EFFECT OF CULTIVAR, RATES AND TIME OF NITROGEN FERTILIZER APPLICATION ON YIELD AND YIELD COMPONENTS OF LOWLAND IRRIGATED RICE *(Oryza sativa* L*)*

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ABSTRACT

Nitrogen (N) is one of the major elements required by rice (*Oryza sativa* L) plants for growth and development. Nitrogen deficiency in rice is caused by losses of the element from the soil- plant system, mainly through denitrification, ammonia volatilization, leaching and runoff. Thus, careful management of N both in terms of rates and timing of application is essential in order to improve its utilization by the plants. An experiment was therefore conducted at Mkindo irrigation project in Mvomero district, Tanzania to evaluate the response of three rice varieties to different rates and times of N application. A split-split plot design with three replications was adopted. The main plots contained three rice varieties (TXD85, TXD306 and Supa). The sub- plots contained four rates of N (0,40,80,and 120 kg N ha^{-1}) while the sub-sub plot represented four times of N application (T1=single dose in dry soil before transplanting, T2=two equal splits: half dose each in dry soil before transplanting and at initial tillering, T3=three equal splits: one- third dose each in dry soil before transplanting, initial tillering and panicle initiation, T4=two equal splits: half dose each at initial tillering and panicle initiation). Dry mass accumulation varied significantly ($P<0.05$) among treatments. Highest dry mass accumulation was recorded in TXD 306 and the lowest in Supa. More dry mass was attained with 120 kg N ha-1 applied as T4 and the lowest without N. Application of N as T4 gave the highest dry mass, while the lowest with N as T1. Grain yield increased significantly ($P<0.05$) with increasing N rates in cultivars TXD 85 and TXD 306 up to 120 kg ha^{-1}. The yield increase in Supa was only up to 80 kg N ha^{-1} after which it declined. Time of N application significantly ($P<0.05$) affected grain yield in rice with highest

results suggest that grain yield increased proportionately with increased N availability in the soil. Grain yield variation among treatments was found to be associated with variations in the number of panicles/m^2, panicle weight and number of grains/panicle. Among growth parameters, grain yield was significantly ($P<0.01$) influenced by grain dry mass, stem dry mass, and total dry mass. Leaf dry mass had no direct contribution to the observed variation in grain yield. Nitrogen use efficiency (NUE) varied among treatments. TXD 306 recorded highest NUE and lowest in Supa. Highest NUE was realized with low N rates (40 kg N ha^{-1}) and lowest with higher N rate (120 kg N ha^{-1}). With regard to time of N application, highest NUE was recorded when N was applied as T4 and lowest as T1. It was therefore concluded that, economic optimum N rate for TXD 85 and TXD306 was 120 and 80 kg N ha^{-1}, respectively, applied as T4 while for Supa was 40 kg N ha^{-1} applied as T4.

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DECLARATION

I, Joel Absalom Moses Zakayo, I do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and has not been submitted for a degree award in any other University.

Signature.....

Date.....6-10-2023

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DEDICATION

This dissertation is dedicated to my late father Absalom, my mother Elizabeth, my wife Ester and my children Bartimayo and Kusuraeli for their love, patience and moral support. It is also dedicated to smallholder farmers of Tanzania who produce the largest portion of rice to feed the nation.

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%	Percent
(NH_4) CO3	Ammonium carbonate
^0C	Degree Celsius
Ca	Calcium
CDU	Crotonylidine diurea
CEC	Cation Exchange Capacity
cm	centimeter
cmol	centimole
CV	Coefficient of variation
DM	Dry matter
DNMRT	Duncan's New Multiple Range Test
E	East
FAO	Food and Agricultural Organization of United Nations
GDM	Grain dry mass
GUP	Guanyl Urea Phosphate
Ha	Hectare
IBDU	Isobutylidine diurea
IRRI	International Rice Research Institute
K	Potassium
KCl	Potassium Chloride
Kg	Kilogram
LDM	Leaf dry mass

m	metre
m.a.s.l	metres above sea level
Mg	Magnesium
mm	millimetre
MAFS	Ministry of Agriculture and Food Security
MOA	Ministry of Agriculture
MSTAT-C	Michigan State University Computer Software
N	Nitrogen
N_2O	Nitrous oxide /Dinitrogen oxide
Na	Sodium
NH_3-N	Ammonium nitrogen
NH_4^+	Ammonium ion
NO	Nitric oxide
NO_2^-	Nitrite ion
NO_3^-	Nitrate ion
NUE	Nitrogen Use Efficiency
P	Phosphorus
S	South
SADC	Southern African Development Committee
SCU	Sulphur coated urea
SDM	Stem dry mass
SE	Standard error
SUA	Sokoine University of Agriculture
T1	Single dose in dry soil before transplanting

T2	Two equal splits: half dose each in dry soil before transplanting, and initial tillering
T3	Three equal splits: one third dose each in dry soil before transplanting and panicle initiation
T4	Two equal splits: half dose at initial tillering and panicle initiation
TDM	Total dry mass
USA	United States of America

CHAPTER ONE

1.0 INTRODUCTION

Rice (*Oryza sativa* L) is an important cereal crop on which about half of the world's population depend upon as food. Human consumption accounts for 85% of the total production of rice, compared to 60% for wheat and 25% for maize (IRRI, 1994). Rice also accounts for 20% of the global human per capita energy and 15% per capita protein (IRRI, 1994). Rice production is concentrated in Asia where more than 90% of the world supply is produced and consumed (Mae, 1997). Besides its importance as food, rice provides employment to the largest sector of the rural population in most of Asia (De Datta, 1981). Other areas where rice is grown are some parts of USA, Latin America, Mediterranean countries and Africa.

Rice is becoming an important crop in Africa. From 1997 to1999 it accounted for 4.3% of the world's rice area, 2.5% of rice production, and 20.0% of the world's rice imports (FAO, 2000). With the exception of few countries that have attained self-sufficiency in rice production, the demand for rice exceeds production and large quantities of rice are imported to meet the demand (IRRI, 1994). For example, Africa consumes a total of about 11.6 million tonnes of milled rice per year (FAO, 1996) of which 4.5 million tonnes (33 – 60%) are imported (Oteng and Sant' Anna, 1999; FAO, 1999). Increased demand for rice as a staple food in Africa reflects a dietary shift from traditional foods (especially roots and tubers), urbanization and socio-economic trends (IRRI, 1984).

Tanzania is neither a major world producer nor consumer of rice; however rice is one of the major cereals grown in the country (Ching'ang'a, 1985). Rice is a staple food for 60% of the population and particularly among the urban population (IRRI, 1994). Tanzania is the second largest rice producer in the Southern African Development Committee (SADC) region (Kihupi *et al.*, 1998). The history of rice cultivation in Tanzania has been detailed by several workers (Carpenter, 1978; Monyo, 1976). However at present all regions cultivate it at varied extents. It occupies about 11% of the total cultivated area of 6.0 million ha (MOA, 1995). The five major rice growing regions include Shinyanga, Morogoro, Mbeya, Mwanza and Tabora which together produce about 70% of the total rice (MAFS,2001).

Although rice production has increased gradually by area expansion, yield per hectare has not increased correspondingly in recent years. The regional and national average rice production per hectare has remained at 0.7 to 1.8 tons as compared to that of Japan (6.3 tons) Korea (6.6 tons), U.S.A. (6.3 tons), Bangladesh (4.4 tons) and Indonesia (5.8 tons) (MOA, 1995; FAO, 2000). The low yields are attributed to such factors as use of low- yielding traditional varieties associated with low response to fertilizers, lack of irrigation facilities, poor soil and water management, little or no application of fertilizers and lack of pest management technologies acceptable to farmers (Ching'ang'a, 1985; Kihupi *et al.*, 1998).

In tropical soils, the major nutrient element limiting yields of rice is nitrogen (De Datta, 1981; Semoka *et al.*, 1995). Correct rates and timing of application of nitrogen fertilizer have a marked effect on N-use efficiency (Patnaik and Rao, 1979).

Poor utilization of fertilizer nitrogen is thought to be largely caused by losses of nitrogen from the soil-plant system. Denitrification, ammonia volatilization and runoff have been identified as potential N – loss mechanisms (Brady, 1990).

Besides, the existence of high yielding rice cultivars that respond well to nitrogen, inefficient utilization of fertilizer N in rice is still a major factor frustrating strategies developed to increase its production. The problem is compounded by relatively high cost of N to small farmers and a wide spread concern about the future prices. Nitrogen is almost universally deficient in rice soils, but chemical sources of nitrogen are becoming increasingly costly. A rice plant often absorbs no more than 25 to 50% of N applied to the soil. The rest is lost or is unavailable to the crop (Chandler, 1979). In addition, fertilizer nitrogen not used by rice may end up in surface and groundwater contributing to environmental pollution, posing hazards to human health and aquatic life (Ladha *et al.*, 1997). This, therefore, demands for a careful management of their use both in terms of rates and timing of its application so as to avoid unnecessary losses, environmental pollution and save farmers money.

While considerable information exists on the effect of timing fertilizer N application on rice soils for various Asian soils, there is scant information on N uptake capacity, use efficiency and the congruency of N supply with rice N demand at various rates and growth stages in tropical African soils. In Tanzania, rice production per unit area is generally low under smallholder farmers' condition. Use of traditional low-yielding cultivars with low N response is some of the factors leading to low yields.

The current rise in prices of N fertilizers has forced resource- limited farmers, who are the major rice producers to apply sub-optimal levels or no N at all. With these

backdrops, it is important to study and identify optimum rates and time of N application, to enhance N uptake and N- use efficiency. The study was therefore carried out to evaluate the response of some improved and local rice cultivars to rates and time of N fertilizer application in order to increase yields and minimize N losses as well as to save farmers' expenditure on fertilizer nitrogen.

The specific objectives were to:

1. Determine the growth and development of selected rice cultivars under different levels and time of fertilizer N application.
2. Assess the nitrogen use efficiency under different levels and time of fertilizer N application.
3. Determine the response of selected rice cultivars to different levels and time of fertilizer N application in terms of yield and yield components.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Rice Production

Rice is widely dispersed around the world, in a broad range from 50 ^{0}N to 40 ^{0}S and from sea level to altitudes of more than 250m (Yoshida, 1981;Takahashi and Tsunoda, 1984). The area estimated to be under rice cultivation in 1991 worldwide was about 148 million hectares out of which 79 million hectares were irrigated, 40.5 million hectares were lowland rain-fed and 17 million hectares were upland (IRRI, 1994). There are 111 rice-growing countries in the world. They include all Asian countries, most countries of the West Africa, North Africa, some countries in Central and Eastern Africa, most of the South and Central American countries, Australia and at least four states in the United States of America (De Datta, 1981).

About 90% of the estimated rice growing area is under smallholder farmers of 0.5 to 2.0 hectares per farm household (Kanyeka *et al.*, 1994). In 2000 a total of 504,000 ha were estimated to be under paddy (FAO, 2000). The annual rice production is about 508,300 tonnes, which decreased from 676,000 tonnes in 1997/98 (MAFS, 2001). The highest total production attained between 1992/93 and 1998/99 was 506,200 tons in 1998/99. In order to surpass this level, production for the year 2001/02 was estimated at 1.1 million tons. Thereafter production was expected to increase to 1.30, 1.33,1.43 and 1.53 million tons respectively for the years 2002/03,2003/04,2004/05 and 2005/06 (MAFS, 2001).

