}
138.00	87.611^{a}
LSD (<0.05)	0.747***
SE±	2.592
Time of Fertilizer Application	
NTA1	72.444^{b}
NTA2	78.778^{a}
NTA3	80.611^{a}
LSD (<5%)	4.967**
SE±	3.050
CV	9.489

*Note: Numbers followed by different letters in the same column indicate significant differences at <5% of probability. Where: **, *** and NS = Significant at <0.01 and at <0.001 probability and non-significant respectively, NTA1= N application time at 1/3 at planting, 1/3 at tillering, and 1/3 at PI; NTA2 = N application time at 1/3 at 15 DAS, 1/3 at PI and 1/3 at heading; NTA3 = N application time at 1/3 at 15 DAS, and 2/3 at PI; CU = Common Urea and SU = Stable Urea.*

Table 4.4: Interaction mean effect of sources, rates, and N timing on growth traits of upland (NERICA-4) rice crop

Treatments	PH	TT
US × 69 × NTA1	74.53^{ebdacf}	56.67^{j}
US × 69 × NTA2	69.90^{edgf}	67.33^{gihj}
US × 69 × NTA3	77.10^{ba}	62.67^{ihj}
US × 103.5 × NTA1	64.87^{g}	68.00^{gifhj}
US × 103.5 × NTA2	76.30^{bdac}	60.00^{ij}
US × 103.5 × NTA3	71.60^{ebdacf}	$78,67^{gdfce}$
US × 138 × NTA1	69.97^{edgcf}	76.67^{gdfce}
US × 138 × NTA2	76.40^{bac}	81.67^{dce}
US × 138 × NTA3	75.80^{ebdac}	82.67^{dc}
CU × 69 × NTA1	78.03^{a}	76.67^{gdfce}
CU × 69 × NTA2	71.87^{ebdacf}	85.67^{c}
CU × 69 × NTA3	68.70^{gf}	73.00^{gdfhe}
CU × 103.5 × NTA1	76.33^{bdac}	70.33^{gifhe}
CU × 103.5 × NTA2	74.93^{ebdacf}	79.67^{dfce}
CU × 103.5 × NTA3	71.80^{ebdacf}	87.00^{bc}
CU × 138 × NTA1	72.73^{ebdacf}	86.67^{bc}
CU × 138 × NTA2	71.53^{ebdcf}	98.33^{ba}
CU × 138 × NTA3	69.67^{egf}	99.67^{a}
LSD (<5%)	6.476*	12.168***
SE±	0.650	1.795
CV (%)	5.35	9.49

*Note: Numbers followed by different letters in the same column indicate significant differences at <5% of probability. Where: *, *** and NS = Significant at <0.05 and at 0.001 probability and non-significant respectively, NTA1= N application time at 1/3 at planting, 1/3 at tillering, and 1/3 at PI; NTA2 = N application time at 1/3 at 15 DAS, 1/3 at PI and 1/3 at heading; NTA3 = N application time at 1/3 at 15 DAS, and 2/3 at PI; CU = Common Urea and SU = Stable Urea.*

4.3 Effect of Sources, Rates and Application Times of N Fertilizer on Yield and Yield Related Parameters

4.3.1 Number of fertile panicles

Results of analysis of variance showed that the main effects of sources and rates of N had significant effect on number of fertile panicles per 1-meter row length whereas main effects of timing of f N application had non-significant effect on number of fertile tillers. The interaction effect among these three factors studied had significant effect on number of fertile panicles per (Appendix Table 3).

Concerning the interaction effect, the maximum number of fertile panicles was recorded (95.67) It was received from the combinations of common urea (CU) at a maximum rate of 138 kg N ha^{-1} applied at a time of 1/3 at 15 DAS + 2/3 at PI (NTA3) which is followed by the combinations of common urea (CU) at a rate of 138 kg N ha^{-1} applied 1/3 at 15 DAS + 1/3 at PI + 1/3 at heading (NTA2) which gave 87.33 number of fertile panicles. Whereas the lower number of fertile panicles (60.00) were obtained from the combinations of urea stable (US) at a rate of 138 kg N ha^{-1} applied 1/3 at 15 DAS + 1/3 at PI + 1/3 at heading (NTA2) and which gave statistically at par (60.67) with urea stable (US) at a rate of 69 kg N ha^{-1} applied 1/3 at 15 DAS + 2/3 at PI (NTA3) (Table 4.6). As the statistical analysis showed that the number of fertile panicles per 1-meter row length was found important yield component factor as it is a major determinant of yield. In conformity with the findings of the present study, Thakur (2011) noted that panicle number of rice crop is the most important factor that causes variation in the grain yield of rice. In accordance with this study, Alim (2012) reported that number of effective tillers hill^{-1} was significantly influenced by the interactions of different doses and sources of nitrogen application. He reported that the maximum number of bearing tillers hill^{-1} (12.34) was found in the application of 60 kg N ha^{-1} as Urea. Kamruzzaman *et al*. (2013) also reported in line with the present study, the combination of N and application timing. But Shiferaw Nesgea *et al*., 2012 notified that the combinations effects of N sources and application time on the number of effective tillers m^{-2} were insignificant ($P > 0.05$). Similarly, Mandana Tayefe *et al*. (2014)

suggested that the number of panicles m^{-2} increased with N fertilization and differences between N rates were significant, which is in harmony of the present study.