Tanzania has not yet self-sufficient in rice. Hence substantial imports continue to be necessary. About 84,470,000 tons per year are imported to cover the shortfall (FAO, 1999). The regional and national average rice production per unit area in Tanzania has remained at 0.7 to 1.8 ton ha^{-1} (FAO, 2000). In addition, production has declined with trends from 1.2 ton ha^{-1} in 1997 to 0.7 ton ha^{-1} in 2000 (FAO, 2000).

2.2 Forms and Sources of Nitrogen in Rice Production

2.2.1 Forms of nitrogen

There are three major forms of nitrogen in mineral soils; organic nitrogen associated with soil humus, ammonium nitrogen fixed by certain clay minerals and soluble inorganic ammonium and nitrate compounds. The amount of nitrogen in the form of soluble nitrate compound is seldom more than 1 to 2% of the total present, except where large application of inorganic fertilizer have been made (Brady, 1990).

The inorganic forms of soil N include ammonium (NH_4^+), Nitrite (NO_2^-), Nitrate (NO_3^-), nitrous (N_2O), nitric oxide (NO),.and elemental N (N_2), which is inert except for its utilization by *Rhizobia* and other N-fixing microorganisms. From the standpoint of soil fertility, NH_4^+, NO_2^- and NO_3^- are the most important and are produced from aerobic decomposition of soil organic matter or from addition of fertilizers. These three forms usually represent 2 to 5% of the total soil N.The N_2O and NO are important forms of N lost through denitrification (Tsidale *et al.*, 1993). Organic soil N occurs as protein, amino acids, amino sugars, and other complex N compounds. The proportion of the total soil N in these fractions is as follows: bound amino acids 20 to 40%, amino sugars such as the hexosamines, 5 to 10%; and

purines and pyrimidine derivatives 1% or less (Tsidale *et al.*, 1993). Soil organic matter is an important source of N in the mineral form taken up by rice plants .The process of releasing N from the soil through mineralization is mostly microbial and biochemical (Patnaik and Rao, 1979).

In a solution culture, rice can absorb and use ammonia - N, nitrate- N, urea - N and amino acid - N. Ammonia is the major stable form of nitrogen in submerged soils, and nitrate is the major form in upland soils (De Datta, 1981). Although relatively low concentration of ammonia is toxic to many upland crops, relatively high concentrations are tolerated and used efficiently by rice. Studies to determine relative effectiveness of ammonia and nitrate as sources of N for rice often encounter difficulty with changes in the pH of the culture solution. The changes result from selective absorption of ammonia or nitrate. However, at realistic nitrogen concentration, ammonia appears to be a better than or as good as nitrate throughout the rice plants' entire cycle (Yoshida, 1981).

2.2.2 Source of nitrogen

Nitrogen is generally needed in most rice soils, particularly in places where nitrogen-responsive rice varieties are grown with improved cultural practices Accumulation of nitrogen in the soil, takes place mainly by application of inorganic N fertilizers and organic manures, from rain, through urea hydrolysis, and by biological nitrogen and rhizosphere nitrogen fixation (De Datta, 1981). Urea is the fast replacing ammonia sulphate as the most important nitrogen fertilizer for rice. Most of the urea nitrogen

is taken up by rice crop after urea is hydrolysed to $(NH_4)_2 CO_3$. The hydrolysis site is the soil rather than the flood water (Delaune and Patrick, 1970).

Biological nitrogen fixation may partly explain the long-term fertility of flooded rice soils. Watanabe *et al.* (1977) summarized data from Japan, Thailand, Indonesia and the Philippines and reported that a single rice crop can take from 37 to 113 kg N/ha from sources other than mineral nitrogen fertilizer. The principal agents for nitrogen fixation for rice are blue-green algae, the water fern, azolla, in association with blue-green algae (*Anabaena azollae).* non symbiotic nitrogen fixing bacteria around the rice plants root zone (in the rhizosphere) and nonsymbiotic bacteria in the bulk of anaerobic soil (Watanabe *et al.*, 1977). Leguminous crops grown in rotation with rice also fix some atmospheric nitrogen (Patnaik, 1978). Green manure crops such as *Sesbania aculeata* and *Crotalaria juncea* (sun hemp) have been found most suitable for growing in situ and for incorporation within 4-6 weeks after sowing. (Patnaik and Rao, 1979).

Adsorption of nitrogen compounds from the atmosphere by the rice plant or the soil water system is another potential source of N (Koyama and App, 1979). A substantial amount of NH_3-N can be transferred from localised industrial and agricultural site via atmosphere to the surrounding areas and contribute to the N of the soils and water (Stevensons, 1982).

2.3 Losses of Nitrogen

According to De Datta (1978) for efficient fertilizer use, it is imperative to understand transformation processes of the nutrient element in wetland soils and to

develop practices to minimize losses of the important resources. Nitrogen is a fertilizer element for rice that undergoes dynamic transformation under different soils, environmental and management factors. Among the pathways of losses that account for only 30 to 50% nitrogen recovery; denitrification leaching, nitrification, immobilization and ammonia fixation are most cited as important (De Datta, 1978). The processes of immobilization and ammonia fixation make nitrogen temporarily unavailable to the rice crop but do not cause loss of nitrogen from the soil system (De Datta, 1981).

2.3.1 Denitrification

Denitrification is anaerobic microbial process in which organic carbon is used as an energy source and nitrate (NO_3^-) as an electron acceptor. Nitrate (NO_3^-) is reduced to gaseous N compounds; i.e. NO_2 and N_2O. Denitrification is common in soils under wet conditions where oxygen is limited and NO_3^- and organic carbon are available for microorganisms (Koops *et al.*, 1997). Conditions leading to favourable gaseous loss of soil nitrogen by bacterial denitrification are poor drainage, temperature of greater than 25°C, soil reaction near neutral and good supply of readily decomposable organic matter (Koops *et al.*, 1997). In a flooded soil denitrification of applied nitrogen fertilizer can be substantial. Findings show that losses of 30 to 40% of the added inorganic fertilizer occurs starting about 7 to 12 days after addition of nitrate – nitrogen fertilizer (De Datta, 1981).

2.3.2 Nitrification

Nitrification is a two-step process in which some of NH_4^+ released during mineralization of organic N is converted first to NO_2^- and then to NO_3^-. The source of NH_4^+ can be from mineralization of organic N or from nitrogen fertilizers containing or forming NH_4^+ (Tsidale *et al.*, 1993). According to them, the factors affecting nitrification in soils are supply of NH_4^+, population of nitrifying organisms, soil pH, soil aeration, moisture and temperature. There are two types of bacteria that are responsible for the nitrification process. These are *Nitrosomonas* and *Nitrobacter*. The former is responsible for conversion of ammonia to nitrite while the latter is involved in the conversion of nitrite to nitrate. The two organisms are alike in requiring the absence of organic matter and presence of oxygen and carbonate (Pillai, 1967).

2.3.3 Ammonia volatilization

Losses of N as ammonia from fertilizer sources containing or producing ammonia are common. Ammonia, a readily identifiable product of nitrogen mineralization, is formed continuously in the soil and water of a flooded paddy (Delaune and Patrick, 1970). The release of ammonia from organic matter decomposed in the absence of oxygen and high pH associated with anaerobic decomposition favours ammonia volatilization from the flooded soils that have large amount of organic matter added. Use of nitrogen fertilizers on rice also contributes to large concentrations of dissolved NH_4^+ - N salts which can be volatilized (De Datta, 1981)

The volatilization of ammonia from the soil is a function of various properties of the soil system involved, including moisture content, soil pH, cation exchange capacity (CEC), soil texture, lime content, temperature and atmospheric conditions of the top soil. In addition, agronomic variables such as rates, sources of nitrogen fertilizer, time, and methods of application are also important. Losses of ammonia measured from different upland and lowland cropping systems have ranged from negligible amount to over 50% of fertilizer N applied, depending upon fertilizer application and environmental conditions (Peoples *et al.*, 1995).

2.3.4 Immobilization

Soils have the ability to chemically and biologically immobilize inorganic N, reactions that are of practical significance in reducing the effectiveness of inorganic N in the soil (Kai and Wada, 1979). Immobilization of nitrogen is caused by microbial fixation of nitrogen, which converts applied inorganic nitrogen to organic form of nitrogen in the soil and decreases the fertilizer nitrogen available to the rice plant (De Datta, 1978). The immobilization (assimilation) of inorganic N by microorganism is rapid during periods of active cell proliferation and slow when microbial activity is low. The nitrogen requirements of microorganisms in flooded soils are generally lower than those of the microbial population of non-flooded soils because anaerobic metabolism is inherently less efficient than aerobic metabolism in providing energy for synthesis of new cells (De Datta, 1981; Williams *et al.*, 1968).

The amount and rate of nitrogen immobilized is controlled largely by environmental conditions such as temperature, moisture, soil aeration, carbon nitrogen ratio of

organic matter added, rate and form of nitrogen applied and nitrification rate (Kai and Wada, 1979; Yoshida and Padre, 1975). Because ammonium is the most preferred form of nitrogen for soil microorganisms, more will be immobilized in a soil where ammonium persists than in one where it is quickly depleted. Therefore, as crop residues undergo microbial decomposition, additional N must be obtained from residual soil N or fertilizer N to support microbial growth (Schepers and Mosier, 1991). Studies at IRRI suggest that immobilization loss is about 20% of the nitrogen added for a Phillipine rice soil (Maahas Clay) and the rate varies among different soils (Yoshida and Padre, 1975).

2.3.5 Leaching

Nitrogen losses by leaching of nitrate and ammonium forms mainly occur in coarse textured soils with low CEC. In soils where the primary source of negative charge is organic rather than inorganic, the ammonium ion is subject to leaching by percolation water and nitrate produced in the oxidized surface layer of a flooded soil moves easily by diffusion and percolation into the underlying reduced layer, where it is rapidly denitrified (De Datta, 1978). Ammonium nitrogen is much less subject to leaching from the soil than nitrate because of its adsorption on the cation – exchange complex (De Datta, 1981).

Losses of ammonium by leaching is more severe in flooded soils than in non-flooded soil because of the following reasons: (a) Ammonium is not likely to accumulate in a well drained soil as in a flooded soil (b) Reduction reaction in a flooded soil produce ferrous and manganous ions, which replace ammonium from the exchange

complex to the soil solution where it is more subject to leaching (c) The constant head of standing water in a flooded soil results in a greater downward percolation of the soil solution than in a non flooded soil (Patrick and Mahapatra, 1968). Losses of nitrogen through leaching are crucial with an estimated loss of 20 kg N/ha annually n realized from rice paddies in Japan (Craswell and Vlek, 1979).

2.3.6 Ammonia fixation by minerals

In some soils quantitative recovery of added ammonium cannot be obtained even when soils are extracted immediately after addition of the ammonium. Ammonium retention is due to clay fixation and some of the ammonium is fixed so tightly that it is resistant to extraction even after prolonged boiling with concentrated hydrochloric acid. The well known ability of 2:1 type of clay mineral to entrap ammonium ions between the silica sheets often accompanied by contraction in the interlayer spacing, has received limited attention in rice soils, probably because fixation is often associated with drying to moisture contents below those usually encountered in lowland rice culture (Broadbent, 1978). However, there are some soils developed from volcanic ash in areas of high rainfall that have predominantly amorphous colloidal hydrated oxides of aluminium and iron and also allophane in some cases. These soils have been observed to posses the ability to fix ammonium.