4.3.2 Number of infertile panicles

The ANOVA result presented in Appendix Table 3, the number of infertile panicles was significantly affected by neither the main effect nor interactions effect of different sources, rates and application time of N. With respect to the N source, Ullah *et al*. (2016), reported that on the contrary of the present study result, the number of non-effective tiller was varied significantly for nitrogen sources. This result is in accordance with the study of Merkebu Getachew and Techale Birhan (2015), who founds that the parameter was not influenced due to the variation of N fertilizer applications.

4.3.3 Number of filled grains per panicle

As per the present study the data in Appendix Table 3 showed that all three treatments of main effects, sources, rates, and application time of N were not found significant effect on number of filled grains per plant. Whereas their interactions had significant difference ($P<0.05$) on the number of filled grains per plant on NERICA-4 rice crop. The result was supported by Shiferaw Nesgea *et al*. (2012*)*.

The highest number of filled grains per panicle (111.67) production was recorded from the combinations of urea stable (US) source with a level of 138 kg N ha^{-1} applied 1/3 at 15 DAS + 1/3 at PI + 1/3 at heading (NTA2), which was followed by a combination of common urea (CU) as a source with a level of 138 kg N ha^{-1}applied 1/3 at 15 DAS + 2/3 at PI (NTA3) and urea stable (US) as a source with a level of 138 kg N ha^{-1}applied 1/3 at planting + 1/3 at tillering + 1/3 at PI (NTA1) and urea stable (US) as a source with a level of 103.5 kg N ha^{-1}applied 1/3 at planting + 1/3 at tillering + 1/3 at PI (NTA1) which all had statistically similar result.While the lowest (74.67) production was recorded from the common urea (CU) with a level of 138 kg N ha^{-1}applied 1/3 at planting + 1/3 at tillering + 1/3 at PI (NTA1). In agreement with this study Kamruzzaman *et al*. (2013) found that filled grains per panicle was influenced due to the interaction effect of application time of N (⅓ N at 15 DAT + ⅓N at 30 DAT + ⅓ N at 45 DAT) and its dose (120 kg N ha^{-1}) which recorded the highest number of grains panicle^{-1} (137.48). The number of grains per panicle is one of the major rice yield components. The higher the number of grains per panicle the higher will be the probability of increasing number filled grains and consequently high grain output (Shiferaw Nesgea *et al*., 2012).

4.3.4 Number of unfilled grains per panicle

The analysis of variance revealed that like as number of field grains per panicle this parameter also had not impacted significantly ($P>0.05$) by main effect of source, rates and N application time on upland rice, NERICA-4 variety. However, number of unfilled grains per plant was found significantly influenced by their interactions (Appendix Table 3). Similarly, Fageria *et al*. (2011), grain sterility was not affected significantly by N source treatment. Likely, other researchers support the present result (Fageria *et al*., 2011; Mandana Tayefe *et al*., 2014), who reported that nitrogen fertilization had no significant effect on unfilled percent and/or grain sterility.

The data in Table 4.6 shows that there was a significant ($P<0.05$) interaction effect of N source, N rates and application timing of N-fertilizer on number of unfilled grains per panicle. The greater number (11.67) of unfilled grains per panicle was recorded from plots treated with combinations of common urea (CU) with a rate of 69 kg N ha^{-1} applied at 1/3 at planting + 1/3 at tillering + 1/3 at PI (NTA1), which was followed by plots treated with combinations of urea stable (US) with a of 138 kg N ha^{-1} applied 1/3 at 15 DAS + 1/3 at PI + 1/3 at heading (NTA2). While the lowest production was recorded from plots treated with combination treatment of common urea (CU) 138 kg N ha^{-1} applied 1/3 at 15 DAS + 1/3 at PI + 1/3 at heading (NTA2) and urea stable (US) at a rate of 138 kg N ha^{-1} applied 1/3 at 15 DAS + 2/3 at PI (NTA3) which was statistically recorded similar result. This result was in accordance with the findings of Kamruzzaman *et al*. (2013), who noted that the interaction among N rate and application timing had significant effect on number of sterile spikelets per panicle. They describe, the maximum number of sterile numbers of spikletes panicle^{-1}(26.52) were recorded from the plots treated with control.

4.3.5 Total above ground fresh biomass yield (TFBM) (t/ha)

The ANOVA result had showed significant effect on total above ground fresh biomass (TFBM) parameters due to the main effect of N rates, its application time and interaction effects between N sources, rates and application time ($P<0.05$), while N source did not (Appendix Table 3). As the data depicted in Table 4.6, among the interaction effects of the treatments, common urea (CU) at 138 kg N ha^{-1} applied 1/3 at 15 DAS + 2/3 at PI (NTA3) and common urea (CU) at a of 138 kg N ha^{-1} applied 1/3 at 15 DAS + 1/3 at PI + 1/3 at heading (NTA2) produced the maximum TFBM yield (22.43 t ha^{-1}) which are statistically similar values. While the lowest (13.13 t ha^{-1}) TFBM yield was obtained from the combinations of common urea (CU) at a rate of 103.5 kg N ha^{-1} applied 1/3 at 15 DAS + 1/3 at PI + 1/3 at heading (NTA2). In agreement with the present result, the total biomass (straw + grain) increased with increasing rates of N (Buri *et al*., 2015). Identical to this finding, the split application of N had a significant effect on TFBM yield was reported by Hirzel *et al*., 2011and Kamruzzaman *et al*., 2013.

4.3.6 Above ground dry biomass yield (DBM) (t ha-1)

Above ground dry matter production was significantly influenced by the main effects of both the amount of N applied and N application time at different growth stage, however, sources of N fertilizer did not (Appendix Table 3). As the data showed the interaction effect between these three treatments also showed significant difference ($P<0.001$).

As per the data indicated in Table 4.6, the interactions of the treatments were affected significantly ($P<0.0001$) the dry matter production on NERICA-4 rice in the study area. The highest (15.1 t ha^{-1}) DBM production was recorded from the plots treated with common urea (CU) at a level of 138 kg N ha^{-1} applied 1/3 at 15 DAS + 1/3 at PI (NAT3) followed by the plots treated with common urea (CU) at a level of 138 kg N ha^{-1} applied 1/3 at 15 DAS + 1/3 at PI + 1/3 at heading (NTA2) which was recorded 14.82 t ha^{-1}. Following these, the plots treated with common urea (CU) at a level of 69 kg N ha^{-1} applied 1/3 at 15 DAS + 1/3 at PI (NAT3) had relatively higher results (13.74 t ha^{-1}) and which was statistically similar in weight to those the stable urea (US) at a level of 103.5 kg N ha^{-1} applied at1/3 at 15 DAS + 1/3 at PI + 1/3 at heading

(NTA2) and from the stable urea (US) at a level of 138 kg N ha^{-1} applied 1/3 at 15 DAS + 1/3 at PI (NAT3) treatments. The lowest (7.27 t ha^{-1}) DBM yield was recorded from the treatments of common urea (CU) at a rate of 103.5 kg N ha^{-1} applied 1/3 at 15 DAS + 1/3 at PI + 1/3 at heading (NTA2). In accordance with the present findings, Kamruzzaman *et al*. (2013) suggested that the plots received 80 kg N ha^{-1} applied by splitting application at ⅓ N at 15 DAT + ⅓N at 30 DAT + ⅓ N at 45 DAT gave the maximum value (30.30 t ha^{-1}).

4.3.7 Grain yield (GY) (t ha-1)

The experimental finding revealed that N fertilizer rates and application time had significant effects on grain yield (at $P<0.01$ and $P<0.05$, respectively), however, source of nitrogen fertilizer did not have significant difference on this parameter (Appendix Table 3). On the other hand, the present study portrayed that there were also interaction effects among these factors on grain yield of upland rice, NERICA-4 (Table 4.6). On contrary of the present results, Alim (2012), showed that there was a marked influence on grain yield by the application of different sources

Concerning the interaction effect between these three factors (N source, rates and time of application), the maximum yield (6.16 t ha^{-1}) were recorded from the plots treated with common urea (CU) with a rate of 69 kg N ha^{-1} applied at 1/3 at 15 DAS + 2/3 at PI (NTA3). Besides, the combinations of common urea (CU) at a rate of 138 kg N ha^{-1} applied 1/3 at 15 DAS + 1/3 at PI + 1/3 at heading (NTA2) and from common urea (CU) with a rate of 138 kg N ha^{-1} applied 1/3 at 15 DAS + 2/3 at PI (NTA3), gave statistically similar result. While the lowest (3.43 t ha^{-1}) yield was recorded from the plots treated with the combinations of common urea (CU) with a rate of 103.5 kg N ha^{-1} applied 1/3 at 15 DAS + 1/3 at PI + 1/3 at heading (NTA2) (Table 4.6). In accordance with the present result, Fageria *et al*. (2011) reported that the grain yield was significantly affected due to the interactions of Nitrogen source and N rates. Other researchers also confirmed similarly as the interaction effects among the Nitrogen application times and N rates had a significant effect on rice grain yield (Kamruzzaman *et al*., 2013).

Though many literatures (Das *et al*., 2015; Amare *et al*., 2019) stated for the significant effects of slow releasing N nutrient sources on yield and yield components, some (Maria *et al*., 2016;

Jiana *et al*., 2017) have reported non-significant effects in line with the present finding. The findings of Jiana *et al*., 2017 had reported that though there was non-significant difference between N sources, the ranking of treatments showed that ordinary urea fertilizer applied in splits (50% at preplant and other 50% at the tillering stage) produced better grain and biomass yields compared to single dose application of controlled-release N fertilizer all at rate of 108 kg N ha^{-1}. Furthermore, the works of Maria *et al*., (2016) which was done on upland rice concerning different nitrogen sources indicated that coated slow releasing urea did not provide increases in rice grain yield in relation to common urea. This fact shows that the coated urea sources behave similarly to common urea in some situations. A possible explanation for this lack of results was the rains that occurred shortly after the application of the nitrogen fertilizers. This rain condition up to three days after nitrogen fertilization with urea is considered ideal to obtain better efficiency of N applied at topdressing, since N losses are minimal regardless of the source or form of the nitrogen fertilizer (Maria *et al*., 2016). Thus, for the conditions where rain incorporating urea, the choice of what source of N would be used will depend on the price. In this case, common urea is advantageous over the other nitrogenous fertilizers tested. Likewise, Fageria and Carvalho (2014) found no differences in rice when using common urea and urea coated with polymer. Thus, according to these authors, the use of coated urea appears feasible only in places with risk of dry spells greater than nine days after the completion of nitrogen topdressing (Maria *et al*., 2016).

4.3.8 Straw yield per ha (SY) (t ha-1)

As the data indicated in the Appendix Tables 3, straw yield of the NERICA-4 rice did not significantly (P>0.05) affect by the main effect as well as the interaction effects between N sources, rates and application time. In line with the present research, rice straw yield responds insignificantly due to the variation of N sources and time of application in the findings of Shiferaw Nesgea *et al*., (2012). However, in disparity, Naser *et al*., (2011) showed that straw yield increased with increasing of N.