Among the factors that affect ammonium retention or fixation by minerals are pH, moisture content, clay mineral content, nature of clay minerals, organic matter, and presence of cations such as potassium ions (Broadbent, 1978). In some soils,

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ammonium fixation may be a factor in decreasing nitrogen loss by retarding the rate of nitrification (De Datta, 1981).

2.4 Management of Fertilizer Nitrogen

Since the introduction of modern high yielding rice varieties in South and South East Asia in the mid 1960's management of fertilizer nitrogen have received considerable attention. This was aggravated by more recent energy shortage and concern about fertilizer nitrogen shortage. Shortages and heavy losses of fertilizer nitrogen in rice fields when application rates are high, as in the case of modern rice varieties, have led fertilizer technologists to develop fertilizer materials for more efficient nitrogen use (Prasad and De Datta, 1979). Examples of such materials include urea form, sulphur - coated urea and isobutylidene diurea (Jones, 1982).

Better management of nitrogen fertilizer are related to factors such as rate and time of nitrogen application, choice of sources of nitrogen and methods of nitrogen fertilizer application. Use of slow release nitrogen sources and nitrification inhibitors are also advocated.

2.4.1 Rate and timing of nitrogen application

Getting higher yields with the same amount of nutrient absorbed by the plant can increase the efficiency of fertilizer use. In order to achieve this, it is necessary to apply the fertilizer at a time that will best meet the demand of the rice plant (Yoshida, 1981). The goal of N fertilizer application is to apply just a sufficient amount to satisfy crop needs above that which the soil and other contributions (e.g.

manure, cover crops, legumes and irrigation applications) do not provide (Smith and Cassel, 1991). Rice plants can absorb fertilizer N from the floodwater or the soil near the floodwater at very high rates if application coincides with plant demand. Rates approaching 10 kg N per hectare per day have been measured for urea broadcast into the floodwater at panicle initiation. Development of root system and canopy prior to this high demand, fertilizer N is subject to the greatest losses through ammonia volatilisation and immobilization (Kirk and Olle, 2000).

Rice plants of medium growth duration (145 days), when grown at low levels of nitrogen (about 20 kg/ha), use fertilizer most efficiently for grain production during the maximum tillering stage and around flowering stage. A high nitrogen supply tends to decrease number of filled spikelets and the weight of 1000 grains. Therefore split application of nitrogen, with one dose at transplanting and another at panicle initiation is best for obtaining high grain yields, particularly in the case of medium and long-season varieties (De Datta, 1978).

Studies in India and Phillipines suggest two to three application of N per crop for higher efficiency. More split doses are needed for long duration varieties for lighter soils (Modgal *et al.*, 1974; De Datta *et al.*, 1974). Time of application becomes critical with decreased nitrogen rate. At IRRI medium duration (124 to 127 days) varieties showed the highest efficiency of use when fertilizer nitrogen at half the optimum rate (60 kg N/ha) was applied just before panicle initiation. A shorter – season rice variety showed highest efficiency after basal application but responded well to the nitrogen applied just before panicle initiation (De Datta *et al.*, 1974).

2.4.2 Methods of nitrogen application

Following the denitrification losses of nitrogen from flooded rice soils, placement of nitrogen in the reduced soil layer has been considered the best method to decrease nitrogen losses and increase fertilizer nitrogen-use efficiency in lowland rice. Deep placements of ammonia fertilizers have been recommended on the basis of significance of soil layer differentiation in wet soils (Mitsui, 1977). Pre-plant nitrogen fertilizer should be thoroughly incorporated during land preparation and the soil should be kept flooded (De Datta *et al.*, 1968).

Prasad and De Datta (1979) using non-labelled nitrogen fertilizers reported that deep placement was superior to broadcast application for both grain yield and nitrogen uptake. Use of pellets and nitrogen placement gave similar grain yields but more of the applied nitrogen was recovered from the pellets application. Application of nitrogen in mud balls a technique developed by Japanese has received considerable attention in recent years. At IRRI, application of low nitrogen rates (60 kg N/ha) as mud balls in the reduced soil layer gave similar yield as those obtained with 100 kg N/ha applied in split application (De Datta, 1978). However, the labour required to make the mud balls and apply them is deterrent to extension of the technique (De Datta, 1981).

The concept of placement of fertilizer in the soil is becoming more relevant since the introduction of modified urea materials such as urea briquettes and urea super granules. Placement of urea briquettes has shown to give significantly higher grain

yield over the best application method. Briquettes are economically superior to mud balls because they do not required farm labour for manufacturing (De Datta, 1981).

Foliar application of nitrogen fertilizers is another method that has received attention. Application of 25% of the required nitrogen through foliage for higher efficiency was recommended by Sharma and Rajat De (1975). However, foliar application of urea in split doses did not give favourable results over conventional methods at IRRI (De Datta *et al.*, 1974). Direct measurements of gaseous emissions in such system using urea-N showed that only little N was lost by ammonia volatilisation from foliar applied urea unless rainfall wasted away unassimilated urea from the plant onto the soil (Smith *et al.*, 1991).

2.4.2 Choice of nitrogen source

With inorganic sources of N the choice of nitrogen for flooded rice depends on the method and time of application. Many farmers apply fertilizer N in two and three doses, with part at planting and the remainder as a top dressing during various growth stages. The nitrogen applied at planting should be in ammonium (NH_4^+) form. The source of nitrogen used as topdressing is less critical; NH_4^+ and nitrate (NO_3^-) forms appear equally effective, because when the crop is fully established the nitrate form is rapidly taken up by rice crop before it can be leached down to the reduced soil layer where it might be lost through denitrification. Several research reports have compared sources of fertilizer nitrogen for flooded rice. In most situations, ammonium – containing or ammonium – producing (urea) fertilizers are similar in effectiveness based on grain yield (De Datta and Magnaye, 1969).

Management of straw and other organic sources of nitrogen have received considerable attention. Their use has been influenced by two main factors; (a) The fear that continuous application of certain inorganic N fertilizers although they may give better yields in the first few years, can increase soil acidity and cause appreciable deterioration in soil productivity; (b) The belief that compost and organic sources of nitrogen are essential for obtaining high yields. In general, compost and other organic sources are applied as basal dressing (Tanaka, 1978).

2.4.3 Use of slow – release nitrogen sources

There are a number of proved advantages of fertilizer that release their plant nutrient slowly throughout the growing season or longer. These slow-release fertilizers offer potential for increasing fertilizer efficiency, decreasing cost of application due to fewer applications, minimizing losses by leaching, fixation, or decomposition, eliminating or at least minimizing luxury consumption and avoiding damage to the seedlings (Freney *et al.*, 1996)

Slow release fertilizers which provide nitrogen that roughly coincides with that required by growing plants are made by synthesis of chemical compounds with inherently slow rates of dissolution and coating of conventional soluble fertilizers to reduce their dissolution rates (Horn, 1979). Leaching losses of both NO_3^- (<3%) and NH_4^+ (<4%) were drastically decreased when using controlled released fertilizers (Alva, 1992).

2.4.4 Use of nitrification inhibitors

Because a major portion of the fertilizer nitrogen lost from the fields may be lost after the nitrification of amide and ammonium nitrogen to nitrates, nitrification inhibitors have been tested to minimize such losses (Jones 1982). In almost all cases the inhibitor is intended to block the conversion of ammonium nitrogen to nitrate by inhibiting *Nitrosomonas* growth or activity. Examples of nitrification inhibitors are, Dicyan–diamide, AM (2 amino 4 chloro 6 methylpyrimidine), and ST (2 sulfanilamidiathiazole). In India extract *of* neem *(Azadirahta indica* Juss*)* kernels was found to possess nitrification-inhibitory properties, with 22% increase in rice grain yield due to treatment of urea with acetone extract of neem (Prasad and De Datta, 1979).

2.4.5 Water management

Since maximum denitrification rates are commonly observed when water filled pore spaces in the soil is greater than 90%, minimizing the time the soil is saturated should limit denitrification. Flood irrigation has been used to disperse some of the surface applied urea and wash the solubilized urea into the soil. When this technique was used to apply urea in flooded rice crop, there was no ammonia lost to the atmosphere (Freney *et al.*, 1996). Managing floodwater depth is important in controlling N loss through volatilisation. Broadcast urea was hydrolysed at faster rate in shallow (5 cm) water than in deep (14 cm) water, with the result that ammonium-nitrogen concentration was higher in shallow water (Freney *et al.*, 1996).

2.5 Nitrogen Use Efficiency (NUE)

Fertilizer use efficiency is an output of any crop per unit of fertilizer nutrient applied under specified set of soil and climatic conditions (De Datta, 1981). Barber (1977) defined fertilizer use efficiency as an increase in yield of harvested portion of the crop per unit of fertilizer nutrient applied. For instance, by changing the agronomic practices increases yield without changing the rate of nutrient application, the efficiency of fertilizer nutrient has increased. Therefore NUE in rice refers to an increase in yield of harvested portion (grains) per unit of fertilizer N used.

The plant use efficiency of a top dressed N depends on several factors, including source and rate of N applied, application time, soil moisture and other climate related variables (Alcoz *et al.*, 1993). Other factors include varietal response, time of planting, water management, weed control and insect and disease control (De Datta, 1981). Calculation of NUE is based on deduction of grain yield (kg ha^{-1}) in control plot from that in the test plot and dividing by the amount of N applied (kg ha^{-1}). Maximum efficiency should be obtained by the least possible application coinciding with the stage of development that still permits N uptake (Olson and Kurtz, 1982), thus avoiding unnecessary loss by leaching and unnecessary vegetative growth, which may result in lodging of plants and subsequent reduction in grain yield. Furthermore, the chances of N losses for applied N at this stage are reduced because an active root system is present for absorbing the fertilizer N when it is supplied.

With the present levels of fertilizer N use efficiency (<40%) in rice, it is estimated that an increase of about 300% in N will be required to achieve an average yield of 8

ton ha^{-1} by 2025. Many fertilizer application methods and fertilizer types can help to optimise N use in rice (Cassman and Pingali, 1995).

2.6 Measures to Increase NUE

Available data from most rice growing countries indicate that proper N timing is important to reduce losses and increase NUE. Conventional nitrogen fertilizer should be applied two to three doses, with one dose applied at tiller initiation stage. Placement of fertilizer nitrogen as urea super granules or as urea briquettes in the reduced zone 12 to 15 cm below soil surface also increase NUE (Prasad and De Datta, 1979). The use of slow release nitrogen fertilizers such as sulphur coated urea (SCU) appears promising in a number of rice growing countries, where flooding makes fertilizer application with conventional techniques meaningless. Isobutylidine diurea (IBDU), crotonylidine diurea (CDU) and guanyl urea phosphate (GUP) were most effective in increasing rice yields. However, the relative high cost of all such fertilizers has restricted their use (Matsuo and Suthidhani, 1972).

Tillage operations that incorporate fertilizers into soil may also improve the efficiency of fertilizer nitrogen by placing it into the root zone (Olson and Kurtz, 1982). Management practices such as removal of weeds and insect control, manipulation of plant density and water control can also assist in improving the NUE in rice (De Datta, 1981).

2.7 Effect of Nitrogen on Growth

Nitrogen is the most important nutrient for rice and its deficiency occurs almost everywhere unless nitrogen is applied (Yoshida, 1981). Nitrogen is a component of amino acids and also a constituent of protein molecules. It is also part of chlorophyll molecules. Vigorous plant growth is associated with adequate nitrogen nutrition (Marschner, 1995). The pale green colour of nitrogen deficient plants is the most commonly deficient symptom exhibited by growing plants (Thompson and Troeh, 1973).

When the rice plants are subjected to nitrogen deficiency, the stomatal resistance of leaves, particularly that of lower leaves increases sharply, indicating that the stomata are closed to considerable degree. This increased stomatal resistance is associated with decreased photosynthetic rate (Yoshida, 1981). Excess nitrogen produces succulence in plants and enhances the sensitivity of plant to water and temperature stress. Plants also become susceptible to lodging and pest and diseases attack (Mahapatra *et. al.*, 1985).

2.8 Effect of Time of N Application on Grain Yield and Yield components

Grain yield can be described as the product of number of panicles per unit area, the number of spikelets per panicle, percentage of filled spikelets and mean kernel weight (Wu *et al.*, 1998). Each of these components has its own critical period which nitrogen affects development of the plant and the final yield (Mae, 1997).

Work done by Modgal *et al.* (1974) to compare single basal application of nitrogen with its split application in terms of yield of high yielding rice varieties demonstrated that split application of nitrogen influenced the yield contributory characters such as panicles per square metre number of spikelets per panicle and grain yield. It was also noted that three splits of nitrogen i.e. at planting, tillering and panicle initiation stages were more beneficial than two splits. Application of nitrogen in four splits at planting, tillering, panicle initiation and at booting stage gave the highest grain yield, being at par with three split application, half dose at planting and two equal splits at tillering and panicle initiation. Hence application of nitrogen in three splits and four splits at optimal critical stages of longer duration (155 to 165 days) rice was better than single or two equal splits application from the view point of achieving maximum efficiency (Roy and Jha, 1977).

2.9 Effect of Nitrogen on Varieties

Variation in nitrogen uptake among rice ecotypes, plant types and hybrids has been observed (Sta Cruz and Wada, 1994). Generally, genotypes that perform well at low nitrogen levels are tall, with a low percentage of productive tillers, high dry matter production, low panicle to straw weight ratios and are susceptible to lodging. They relatively grow fast in the early growth stage and cover the field without N addition. At high N levels, higher growth rates in the early growth stages result in mutual shading during the middle and late growth stages. This reduces N uptake because net photosynthesis is decreased, resulting in few tillers and weaker roots. By contrast genotype that respond well to high N levels have short stature high panicle to straw

weight ratios, high percentage of productive tillers, and slow growth in the early growth stages and show little mutual shading (Tanaka *et al.*, 1964).

2.10 Effect of N Rates and Time of Application on Dry Mass Accumulation

The dry mass (DM) of the plant is a function of a number of variables including soil moisture availability, soil nitrogen supply, intercepted solar radiation and air temperature (Wada, 1971). Maximum economic yield requires the optimum partitioning of accumulated photosynthates into the plant organs or components that constitute the economic yield. Optimum diversion of photosynthates to the plant organs implies regulation of the partitioning process (Kumar and Singh, 1985).

Norman *et al.* (1998) conducted field studies to evaluate the optimum rate and timing of N application in rice and observed that increasing N rates significantly increased fertilizer N uptake efficiency, total N uptake, total DM and grain yield. They further observed that midseason N application increased total DM, total N uptake and grain yields compared to none. There was no significant difference on dry mass accumulation from split application of midseason N compared with single application at midseason.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Site

The experiment was conducted at Mkindo smallholder irrigation project in Mvomero district, Morogoro Region. The area is situated at 360 m.a.s.l, $6^0$5'S $37^0$40'E and 55km from Morogoro municipality along the road to Turiani. The experiment commenced in December 2001and ended in May 2002.

3.2 Soil Sampling and Analysis

Soil was randomly collected from the top 20cm in each block. Samples were mixed, air dried, ground and sieved through an 8 mm sieve to make a composite sample. The composite sample was again sieved through a 2mm sieve for laboratory analysis to determine its physical and chemical properties. The soil physical and chemical properties were analysed in the Department of Soil Science laboratory at Sokoine University of Agriculture (SUA), Morogoro. Analysis for soil particle size distribution was conducted by hydrometer method as described by Gee and Bauder (1986). Determination of pH (in water and KCl) was done by using a pH meter (MacLean, 1982). Organic carbon was determined by Walkey and Black method as described by Nelson and Sommers (1982). Total nitrogen was analysed by Micro-Kjeldahl as described by Bremmer and Mulvaney (1982). Available phosphorus was analysed by Bray I and Kurtz No. 1 method (Bray and Kurtz, 1945). Exchangeable bases Ca, Mg, K and Na were analysed from ammonium acetate leachate by atomic absorption spectrophotometry (Lindsay and Norvell, 1978) while cation exchange capacity was determined by ammonium acetate saturation method (Rhodes, 1982).

At the experimental site, the textural class of the soil was found to be sandy clay loam and slightly acidic (pH 6.3) with very low percentage of organic carbon. Cation exchange capacity was medium. Total N and available P were also low. Exchangeable bases ranged from high (Mg) to medium (Ca and Na), while K was generally low. Results of soil analysis are presented in Table 1.

3.3 Meteorological Data

Weather data were obtained from Dakawa Research Station located about 10 km from the experimental site. The data recorded were for rainfall and temperature. During the cropping season, total rainfall at Mkindo was 773.3mm. A highest rainfall of 289mm was recorded in April while a lowest value of 20.0 mm occurred in December at the commencement of the experiment (Fig.1). Overall, the total rainfall recorded was average for the experimental site. Supplementary irrigation was used during dry spells. During the season, Mkindo village temperatures were generally high, ranging from 23.4 °C to 30.1°C (Fig. 2). These temperatures were considered conducive for growth of the rice crop.

3.4 Land Preparation

The land was ploughed and harrowed using hand hoes. Bunds of 40 cm wide were made to demarcate the plots and protect them from undesirable treatments. The

Table 1. Physical and chemical properties of the soil at the experimental site

Parameter	Value	Remarks *
Particle size Distribution:		
Clay	35.0	
Silt	6.2	
Sand	30.0	
Textural class	SCL	Sandy Clay loam
pH in water (1:25)	6.5	Slightly acidic
pH in KCL (1:2.5)	5.4	
Organic Carbon (%)	0.4	Very low
Total N (%)	0.08	Very low
Bray 1 available P (mg/kg)	4.6	Low
CEC (c mol (+)/kg)	17.0	Medium
Exchangeable bases (cmol (+)/kg):-		
Ca	5.3	
Mg	3.1	
K	0.1	
Na	0.6	

*According to Landon (1991).

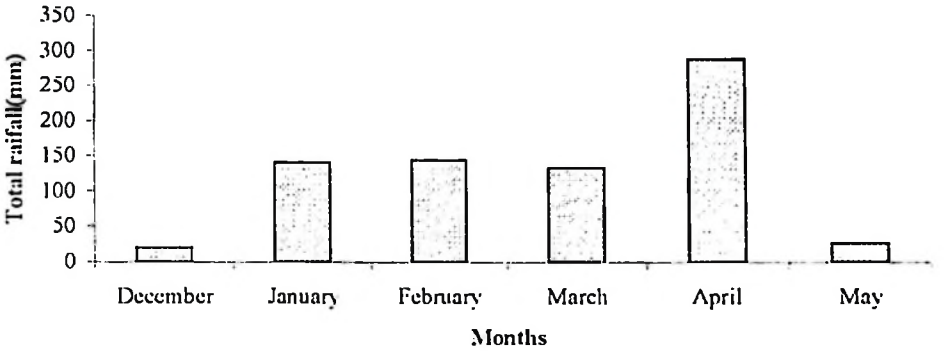

Figure 1. Rainfall distribution at the experimental site from December 2001 to May 2002

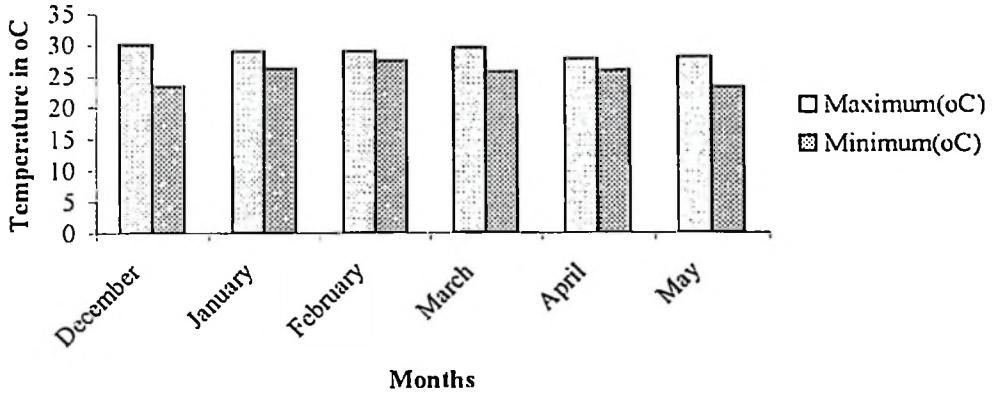

Figure 2. Temperature variation at the experimental site from December 2001 to May 2002

individual plots had a dimension of 1.5m x 2.0 m. Every plot in the field was uniformly levelled.

3.5 Experimental Design and Treatments

The experiment was laid in a split – split plot design, with three replications. Three rice varieties (TXD 85, TXD 306 and Supa) were assigned to the main plots. The subplot treatments were rates of N (0, 40, 80 or 120 kg/ha). The sub-subplot treatments were time of application of N fertilizer, viz:

(i) T1= single dose in dry soil before transplanting.

(ii) T2= two equal splits: half dose each in dry soil before transplanting and at initial tillering stage.

(iii) T3 = three equal splits: one third dose each in dry soil before transplanting, at initial tillering and at panicle initiation.

(iv) T4 = two equal splits half dose each at initial tillering and at panicle initiation

Nitrogen in the form of urea was incorporated in dry soil one week before transplanting, while it was topdressed for the rest of the treatments.

3.6 Seed Soaking and Pre-sprouting

The seeds for every variety were soaked in water for 24 hours to promote water absorption. The soaked seeds were then put in a gunny bag where water could easily be removed for 48 hours. Wet rice straws were used to cover the seed to avoid desiccation. Water was replenished from time to time during pre-sprouting process.

3.7 Preparation of Wet Nursery

The nursery plot was ploughed and puddled a week before sowing. The nursery bed prepared on the previous day of sowing was drained to stabilize the surface soil.

3.8 Sowing

Pre-geminated seeds were sown on wet nursery during the last week of December 2001. The surface of the nursery was kept exposed to the air without submerging it. Irrigation of the nursery bed was done frequently to keep a water depth of about 3 cm on the surface, and thereafter the water was drained immediately, to expose the surface again to avoid poor seedling establishment.

3.9 Transplanting

Seedlings were transplanted at the age of 21 days old. Spacing of 20 cm x 20 cm was adopted, by using a transplanting rope with a line marker where the seedlings were planted at the marks labelled on the rope at constant interval. Each plot had eleven rows in which one seedling per hill was transplanted.