4.3.9 Total 1000-grain weight (TGW) (g)

Like the straw grain yield, the result of analysis of variance in respect to 1000-grain yield was did not show significant (P>0.05) effect due to the main effect of N source, rates and time of application (Table 4.5). However, it was significantly affected (P<0.005) among their interactions (Table 4.6). Studies reported by different authors revealed that the total 1000-grains weight had not significantly influenced by the application of different contents of N fertilizer. Similarly, Fageria *et al*. (2011) and Shiferaw Nesega *et al*. (2012), reviewed that N source did not show significant effect on 1000-grains weight of rice.

Shiferaw Nesega *et al*. (2012) also noted time of N fertilizer application did not show significant effect on the 1000-grains weight at par of the present research. Early application of nitrogen fertilizer may help the plant to get competency to take more nutrient and solar radiations. This lead for the tall plant length (Tsedalu Jemberu *et al*., 2015). Studies reported by different authors revealed that the total 1000-grains weight had not significantly influenced by the application of different contents of N fertilizer (Fageria *et al*. 2011; Shiferaw Nesega *et al*. 2012).

Shiferaw Nesega *et al*. (2012) also noted time of N fertilizer application did not show significant effect on the 1000-grains weight at par of the present research. Early application of nitrogen fertilizer may help the plant to get competency to take more nutrient and solar radiations.

Likewise, Fageria (2007) reported that N is one of the most important nutrients in increasing yield component of rice, including 1000 grain weight. However, Fageria, *et al*. (2011), reported that N source X N rate interaction for thousand grains weigh was not significant. In case of thousand grain weight, although it is an important yield determining component (Ahmed *et al*., 2005; Hailu Tefera, 2010; Haque and Haque, 2016).

4.3.10 Harvest index (HI)

Harvest index of NERICA-4 upland rice was not affected significantly by all the main effect of N source, rates and application time and their interaction effects between these factors

(Appendix Table 3). Likewise, Fageria *et al*. (2011), recorded as N source was not found significant difference on harvest index (HI). In addition, as of Kamara *et al*. (2011) and Kamruzzaman *et al*. (2013), application time of N fertilizer was not made significance difference on HI like as the present study result. As par with the present findings, Kamruzzaman *et al*. (2013) findings also suggested that N rate did not have a significant effect on HI of rice crop.

As similar as this research, according to different authors (Fageria, *et al*., 2011), effect of interactions between Nitrogen source and N rates for grain harvest index was not significant. Kamara *et al*. (2011), also reported the same result with current research as the interactions among N rates and time of application did not affect harvest index of rice crop.

Table 4.5: mean main effect of sources, rates, and timing of N application on yield and yield related attributes of upland rice (NERICA-4)

Treatments	Number of fertile panicles	Total fresh biomass yield (t ha^{-1})	Dry biomass yield (t ha^{-1})	Grain yield (t ha^{-1})
N sources				
Stable Urea (SU)	69.889^{b}	17.795	11.407	4.900
Common Urea (CU)	77.37^{a}	18.243	11.445	4.932
SE±	2.167	0.741	0.540	0.237
LSD (<5%)	4.938*	NS	NS	NS
Nitrogen Rates, kg/ha				
69.00	68.833^{b}	16.893^{b}	10.378^{b}	4.483^{b}
103.50	73.33^{ab}	17.628^{b}	11.018^{b}	4.696^{b}
138.00	78.722^{a}	19.537^{a}	12.887^{a}	5.569^{a}
SE±	2.601	0.879	0.619	0.267
LSD (<5%)	6.048*	1.782*	1.26***	0.699**
Time of Fertilizer Application				
NTA1	71.778	16.363^{b}	10.359^{b}	4.477^{b}
NTA2	73.944	18.11^{ba}	11.438^{a}	4.848^{ba}
NTA3	75.167	19.588^{a}	12.481^{a}	5.423^{a}
SE±	2.799	0.857	0.633	0.276
LSD (<5%)	NS	1.782**	1.260**	0.699*
CV	12.126	14.601	16.281	20.995

*Note: Numbers followed by different letters in the same column indicate significant differences at <5% of probability. Where: *, ** and NS = Significant at <0.05, at <0.01probability and non-significant respectively, NTA1= N application time at 1/3 at planting, 1/3 at tillering, and 1/3 at PI; NTA2 = N application time at 1/3 at 15 DAS, 1/3 at PI and 1/3 at heading; NTA3 = N application time at 1/3 at 15 DAS, and 2/3 at PI; CU = Common Urea and SU = Stable Urea.*

Table 4.6: Mean interaction effect of sources, rates and Nitrogen fertilizer application times on yield and yield related attributes on upland rice crop (NERICA-4)