3.10 Water Control

Initially, at transplanting period the water in each individual plot was maintained at a depth of 2.0 cm. This depth was raised, as the plant grew taller from 5 to 10 cm above the soil surface.

3.11 Weed Control

Hand weeding was performed twice, at 20 and 35 days after transplanting.

3.12 Sampling Area

The central portion of each plot of 1 m x 1 m dimensions was kept as the net harvestable area. The rest of the area was used for collecting samples that were used for determination of dry matter and yield components.

3.13 Crop Growth and Development Data

3.13.1 Days to 50% flowering

Number of days to 50% flowering was recorded by counting the number of days from pre-sprouting to when 50% of the plants in each plot had flowered.

3.13.2 Plant height

Ten plants in each plot were randomly selected, and measured by wooden ruler from the ground surface to the full stretched tip of the panicle at physiological maturity. The mean plant height was computed and recorded.

3.13.3 Dry mass production

Within the sampling area, four plants were randomly selected. These were cut just above the ground level at physiological maturity. The plants were then washed clean, separated into leaves, stems and grains. Those samples were put in paper bags, and oven dried at 70°C for four days to constant weight. The partitioned shoot dry matter (leaves, stem and grains) was determined for each sample.

3.13.4 Yield and yield components

3.13.4.1 Number of tillers per m^2

Number of tillers per m^2 was determined by counting all tillers in 1 m x 1 m at centre of each plot at heading stage of growth of the rice plant.

3.13.4.2 Number of panicles per m^2

At physiological maturity all panicles of the above central area (section 3.12.4.1) were counted and the number of panicles m^{-2} was recorded.

3.13.4.3 Number of grains per panicle

Ten panicles from each plot were randomly selected. The panicles were harvested, put in an envelope and were threshed. Both the filled and unfilled grains were counted. The mean number of grains per panicle was computed and recorded.

3.13.4.4 Percentage field grains

Grains from the above (section 3.13.4.3) ten threshed panicles from each plot were put in a beaker. Water was added to the beaker where filled and unfilled grains were separated. After counting the number of filled and unfilled grains, the filled grains percentage was calculated as the number filled grains divided by total number of grains (filled + unfilled grains) multiplied by hundred.

3.13.4.5 Panicle weight

From each sampling area, ten randomly selected panicles were harvested, weighed and the mean weight for each plot computed.

3.13.4.6 One- thousand grain weight

The weight of 1,000 grains was obtained by weighing five dried samples of filled grains at 14% moisture content from each plot. The mean for each plot was calculated and recorded as 1,000-grain weight.

3.13.4.7 Grain yield

Mature rice plants were harvested from a net area of $1m^2$ in each plot. These were threshed, cleaned and sun dried and weighed. The weight of the grains was then standardized to 14% moisture content.

3.14 Nitrogen Use Ufficiency (NUE)

This was calculated as:

$$NUE = \frac{\text{grain weight (g) in N treated plots – grain weight (g) in control}}{\text{N applied (g).}}$$

3.15 Data Analysis

Collected data were analysed by using MSTAT-C statistical program. Mean separations among treatment means were done using Duncan's New Multiple Range Test (DNMRT). Correlation analysis of grain yield and components of yield was also performed. The statistical model for the analysis was:

$$X_{ijkm} = \mu + \beta_i + A_j + \sigma_{ij} + B_k + AB_{jk} + W_{ijk} + C_m + AC_{im} + BC_{km} + ABC_{jikm} + Eijkm$$

Where:

X_{ijkm} = Response

μ = General effect

$ß_i$ = Block effect

Aj = Main factor effect

σi_j = Whole plot error

B_k = Sub – factor effect

AB_{jk} = Sub – sub-factor effect

BC_{km} = Two way interaction

ABC_{jkm} = Three way interaction

E_{ijkm} = Subplot random error effect

3.16 Economic Analysis of Varieties and N Rates

The economic analysis of varieties and N rates was performed through the following steps:

(i) Computation of amount of N fertilizer material (urea) required per ha for each N rate and variety.

(ii) Computation of monetary cost of N fertilizer material per ha, which was obtained by multiplying the amount of N needed per ha by the price of urea per kg.

(iii) Conversion of yield harvested per plot to yield in kg per ha.

(iv) Computation of gross revenue by multiplying the yield per ha and the farm gate price of paddy.

(v) Net revenue was obtained by deducting the cost of N fertilizer from the gross revenue i.e. step (iii)- step (ii).

(vi) Comparison of net revenues for varieties with the corresponding N rates was performed, followed by selection of the best economic optimum N rate for each variety.

CHAPTER FOUR

4.0 RESULTS

4.1 Crop Growth and Development

4.1.1 Total dry mass (TDM)

The above ground total dry mass (TDM) differed significantly ($P<0.05$) among varieties. TXD 306 recorded the highest TDM while the lowest was recorded in Supa (Table 2). TDM increased with increasing N rates, with highest values being recorded with 120 kg N ha^{-1} and the lowest with 0 kg N ha^{-1}. The time of N application significantly ($P<0.05$) affected TDM. Application of N as T4 gave the highest TDM, while the lowest values were recorded when N was applied as T1 (Table 3). The interaction of varieties and rates of N on TDM was significant ($P<0.05$). Thus varieties produced more TDM at 120 kg N ha^{-1} than at 0 kg N ha^{-1} (Table 4).

TDM was observed to differ significantly ($P<0.05$) among varieties and time of N application. Highest TDM was recorded when N was applied as T4 in all varieties. The interaction of varieties, N rates and time of N application on TDM was significant ($P<0.05$). In this case TXD 306 recorded the highest TDM with 120 kg N ha^{-1} applied as T4. Within the same rate of N and time of N application, Supa gave the lowest TDM (Table 5).

4.1.2.Leaf dry mass (LDM)

The varieties differed significantly ($P<0.05$) on leaf dry mass (LDM) accumulation. Supa recorded the highest mean value, followed by TXD 306. TXD 85 recorded the

Table 2. Effect of varieties and N rates on leaf dry mass, stem dry mass and total dry mass

Variety	Time of N application*	LDM (g/m^2)	SDM (g/m^2)	TDM (g/m^2)
TXD 85	T1	98.8 f	516.6 h	836.5 gh
	T2	106.1 f	541.7 g	884.6 fg
	T3	147.1 de	579.7 f	985.4 de
	T3	164.3 cd	605.2 e	1031.3 cd
TXD 306	T1	136.3 e	634.3 d	1062.6 bc
	T2	146.0 de	657.5 c	1116.45 b
	T3	181.9 c	724.7 b	1252.4 a
	T4	218.7 b	752.9 a	1318.4 a
Supa	T1	213.3 b	348.8 k	787.5 h
	T2	227.6 b	372.3 j	844.6 gh
	T3	280.1 a	402.5 i	943.1 ef
	T4	285.2 a	418.2 i	970.8 de
Mean		183.7	546.1	1002.8
SE		7.1	4.8	19.0
CV		5.6	3.0	1.9

Means within column(s), followed by the same letter(s) are not significantly different at $P<0.05$ according to DNMRT.

LDM=Leaf dry mass

SDM=Stem dry mass

TDM=Total dry mass

*T1=N application as single dose in dry soil before transplanting.

T2=N application as two equal splits i.e. half dose each in dry soil before transplanting and initial tillering.

T3=N application as three equal splits i.e. one third dose each in dry soil before transplanting, initial tillering and panicle initiation.

T4=N application as two equal splits i.e. half dose each at initial tillering and panicle initiation.

Table 3. Effect of N rates and time of N application on leaf dry mass, stem dry mass, grain dry mass and total dry mass

Rate of N (kg/ha)	Time of N application	LDM (g/m^2)	SDM (g/m^2)	GDM (g/m^2)	TDM (g/m^2)
0	T1	107.4 j	402.5 j	171.7 e	681.6 h
	T2	105.5 j	395.1 jk	169.8 e	670.4 h
	T3	106.4 j	377.0k	167.8 e	651.2 h
	T4	105.2 j	392.0 jk	165.8 e	663.0 h
40	T1	152.8 I	469.9 i	241.8 d	864.5 g
	T2	170.9 g	498.9 h	265.4 cd	935.2 fg
	T3	206.6 e	554.7 g	237.3 cd	998.6 e
	T4	239.3d	574.3 f	292.1 bcd	1105.7 de
80	T1	163.4 hi	502.5 h	287.4 cd	953.3 f
	T2	178.3 fg	545.3 g	309.4 abc	1033.0 d e
	T3	244.7 c	594.2 e	343.3 ab	1182.2 bc
	T4	271.1 b	619.9 d	353.8 a	1244.8 bc
120	T1	172.3 gh	626.7 d	284.2 cd	1083.2 de
	T2	184.9 f	651.1 c	313.4 abc	1149.4 cd
	T3	254.5 c	750.0 b	342.8 ab	1347.3 a
	T4	285.4 a	782.2 a	352.1 a	1419.7 a
Mean		184.3	546.0	268.6	998.9
SE		3.1	5.6	15.8	23.8
CV		5.6	3.0	4.0	1.9

Means within column, followed by the same letter(s) are not significantly different at $P<0.05$ according to DNMRT. Definition of symbols is as in Table 2.

Table 4. Effect of varieties and N rates on leaf dry mass, stem dry mass and total dry mass

Variety	Rate of N (kg/ha)	LDM (g/m^2)	SDM (g/m^2)	G DM (g/m^2)	TDM (g/m^2)
TXD 85	0	98.8 f	336.4 i	172.4 ef	607.6 f
	40	106.1 f	346.4 g	234.1 def	686.6 e
	80	147.1 de	566.1 ef	280.4 cd	993.6 de
	120	164.3 cd	794.3 a	290.7 c	1249.3abc
TXD 306	0	136.3 e	577.8 e	180.9 def	895.0 e
	40	146.0 de	696.2 d	317.1 abc	1159.3 bc
	80	181.9 e	733.0 c	393.2 ab	1308.1 ab
	120	218.9 b	762.5 b	398.3 a	1379.7 a
Supa	0	213.3 b	260.7 j	153.2 f	627.2 f
	40	227.6 b	328.9 i	263.8 cde	820.3 e
	80	280.1 a	397.3 h	297.0 bc	974.4 de
	120	285.2 a	554.5 fg	280.5 cd	1120.2 cd
Mean		183.8	529.5	271.8	985.1
SE		7.1	4.8	27.4	45.1
CV		5.6	3.0	4.8	1.9

Means within columns, followed by the same letter(s) are not significantly different at $P<0.05$ according to DNMRT.

Table 5. Effect of varieties, N rates and time of application on total dry mass

Variety	Time of N application	Total dry mass (g/m^2) 0 N	40 N	80 N	120 N	Mean
TXD 85	T1	615.9 s	794.2 qr	853.7 q	1082.0 klm	836.4
	T2	603.0 s	856.6 q	930.7 p	1148.0 ij	884.6
	T3	555.9 s	957.5 op	1081.0 klm	1348.0 e	985.6
	T4	577.6 s	1010.0 no	1128.0 ijk	1409.0 d	1031.1
TXD 306	T1	858.0 q	1046.0 mn	1162.0 hi	1185.0 hi	1062.7
	T2	847.6 q	1127.0 I-l	1245.0 g	1247.0 g	1116.6
	T3	837.0 q	1280.0 fg	1419.0 cd	1474.0 bc	1252.5
	T4	839.4 q	1326.0 ef	1508.0 b	1600.0 a	1318.3
Supa	T1	571.2 s	751.8 r	844.4 q	982.8 op	787.5
	T2	564.8 s	822.5 q	923.2 p	1068.0 k-n	844.6
	T3	561.1 s	927.6 p	1063.0 lmn	1221.0 gh	943.2
	T4	572.0 s	966.3 op	1096.0j-m	1249.0 g	970.8
Mean						1002.8
SE		666.9	988.8	1104.5	1251.1	19.6
CV						2.1

Means within rows or columns, followed by the same letter(s) are not significantly different at $P<0.05$ according to DNMRT. Definition of symbols is as in Table 2.

lowest LDM. LDM increased with increasing N rates. The highest LDM was recorded in plots with 120 kg N $ha^{-1}$and the lowest in plots without N (Table 4). LDM accumulation differed significantly ($P<0.05$) among times of N application. The highest LDM was attained when N was applied as T4 while the lowest as T1. The interaction of varieties and rates of N application differed significantly ($P<0.05$). All varieties had the highest LDM with 120 kg N ha^{-1} while the lowest was obtained with 0 kg N ha^{-1}.

The interaction of varieties and time of N application on LDM also differed significantly ($P<0.05$). The highest LDM was recorded when N was applied as T4 in all varieties. However, LDM in T4 or T3 were similar in Supa (Table2). The rates of N and time of N application on LDM differed significantly ($P<0.05$). The highest LDM was recorded in plots with 120 kg N ha^{-1} applied as T4, and under the same rate, lowest LDM was recorded when N was applied as T1 (Table 3).

The interaction of varieties, N rates and time of N application differed significantly in LDM ($P<0.05$) production. Varieties produced more LDM with 120 kg N ha^{-1} applied as T4, while less LDM was produced with lowest N rates applied as T1 (Table 6).

4.1.3 Stem dry mass (SDM)

The varieties differed significantly ($P<0.05$) in stem dry mass (SDM). TXD 306 recorded the highest SDM, while Supa recorded the lowest (Table 4).

Table 6. Effect of varieties, N rates and time of application on leaf dry mass

Variety	Time of N Application	Leaf dry mass (g/m^2)				
		0 N	40 N	80 N	120 N	Mean
TXD 85	T1	78.1 s	102.2 qrs	102.1 qrs	112.9 qr	98.8
	T2	80.9 s	110.7 qr	110.0 qr	121.6 pq	106.0
	T2	79.4 s	129.6 opq	187.0 kl	192.6 jkl	147.1
	T4	78.0 s	153.9 mno	204.9 ijk	220.4 hij	164.3
TXD 306	T1	89.7 rs	142.1 nop	155.4 mno	157.9 mno	136.2
	T2	84.8 rs	152.8 mno	169.8 lmn	176.7 lm	146.0
	T3	85.3 rs	189.5 kl	219.3 hij	233.8 fgh	181.9
	T4	83.9 rs	222.3 ghi	274.1 de	294.6 cd	218.9
Supa	T1	154.5mno	220.0 hij	232.7 f-I	246.1 fgh	213.3
	T2	150.7 mno	249.1 efg	254.2 ef	256.4 ef	227.6
	T3	154.6 mno	300.8 c	327.8 ab	337.3 ab	280.1
	T4	153.6 mno	311.8 bc	334.3 ab	341.2 a	285.2
Mean		106.1	190.4	214.4	324.3	183.8
SE						8.5
CV						2.1

Means within column(s), followed by the same letter(s) are not significantly different at $P<0.05$ according to DNMR. Definition of symbols is as in Table 2.

The SDM increased with increasing N rates. The highest SDM was recorded with application of 120 kg N $ha^{-1}$and the lowest with 0 kg N ha^{-1}.

The interaction of N rates and time of N application on SDM was significant. Greater SDM was recorded in treatments with 120 kg N ha^{-1} applied as T4 while the lowest was recorded in those with low N rates applied as T1 (Table 3). The interaction of varieties and N rates on SDM was significant ($P<0.05$). Highest SDM was recorded in all varieties with application of 120 kg N ha^{-1}, while the lowest SDM was in those treatments without N.

Generally, SDM was associated with higher N rates applied as T4. Lowest SDM was observed in treatments with lower N rates applied as T1 (Table 6). There was also a significant interaction among varieties, N rates and time of N application on SDM. All varieties accumulated more SDM with 120 kg N ha^{-1} applied as T4 and less with low N rates applied as T1 (Table 7).

4.1.4 Number of tillers / m^2

The number of tillers/m^2 differed significantly ($P<0.05$) among varieties. TXD 306 had the highest number of tillers/m^2, followed by TXD 85. Supa recorded the lowest number of tillers/m^2 (Table 8). Rates of N application significantly ($P<0.05$) influenced the number of tillers/m^2. Highest number of tillers/m^2 was recorded at the highest N rate, i.e. 120 kg N ha^{-1} .The lowest number of tillers/m^2 was recorded in treatments without N.

Table 7. Effect of varieties, N rates and time of application on stem dry mass

Variety	Time of N application	Stem dry mass (g/m^2) 0 N	40 N	80 N	120 N	Mean
TXD 85	T1	363.4 rst	485.9 o	501.8 no	715.3 efg	516.6
	T2	350.9 r-u	517.7 no	550.3 lmn	747.8 def	542.2
	T3	300.4 u-x	581.2 klm	593.2 kl	843.9 ab	579.8
	T4	330.8 s-v	600.6 kl	619.0 jk	870.1 a	605.1
TXD 306	T1	582.6 klm	624.5 ijk	656.1 hij	673.9 ghi	634.3
	T2	578.1 klm	668.1 g-j	700.9 fgh	683.2 gh	657.6
	T3	575.2 klm	734.8 def	769.8 cd	819.2 b	724.7
	T4	575.3 klm	757.4 cde	805.1 b	873.6 a	752.8
Supa	T1	261.5 wx	291.8 vwx	349.4 r-u	490.9 o	348.4
	T2	256.3 x	311.0 t-w	384.6 qr	537.5 mno	372.3
	T3	255.4 x	348.1 r-u	419.6 pq	587.0 klm	402.5
	T4	269.7 wx	364.8 rs	435.5 p	602.8 kl	418.2
Mean		391.6	523.7	565.4	703.8	546.2
SE						15.8
CV						3.1

Means within rows or columns, followed by the same letter(s) are not significantly different at $P<0.05$ according to DNMRT. Definition of symbols is as in Table 2.

Table 8. Effect of varieties and N rates on plant height, days to 50% flowering and number of tillers/m^2

Variety	Rate of N (kg/ha)	Plant height (cm)	Days to 50% flowering	Number of tillers/m^2
TXD 85	0	81.8 e	95.5 b	183.0 e
	40	91.8 cd	91.0 bcd	256.7 c
	80	90.1 d	89.5 cde	293.6 b
	120	91.4 cd	88.3 e	323.4 a
TXD 306	0	79.8 e	89.1 de	200.3 d
	40	91.4 cd	83.9 f	285.6 b
	80	90.2 d	82.5 f	321.9 a
	120	90.9 cd	83.3 f	332.7 a
Supa	0	92.9 c	99.8 a	121.1 g
	40	120.5 a	93.1 bc	148.8 f
	80	125.0 a	92.6 bcd	158.0 f
	120	126.8 a	92.1 bcd	181.3 e
Mean		97.7	89.9	234.7
SE		12.2	0.9	18.6
CV		4.6	0.9	9.5

Means within columns, followed by the same letter(s) are not significantly different at $P<0.05$ according to DNMRT.

Table 9. Effect of varieties and time of N application on plant height, days to 50% flowering and number of tillers/m^2

Variety	Time of N application	Plant height	Days to 50% flowering	Number of tillers/m^2
TXD 85	T_1	86.8 fg	93.0 c	231.1
	T_2	88.1 ef	92.5 c	258.5
	T_3	90.0 de	89.5 d	283.0
	T_4	90.1 de	87.4 e	293.0
TXD 306	T_1	85.7 g	86.6 e	256.5
	T_2	88.4 def	85.6 e	273.4
	T_3	87.5 fg	83.4 f	300.1
	T_4	90.6 d	83.0 f	310.3
Supa	T_1	113.4 c	96.6 a	134.0
	T_2	116.8 ab	95.4 ab	140.0
	T_3	118.7 a	93.5 bc	162.0
	T_4	116.3 b	92.1 c	175.0
Mean		97.7	89.9	234.7
SE		0.6	0.56	N.S
CV		12.2	0.9	5.6

Means within columns followed by the same letter(s) are not significantly different at $P<0.05$ according to DNMRT. Definition of symbols is as in Table 2.

The varieties and time of N application interactions did not influence significantly the number of tillers/m^2 (Table 9). The interactions of varieties, N rates and time of N application had a marked effect on the number of tillers/m^2. For example, varieties recorded in plots with 80 or 120 kg N ha^{-1} while shortest ones were recorded in produced more tillers/m^2 with 120 kg N ha^{-1} applied as T4 while less numbers were with low N rates applied as T1 (Table 10).

4.1.5 Days to 50% flowering

Days to 50% flowering differed significantly among varieties ($P<0.05$). TXD 306 flowered earlier, followed by TXD 85;Supa was late in flowering (Table 8). There were significant differences among N rates on days to 50% flowering. Late flowering was recorded in plots without N. Time of N application significantly affected days to 50% flowering among varieties ($P<0.05$).

Longest days to 50% flowering were recorded when N was applied as T1 or T2, while the shortest were obtained where N was applied as T3 or T4 (Table 9).

The interaction of varieties, rates of N and time of N application on days to 50% flowering was significant ($P<0.05$). In this case, TXD 85 flowered earlier than TXD 306 with 120 kg N ha^{-1} applied as T4, while at the same rate and time of N application Supa flowered later than either TXD 85 or TXD 306 (Table 11).

4.1.6 Plant height

In this study, significant differences in plant height were observed among varieties ($P<0.05$). Supa had the tallest plants, followed by TXD 85. In all varieties plant

Table 10. Effect of varieties, rates and time of N application on tillers/m2

Variety	Time of N application	Number of tillers/m^2				
		0 N	40 N	80 N	120 N	Mean
TXD 85	T1	178.0 n-s	226.0 i-m	242.7 h-k	278.0 fgh	231.2
	T2	181.7 n-r	257.7 g-i	291.7 efg	303.0 cdf	258.5
	T3	187.7 l-q	286.0 fg	303.3 cdf	355.0 a	283.0
	T4	184.7 m-q	293.0 d-g	336.7a-d	357.7 a	293.0
TXD 306	T1	203.0 k-o	230.3 i-l	283.7 f-h	309.3 b-f	256.6
	T2	200.0 k-p	251.7 g-j	320.7 a-f	321.3 a-f	273.4
	T3	209.3 j-q	319.7a-f	333.0 a-e	338.7 abc	300.2
	T4	189.0 l-q	340.7 abc	350.3 ab	361.3 a	310.3
Supa	T1	122.3 u	126.3 u	140.3 r-u	147.3 q-u	134.0
	T2	130.0 tu	136.0 stu	137.0 stu	157.0 p-u	140.0
	T3	117.0 u	157.7 p-u	171.3 o-t	202.3 k-o	162.1
	T4	123.0 u	175.3n-s	183.3 m-r	218.7 i-n	175.1
Mean		168.8	233.3	257.8	279.1	234.8
SE						12.9
CV						9.5

Means within rows or columns, followed by the same letter(s) are not significantly different at $P<0.05$ according to DNMRT. Definition of symbols is as in Table 2.