Treatments	NFP	NFG	NUG	TFBM	DBM	GY	TGW
US × 69 × NTA1	62.67^{fed}	76.67^{ed}	5.33^{bdc}	13.23^{gf}	8.25^{gih}	3.74^{dc}	30.06^{bac}
US × 69 × NTA2	69.67^{fedc}	93.0^{ebdac}	6.67^{bdc}	16.41^{egdf}	10.2e^{gdfih}	4.54^{bdac}	29.37^{bdac}
US × 69 × NTA3	60.67^{f}	89.33^{ebdc}	5.33^{bdc}	14.55^{egf}	8.67^{gfih}	3.93^{bdc}	27.70^{bdc}
US × 103.5 × NTA1	73.33^{fbedc}	106.67^{ba}	4.33dc	20.20^{bdac}	13.2^{bdac}	4.51^{bdac}	28.43^{bdac}
US × 103.5 × NTA2	78.67^{bc}	95.0^{ebdac}	7.33^{bdac}	21.42^{ba}	13.64^{bac}	5.84^{a}	28.473^{bdac}
US × 103.5 × NTA3	76.00^{bedc}	98.33^{bdac}	4.00^{dc}	20.20^{bdac}	13.13^{ebdac}	5.63^{ba}	26.12^{d}
US × 138 × NTA1	79.33^{bc}	106.67^{ba}	8.33^{bac}	16.67^{egdfc}	10.7^{egdfch}	4.88^{bdac}	29.37^{bdac}
US × 138 × NTA2	60.00^{f}	111.67^{a}	9.33^{ba}	16.513^{egdf}	11.38^{edfc}	5.18^{bac}	30.07^{bac}
US × 138 × NTA3	68.667^{fedc}	80.67^{ed}	3.67^{d}	20.96^{bac}	13.54^{bac}	5.84^{a}	27.11^{bdc}
CU × 69 × NTA1	72.667^{fbedc}	103.67^{bac}	11.67^{a}	16.16^{egdf}	10.06^{egfih}	4.59^{bdac}	27.85^{bdc}
CU × 69 × NTA2	74.33^{fbedc}	90.67^{ebdac}	5.33^{bdc}	19.19^{bdac}	11.31^{egdfc}	3.94^{bdc}	31.83^{a}
CU × 69 × NTA3	73.00^{fbedc}	107.00^{ba}	7.67^{bdac}	21.87^{ba}	13.74^{bac}	6.16^{a}	27.89^{bdc}
CU × 103.5 × NTA1	61.33^{fe}	85.67^{ebdc}	8.00^{bdac}	13.23^{gf}	8.18^{ih}	3.81^{dc}	26.57^{dc}
CU × 103.5 × NTA2	73.67^{fbedc}	87.33^{ebdc}	7.33^{bdac}	13.13^{g}	7.27^{i}	3.43^{d}	28.57^{bdac}
CU × 103.5 × NTA3	77.00^{bdc}	87.67^{ebdc}	5.00^{bdc}	17.57^{ebdfc}	10.7^{egdfch}	4.96^{bdac}	31.63^{a}
CU × 138 × NTA1	81.33^{bac}	74.67^{e}	4.67^{dc}	18.69^{ebdac}	11.82^{ebdc}	5.34^{bac}	30.43^{ba}
CU × 138 × NTA2	87.33^{ba}	82.33^{edc}	3.67^{d}	21.967^{a}	14.82^{ba}	6.15^{a}	29.49^{bdac}
CU × 138 × NTA3	95.67^{a}	107.67^{ba}	6.00^{bdc}	22.43^{a}	15.10^{a}	6.01^{a}	31.83^{a}
LSD (<5%)	14.815 **	22.224*	4.3693*	4.3659***	3.087***	1.7126 *	3.5438 *
SE±	1.602	2.127	0.409	0.522	0.382	0.167	0.342
CV (%)	12.126	14.382	41.698	14.602	16.281	20.995	7.353

*Note: Numbers followed by different letters in the same column indicate significant differences at <5% of probability. Where: *, **, *** and NS = Significant at <0.05, <0.01, <0.001 probability and non-significant respectively, NFP= Number of Fertile Panicles, NFG= Number of Fertile grains, NUG= Number of Unfertile grains, TFBM = Total Fresh Biomass Yield, DBY = Total Dry Biomass Yield, GY = Grain yield, TGW= Thousand Grain Weight.*

4.4 Partial Budget Analyses

As the partial budget analysis indicated in Table 4.8, the plots treated with common urea (CU) at of 69 kg N ha^{-1} which was applied at 1/3 at 15 DAS and 2/3 at PI, was found the maximum net benefit, 93,393.53 ETB. Whereas the rest treatments were exhibited lower net benefits.

As the data showed (Table 4.8), of the total treatments there was only one un-dominated treatments, which has minimum total variable cost but maximum net benefit as compared to the others. The result indicated that the net benefit had decreased except in the case of the treatment of the common urea (CU) at a rate of 69 kg N ha^{-1} which was applied at 1/3 at 15 DAS and 2/3 at PI. Hence, the treatments had higher benefits and lower costs, this treatment was recommended. The rest treatments were not recommended to farmers, because of higher costs and lower net benefits, which are dominated. These can be eliminated from further consideration; and the value of the increase in yield is not enough to compensate for the increase in costs.

Therefore, although it requires careful marginal analysis using an appropriate minimum rate of return to make farmer recommendations, since there is not any another un-dominated treatment, no need of conducting marginal analysis. Since then, in conclusion, it should be noted that the recommendation is carried out without calculating MRR and hence, the net positive benefit obtained with treatment of common urea (CU) as a source + 69 kg N ha^{-1} + at 1/3 at 15 DAS and 2/3 at PI time of applications was economically profitable and can be recommended for farmers in the study area and other areas with similar agro-ecological and edaphic conditions.

Table 4.7: Cost and benefit analyses of N sources, rates and time of N fertilizer application for rain-fed upland rice production in *Fogera* District of Ethiopia

Treatments						
N-Sources	N-Rates	N-Fertilizer Application Times	GFB (ETB/ha)	TVC (ETB/ha)	NB (ETB/ha)	Dominance
CU	69	NTA3	95,550.03	2,156.50	93,393.53	
CU	69	NTA1	72,346.5	2,206.5	70,140	D
CU	69	NTA2	62,971.965	2,206.5	60,765.47	D
SU	69	NTA3	62,621.505	2,362.15	60,259.36	D
SU	69	NTA1	60,043.995	2,412.15	57,631.85	D
SU	69	NTA2	72,211.005	2,412.15	69,798.86	D
CU	103.5	NTA3	77,848.965	3,184.75	74,664.22	D
CU	103.5	NTA1	61,129.53	3,234.75	57,894.78	D
CU	103.5	NTA2	55,243.53	3,234.75	52,008.78	D
SU	103.5	NTA3	87,869.475	3,493.22	84,376.25	D
SU	103.5	NTA1	71,436.465	3,543.22	67,893.24	D
SU	103.5	NTA2	91,005.03	3,543.22	87,461.81	D
CU	138	NTA3	93,701.475	4213	89,488.48	D
CU	138	NTA1	83,590.965	4263	79,327.97	D
CU	138	NTA2	95,918.535	4263	91,655.54	D
SU	138	NTA3	90,785.97	4624.3	86,161.67	D
SU	138	NTA1	76,375.035	4674.3	71,700.74	D
SU	138	NTA2	80,811.495	4674.3	76,137.2	D

Note: TVC = GFB = gross field benefit (Ethiopian Birr ha^{-1}*); total variable costs (Ethiopian Birr* ha^{-1}*); NB = net benefit (Ethiopian Birr* ha^{-1}*); D = dominated treatment.*

Chapter 5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In conclusion, as per the present study, it is found that the main effects of the treatments studied, viz., N sources, rates and times of application were less likely responded significantly by the phenological, growth, and yield and yield related parameters except few traits in general. Especially sources of N did not make much difference except total tillers and number of fertile panicles parameters of NERICA-4 rice crop which common urea (CU) was gave the maximum result than urea stable (US) and even in most of other parameters which were affected insignificantly, in both parameters. The main effect of N rate also significantly affects only the total tillers as a growth parameter and NFP, TFBM, DBM and GY of yield and yield related traits. The higher result was obtained from highest N rate used (138 kg N ha^{-1}) in most growth characteristics and yield and yield related characteristics in comparison to the lower treatment in this experimental trial. Besides, N application times significantly affects DM from phenology traits, total tillers from growth traits and TFBM, DBM and GY from yield and yield related traits of upland rice in the study area. Application of N at 1/3 at 15 DAS + 2/3 at PI (NTA3) was found the appropriate time which had a significant difference in these parameters and gave higher result in most phenology, growth and yield and yield related attributes studied. From the study it revealed that most yield contributing characteristics, i.e., number of fertile panicles, number of filled grains, number of unfilled grains, total fresh biomass yield, dry biomass yield, grain yield, 1000-grain weight, and harvest index were significantly affected by the interactions among the N sources, rates and times of application. The maximum grain yield (6.15 t ha^{-1}) of upland rice of NERICA-4 variety was recorded from the plots treated with common urea (CU) × with rate of 69 kg N ha^{-1} × applied at 1/3 at 15 DAS + 2/3 at PI (NTA3). The economic analysis also indicated that it was also found the best and appropriate combinations for better production of upland rice (NERICA-4 which gave highest net benefit (93,393.53 ETB ha^{-1}) but least cost at an acceptable limit of rate of return.

5.2 Recommendations

As the result indicated in this experiment, the combinations of common urea (CU) at a rate of 69 kg N ha^{-1} applied at 1/3 at 15 DAS + 2/3 at PI (NTA3) was produced the higher grain yield and most yield component parameters with corresponding higher economic rate of return among treatments used in NERICA-4 rice crop in the study area. Thus, this treatment is likely to be recommended appropriate inputs those would be used for better maximization of the production and productivity of upland rice in *Fogera* district in rain feed conditions. However, it is advisable that the research should be replicated further in different areas having similar ecologies and edaphic conditions with the study area to come up with better and concrete evidence for confidential recommendation to contribute in maximization of upland rice yield and to improve economic of rice inputs in the study area as well as in other areas in the country.

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APPENDICES

Appendix Table 1: Summary mean square ANOVA of the effect of the N sources, rates and application times on phenology of upland rice (NERICA-4)

Source of variation	Df	DH	DM
NS	1	0.296^{ns}	0.074^{ns}
NR	2	0.519^{ns}	0.796^{ns}
NTA	2	3.852^{ns}	4.796^{*}
NS×NR×NTA	4	2.935^{ns}	1.824^{*}
Error	34	2.172	0.659

*Where: * = significant at <0.05 probability rates and ns = non-significant at <0.05, DF=Degree of freedom, DH= 50% of heading (days), DM= 50% Physiological maturity (days), NS = Nitrogen Sources, NR= Nitrogen Rates, NTA= Nitrogen Application Times, NS x NR x NTA = interaction effects of Nitrogen Sources, Nitrogen Rates and Nitrogen Application Times.*

Appendix Table 2: Summary mean square ANOVA of the effect of the N sources, rates and application times on growth of upland rice (NERICA-4)

Source of variation	Df	PH	PL	TT
NS	1	0.125^{ns}	0.031^{ns}	2521.500***
NR	2	2.902^{ns}	2.025^{ns}	1502.000***
NTA	2	5.205^{ns}	3.587^{ns}	330.500**
NS×NR×NTA	4	18.34^{ns}	1.633^{ns}	55.222***
Error	34	15.232	1.217	53.775