Table 11. Effect of varieties, N rates and time of application on days to 50% flowering

Variety	Time of N application	Days to 50% flowering				
		0 N	40 N	80 N	120 N	Mean
TXD 85	T1	99.3 b-g	93.7 b-f	92.7 d-i	92.3 e-j	94.5
	T2	93.0 c-h	94.0 b-e	92.7 d-i	90.7 h-l	92.6
	T3	94.0 b-e	90.3 l-m	88.0 mno	85.7 pq	89.5
	T4	94.0 b-e	86.0 opq	85.0 pqr	84.7 pqr	87.4
TXD 306	T1	89.0 lmn	85.6 opq	85.3 pq	86.7 nop	86.6
	T2	89.0 lmn	85.3 pq	84.3 pqr	84.0 qr	85.6
	T3	89.3 lmn	82.7 rs	80.3 st	81.3 st	83.4
	T4	89.0 lmn	81.7 b	80.0 t	81.3 st	83.0
Supa	T1	100.7 a	95.7 b	95.3 bc	95.0 bcd	96.6
	T2	99.7 a	95.0 bcd	94.0 b-e	93.0 c-h	95.4
	T3	100.0 a	91.7 e-k	91.3 f-l	91.0 g-l	93.5
	T4	99.0 a	90.0 j-m	89.7 klm	89.7 klm	92.1
Mean		94.7	89.3	89.3	87.9	90.0
SE						0.7
CV						0.9

Means within rows or columns, followed by the same letter(s) are not significantly different at $P<0.05$ according to DNMRT. Definition of symbols is as in Table 2.

height increased with increasing N rates. Among N rates, the tallest plants were plots without N. Plant height in treatments with 80 or 120 kg N ha^{-1} were similar (Table 8). Height of plants was also influenced by time of N application. In this case, tallest plants were recorded where N was applied as T4 in all varieties. However, in TXD 85 there was no statistical difference when was applied as T3 or T4 (Table 9).

The interaction of N rates and time of application was significant ($P<0.05$). Tallest plants were recorded in plots with 40 kg N ha^{-1} and above that rate applied either as T3 or T4 (Table 12).

There were significant treatment interaction among varieties, rates and time of N application on plant height. TXD 85 had tallest plants in plots with 40 kg N ha^{-1} when applied either as T3 or T4. TXD 306 recorded tallest plants in plots with 120 kg N ha^{-1} applied as T4. Supa recorded tallest plants with 120 kg N ha^{-1} when applied as T3 (Table 13).

4.2 Nitrogen Use Efficiency

Nitrogen use efficiency (NUE) differed significantly ($P<0.05$) among varieties. TXD 306 and TXD 85 gave the highest NUE, while Supa gave the lowest (i.e. TXD 306> TXD 85 > Supa). With regard to effects of varieties and rates of N application, results revealed significant ($P<0.05$) differences in NUE. Highest NUE was observed with 40 kg N ha^{-1} in all varieties, while the lowest was recorded with 120 kg N ha^{-1} (Fig. 3).

Table 12. Effect of N rates and time of N application on plant height, days to 50% flowering and number of tillers/m^2

Rate of N (kg/ha)	Time of N application	Plant /height	Days to 50% flowering	Number of tillers/m^2
0	T1	84.4 f	94.3 a	167.8 e
	T2	85.2 f	93.8 a	170.6 e
	T3	84.5 f	94.4 a	171.3 e
	T4	85.2 f	94.0 a	165.6 e
40	T1	98.1 e	91.6 ab	194.2 be
	T2	99.9 de	91.4 ab	215.1 cde
	T3	102.6 abc	88.2 bcd	254.4 abc
	T4	104.2 a	85.8 cd	269.7 abc
80	T1	100.2 cde	91.1 ab	222.2 cde
	T2	101.1 bcd	90.3 abc	249.8 bcd
	T3	103.5 ab	86.5 cd	269.2 abc
	T4	102.3 abcd	84.8 d	290.1 ab
120	T1	98.5 e	91.3 ab	244.9 bcd
	T2	104.8 a	89.2 bcd	260.4 abc
	T3	104.4 a	86.0 cd	298.7 ab
	T4	104.6 a	85.2 d	312.6 a
Mean		97.7	89.9	234.7
SE		0.7	1.2	16.6
CV		2.4	0.9	7.1

Mean within rows or columns, followed by the same letter(s) are not significantly different at $P< 0.05$ according to DNMRT. Definition of symbols is as in Table 2.

Table 13. Effect of varieties, N rates and time of application on plant height

Variety	Time of N application[1.]	Plant height (cm)				
		0 N	40 N	80 N	120 N	Mean
TXD 85	T1	81.5 klm	90.2 e-i	87.8 g-k	87.9 f-k	86.8
	T2	82.6 j-m	87.1 h-l	87.7 g-k	95.1 ef	88.1
	T3	81.3 klm	95.2 ef	92.3 e-i	91.4 e-I	90.0
	T4	82.1 j-m	94.6 efg	92.6 e-i	91.4 e-I	90.1
TXD 306	T1	79.3 m	88.2 f-k	89.8 e-i	85.4 i-m	85.6
	T2	79.9 m	91.5 e-i	90.5 e-i	91.7 e-I	88.4
	T3	80.0 m	91.0 e-i	89.1 f-j	90.1 e-I	87.5
	T4	80.1lm	94.8 e-g	91.2 e-i	96.5 e	90.6
Supa	T1	92.7 e-i	115.9 d	122.9 bc	122.1 bcd	113.4
	T2	93.3 e-h	121.3 cd	125.0 abc	127.5 abc	116.7
	T3	92.4 e-i	121.7 cd	129.1 ab	131.7 a	118.7
	T4	93.4 e-h	123.1 bc	123.0 bc	125.8 abc	116.3
Mean		84.8	101.2	101.7	103.0	97.7
SE						2.1
CV						4.8

Mean within rows or columns, followed by the same letter(s) are not significantly different at $P<0.05$ according to DNMRT. Definition of symbols is as in Table 2.

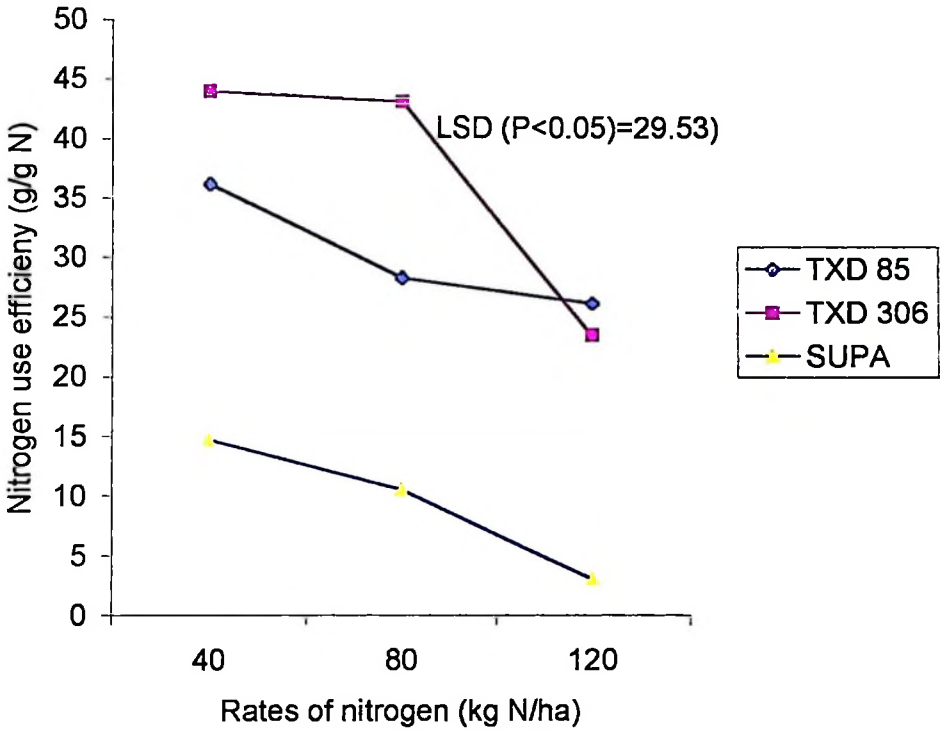

Figure 3. Effect of varieties and N rates and time of application on N-use efficiency

The interaction of varieties, N rates and time of N application on NUE was significant (P<0.05). Application of N as T4 among varieties resulted in TXD 306 giving the highest NUE. Supa recorded lowest NUE with N applied as T4.

Application of N as T1 reduced NUE in all varieties. TXD 306 recorded the highest NUE while Supa had the lowest. TXD 85 was intermediate (Fig.4).

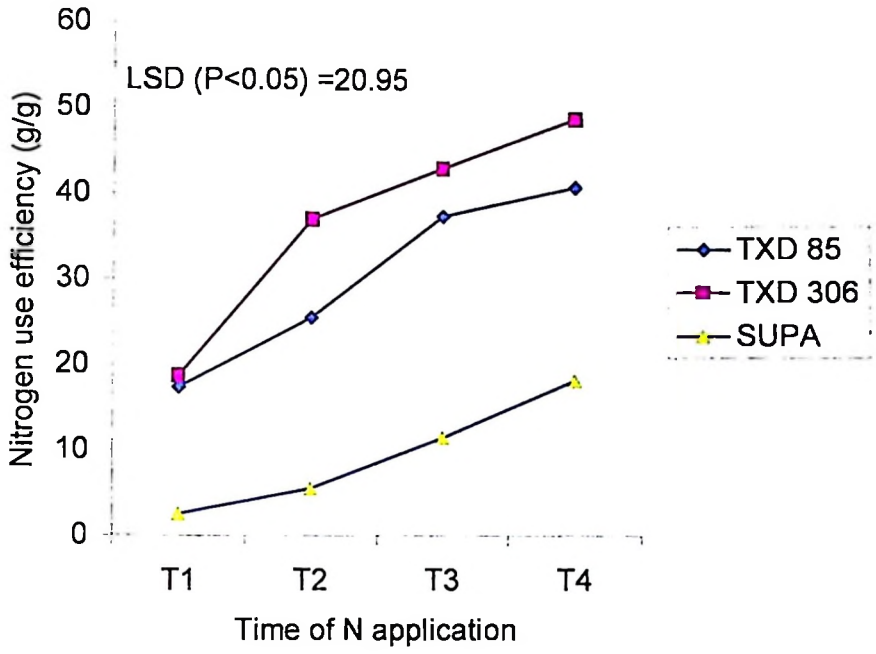

Figure 4. Effect of varieties and time of N application on N- use efficiency

An increase of N above 40 kg N ha^{-1} reduced NUE tremendously. The interaction of rates of N and time of N application on NUE was significant ($P<0.05$). Among N rates, NUE was highest with 40 kg N ha^{-1} applied as T4, and lowest with 120 kg N ha^{-1} applied as T1 (Fig.5).