*Where: *, ** and *** = significant at <0.05, <0.01 and at <0.001 probability rates respectively and ns = non-significant at <0.05, DF=Degree of freedom, PH=Plant Height, PL= Panicle, Length, TT= Total Tillers, NS = Nitrogen Sources, NR= Nitrogen Rates, NTA= Nitrogen Application Times, NS x NR x NTA = interaction effects of Nitrogen Sources, Nitrogen Rates and Nitrogen Application Times.*

Appendix Table 3: Summary mean square ANOVA of the effect of the N sources, rates and application times on yield and yield related parameters of upland rice (NERICA-4)

Source of variation	Df	NFP	NIP	NFG	NUG	TFBM	DBM	GY	SY	TGW	HI
NS	1	755.630*	1.185$^{\text{ns}}$	88.167$^{\text{ns}}$	4.167$^{\text{ns}}$	2.711$^{\text{ns}}$	0.02$^{\text{ns}}$	0.013$^{\text{ns}}$	0.179$^{\text{ንስ}}$	14.748$^{\text{ns}}$	5.821$^{\text{ns}}$
NR	2	441.241*	2.241$^{\text{ns}}$	16.963$^{\text{ns}}$	6.352$^{\text{ns}}$	33.511*	30.70***	5.956**	0.300$^{\text{ns}}$	9.130$^{\text{ns}}$	0.332$^{\text{ns}}$
NTA	2	53.019$^{\text{ns}}$	0.574$^{\text{ns}}$	78.685$^{\text{ns}}$	15.407$^{\text{ns}}$	46.887**	20.259**	4.085*	0.164$^{\text{ns}}$	4.703$^{\text{ns}}$	2.901$^{\text{ns}}$
NS×NR×NTA	4	96.130**	5.769$^{\text{ns}}$	651.028*	12.611*	10.456***	4.322***	1.430*	0.039$^{\text{ns}}$	9.027*	13.380$^{\text{ns}}$
Error	34	79.718	2.656	179.391	6.934	6.923	3.461	1.065	0.395	4.561	45.539

*Where: *, ** and *** significant at <0.05, <0.01 and at <0.001 probability rates respectively and ns = non- significant at <0.05, DF=Degree of freedom, NFP= Number of Fertile Panicles, NIP = Number of Infertile Panicles, TFBM = Total Fresh Biomass Yield, DBY = Total Dry Biomass Yield, GY = Grain yield, SY = Straw Yield, TGW= Thousand Grain Weight, HI= Harvest Index, NS = Nitrogen Sources, NR= Nitrogen Rates, NTA= Nitrogen Application Times, NS x NR x NTA = interaction effects of Nitrogen Sources, Nitrogen Rates and Nitrogen Application Times.*

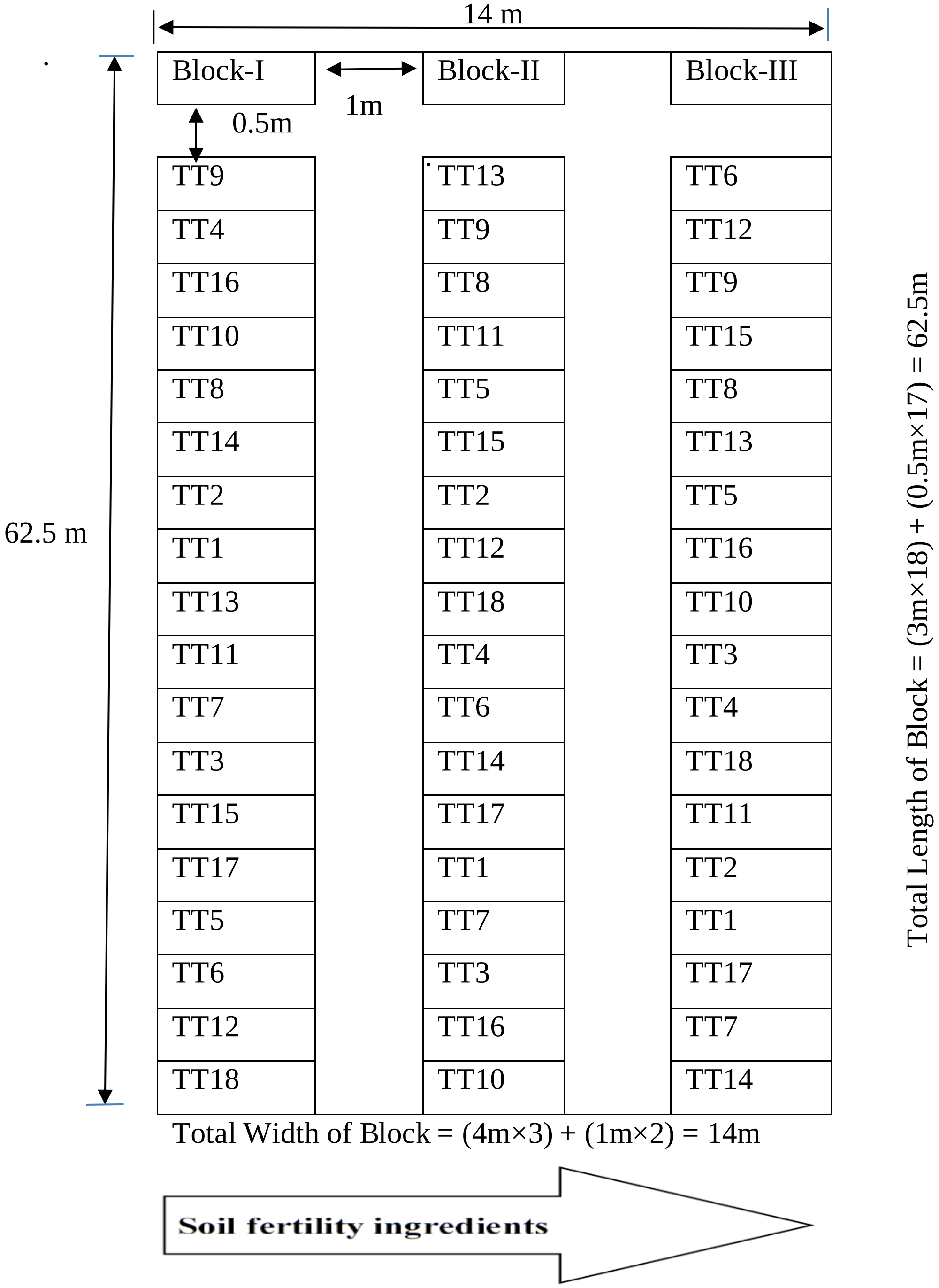
Appendix Table 4: Partial budget analyses

			Yield (t/ha)				GFB (ETB/ha)			TVC		
N sources	N Rates	N application time	Av. GY	Ad. GY 90%	Av.SY	Ad. SY 90%	Ad. GY (ETB/ha)	Ad. SY (ETB/ha)	Total (Y+S)	Labor time	Fertilizer	Total cost
SU	69	NTA1	3.74	3.36	5.06	4.55	55490	4554	60043.99	150	2262.15	2412.15
		NTA2	4.54	4.09	5.27	4.74	67468.01	4743	72211.00	150	2262.15	2412.15
		NTA3	3.93	3.54	4.68	4.212	58409.51	4212	62621.50	100	2262.15	2362.15
	103.5	NTA1	4.51	4.06	5.01	4.51	66924.5	4511.97	71,436.47	150	3393.22	3543.22
		NTA2	5.84	5.26	4.76	4.28	86724	4281.03	91005.03	150	3393.22	3543.22
		NTA3	5.63	5.07	4.68	4.21	83654.51	4214.97	87869.47	100	3393.22	3493.22
	138	NTA1	4.88	4.39	4.29	3.86	72517.01	3858.03	76375.03	150	4524.3	4674.3
		NTA2	5.19	4.66	4.21	3.79	77022.5	3789	80811.49	150	4524.3	4674.3
		NTA3	5.84	5.25	4.51	4.07	86724	4061.97	90785.97	100	4524.3	4624.3
CU	69	NTA1	4.59	4.13	4.65	4.19	68161.5	4185	72346.5	150	2056.5	2206.5
		NTA2	3.94	3.54	5.01	4.52	58460	4511.97	62971.96	150	2056.5	2206.5
		NTA3	6.16	5.54	4.53	4.08	91476	4074.03	95550.03	100	2056.5	2156.5
	103.5	NTA1	3.81	3.43	5.06	4.55	56578.5	4551.03	61129.53	150	3084.75	3234.75
		NTA2	3.43	3.09	4.79	4.31	50935.5	4308.03	55243.53	150	3084.75	3234.75
		NTA3	4.96	4.46	4.71	4.24	73607	4241.97	77848.96	100	3084.75	3184.75
	138	NTA1	5.34	4.80	4.82	4.34	79250	4340.97	83590.96	150	4113	4263
		NTA2	6.15	5.54	5.05	4.54	91376.51	4542.03	95918.53	150	4113	4263
		NTA3	6.01	5.42	4.89	4.40	89297.51	4403.97	93701.47	100	4113	4213

Were Av.GY=Average grain yield, Ad.GY=Adjusted grain yield, Av.SY =Average straw yield, Ad.SY=Adjusted straw yield, GFB=Gross field benefit, G + S = Grain and straw.

***N.B**: Prices of Common Urea (CU)= 13.71 Birr/kg, Price of Urea Stable (US) = 15.081 Birr/kg, Price of upland rice grain =16.50 Birr/kg, Price of upland rice grain straw= 1 Birr/kg. Labour cost of N fertilizer application time (one round) = 50 Birr/ha.*

Treatment arrangement and field layout



Block-I	Block-II	Block-III
TT9	TT13	TT6
TT4	TT9	TT12
TT16	TT8	TT9
TT10	TT11	TT15
TT8	TT5	TT8
TT14	TT15	TT13
TT2	TT2	TT5
TT1	TT12	TT16
TT13	TT18	TT10
TT11	TT4	TT3
TT7	TT6	TT4
TT3	TT14	TT18
TT15	TT17	TT11
TT17	TT1	TT2
TT5	TT7	TT1
TT6	TT3	TT17
TT12	TT16	TT7
TT18	TT10	TT14

Total Area = 14m×62.5m = 875m^2

Appendix Figures 1: Field Layout of the treatments

BIOGRAPHY

The author was born on January 21, 1988 at South Gondar Zone, *Simada,* from his father Mr. Tilahun Tawuye sand his mother Mrs. Muluye Kassaw. He attended his elementary and secondary education at *Wogeda* Elementary and Tagel Secondary and Preparatory School. After completing his high school education in 2004; he joined *Mersa* ATVET College and graduated with a Diploma in plant science in July 2004 and after a 3 years working experience; as a Crop Production and Protection Expert in *Simada* District, he joined Bahir Dar University and graduated with a BSc Degree in Plant Sciences in November 2010. After graduation, he joined South Gondar, *Simada* district Agricultural Development Office in different position up to June 3, 2013 and then Abbay Basin Authority as a Senior Agronomist and has worked there until he joined Bahir Dar University in October 2016 to pursue his MSc. Degree study in Agronomy.