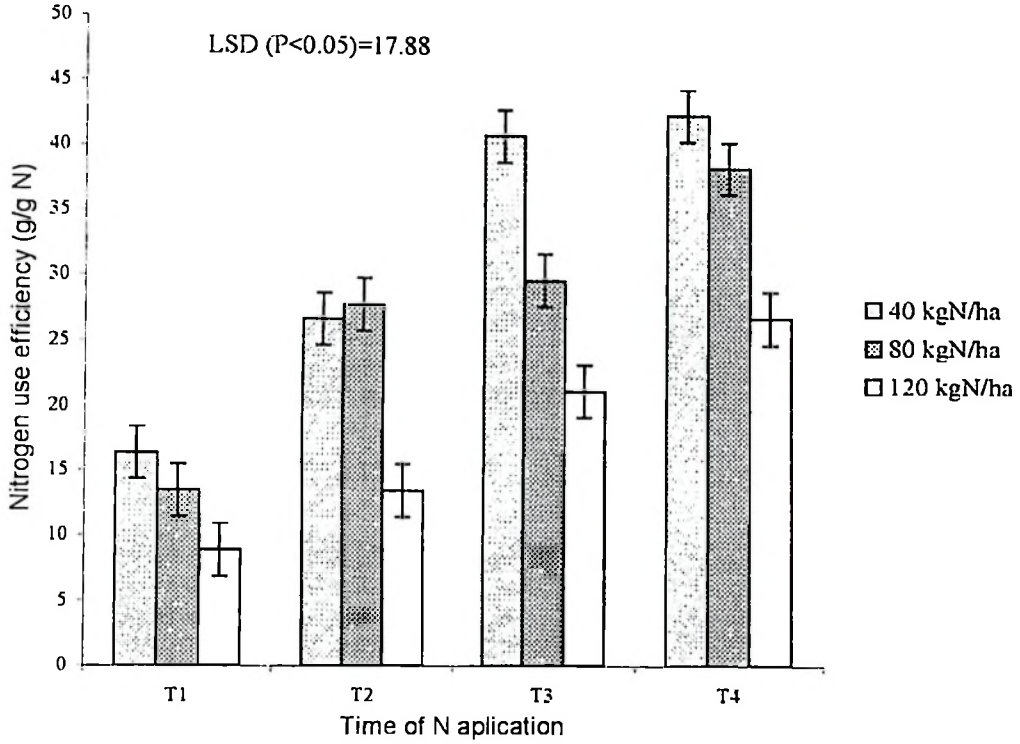

Figure 5. Effect of rates of N and time of application on N- use efficiency

4.3 Yield and Yield Components

4.3.1.Grain yield

The varieties differed significantly (P<0.05) in grain production. TXD 306 gave the highest grain yield, while the lowest was recorded in Supa. Grain yield increased significantly (P<0.05) with increasing N rates. Application of 120 kg N ha^{-1} gave significantly higher yields. The lowest yields were recorded in plots without N. The interaction of varieties and rates of N on grain yield was significant (P<0.05). Among the varieties TXD 306 and TXD 85 showed increasing yields with N rates up to 120

kg N ha^{-1}.

Supa gave highest grain yield with 80 kg N ha^{-1}. At higher rates (120 kg N ha^{-1}) grain yield of Supa declined (Table 14).

Time of N application had considerable effects on grain yield. The highest grain yield was recorded when N was applied as T4 and lowest as T1 (Table 15). The interaction of rates of N and time of N application on grain yield was significant ($P<0.05$). Highest grain yield was recorded with 120 kg N ha^{-1} applied as T4 (Table 15). The interaction of varieties, N rates and time of N application on grain yield was significant ($P<0.05$). TXD 85 and TXD 306 gave significantly higher grain yield with 120 kg N ha^{-1}applied as T4. In contrary, Supa yielded highest grain yield with 80 kg N ha^{-1} also applied as T4. All varieties yielded lowest with N rates below 80 kg N ha^{-1} applied as T1 (Table 16).

4.3.2 Grain dry mass

Grain dry mass (GDM) differed significantly ($P<0.05$) among varieties. The highest GDM was recorded in TXD 306 while Supa had the lowest. The rates of N significantly influenced GDM ($P<0.05$), with the highest values being recorded in treatments with 80 or 120 kg N ha^{-1}. The lowest GDM was recorded in treatments without N (Fig.6). Time of N application significantly affected GDM ($P<0.05$). The highest GDM was recorded when N was applied as T4 while lowest as T1. The interaction effects of N rates and time of N application on GDM was significant ($P<0.05$). Application of 80 or 120 kg N ha^{-1} increased GDM especially when N applied as T3 or T4 (Fig.7).

Table 14. Effect of varieties and N rates on yield and yield components

Variety	Rate of N (kg/ha)	Grains/ panicle	Panicles/ m^2	Panicle weight (g)	1000 grain weight (g)	Grain yield (g/m^2)
TXD 85	0	103.8 b	157.7 e	2.8	25.8	223.2 hi
	40	169.6 a	220.7c	4.8	28.5	367.9 e
	80	177.1 a	250.0a	5.5	28.8	450.5 c
	120	186.2 a	252.3a	6.0	29.2	538.2 a
TXD 306	0	105.5 b	208.2c	2.5	25.8	234.9 gh
	40	159.2 a	237.7b	3.9	28.6	408.2 d
	80	170.0 a	259.3a	4.6	29.0	540.7 a
	120	176.4 a	256.1a	5.1	28.8	494.8 b
Supa	0	115.6 b	103.0g	2.1	28.7	198.4 i
	40	154.1 a	120.5f	4.2	31.5	253.3 fg
	80	162.9 a	131.1f	4.9	31.9	277.4 f
	120	156.9 a	138.3f	5.3	32.5	231.0 gh
Mean		153.0	194.6	4.3	29.1	351.4
SE		8.8	13.3	N.S	N.S	7.3
CV		7.9	23.1	9.0	2.4	22.9

Means within columns, followed by the same letter(s) are not significantly different at $P<0.05$ according to DNMRT.

Table 15. Effect of N rates and time of application on yield and yield components

Rate of N (kg/ha)	Time of N application	1000 grain weight (g)	% Filled grains	Panicle weight (g)	Panicle/m^2	Grain yield ($g/m^{2)}$
0	T1	26.3a	70.2	2.2k	134.2e	229.7f
	T2	27.5ab	77.4	2.5j	136.4e	222.2f
	T3	26.8ab	75.3	2.5j	137.0e	215.3f
	T4	26.6ab	76.2	2.7j		206.8f
40	T1	26.9 cd	70.2	3.1 i	159.6 def	289.6 e
	T2	29.1 abcd	77.4	3.8 g	178.0 b-f	329.8 d
	T3	30.7 abc	75.3	4.8 ef	209.7 a-d	375.0 c
	T4	31.4 ab	76.2	5.3 d	224.8 abc	378.0 c
80	T1	26 6 cd	75.7	3.4 hi	167.9 c-f	330.0 d
	T2	29.8 abcd	80.7	4.7 f	208.2 a-d	393.7 b
	T3	31.6 ab	77.5	5.7 c	236.6 ab	453.3 b
	T4	32.1 a	76.8	6.3 b	241.4 a	514.3 d
120	T1	27.6 abcd	72.8	3.6 gh	160.4 def	331.3 d
	T2	28.9 abcd	76.1	5.1 de	210.7 a-d	385.0 c
	T3	31.8 a	73.4	6.2 b	237.6 a	440.1 b
	T4	32.5 a	77.3	7.0 a	253.6 a	592.2 a
Mean		29.1	76.2	4.3	194.6	351.4
SE		1.1	N.S	0.1	16.0	10.4
CV		2.4	12.7	9.0	23.1	22.9

Means within columns, followed by the same letter(s) are not significantly different at $P<0.05$ according to DNMRT. Definition of symbols is as in Table 2.

Table 16. Effect of varieties, N rates and time of application on grain yield

Variety	Time of N application	Grain yield (g/m^2) 0 N	40 N	80 N	120 N	Mean
TXD 85	T1	242.7 opq	327.3 j-p	391.0 f-k	394.3 f-k	338.8
	T2	233.0 opq	364.0 h-m	419.0 f-j	479.7 dfg	373.9
	T3	202.3 q	397.7 f-k	458.0 e-h	578.3 bcd	409.0
	T4	214.7 pq	382.7 g-l	534.0 cde	700.3 a	457.9
TXD 306	T1	243.7 opq	338.i-o	401.7 f-k	398.0 f-k	345.5
	T2	233.0 opq	390.0 f-k	500.3 def	460.3 e-h	395.9
	T3	247.3 n-q	454.3 e-h	612.0 abc	502.0 def	453.9
	T4	213.3 pq	449.7 e-i	648.7 ab	619.0 abc	482.6
Supa	T1	202.7 q	202.7 q	197.0 q	200.7 q	200.7
	T2	202.3 q	235.3 opq	262.7 m-q	215.0 pq	228.5
	T3	196.3 q	273.0 l-q	290.0 k-q	240.0 opq	249.8
	T4	192.3 q	302.0 k-q	360.3 h-n	268.3 m-q	280.7
Mean		218.6	343.1	422.8	421.3	351.4
SE						33.2
CV						10.2

Means within rows or columns, followed by the same letter(s) are not significantly different at $P<0.05$ according to DNMRT. Definition of symbols is as in Table 2.

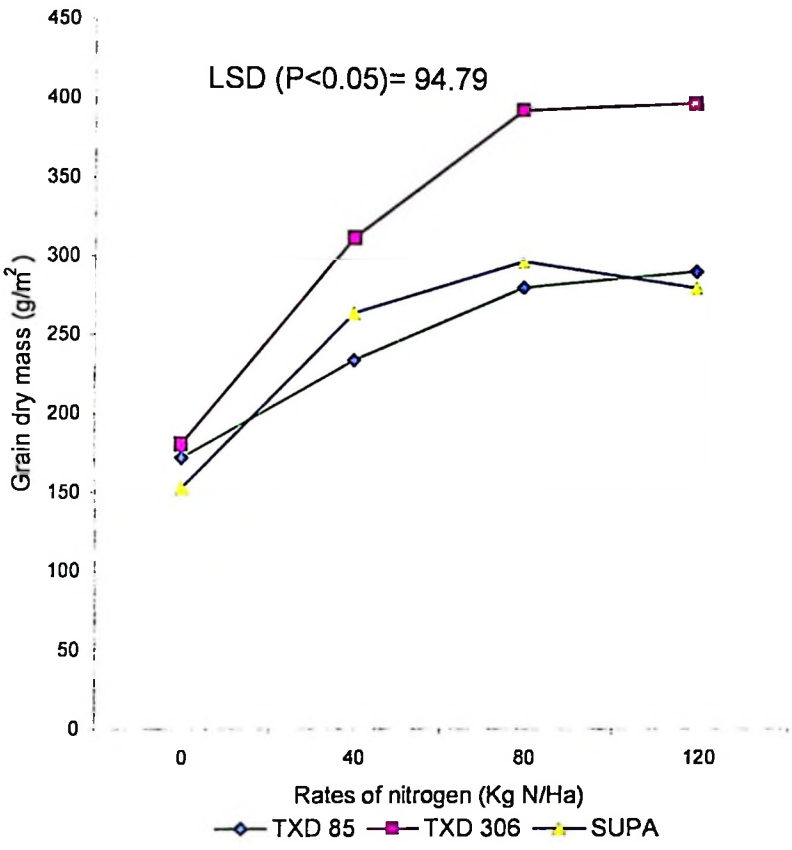

Figure 6. Effect of varieties, rates of N application on grain dry mass

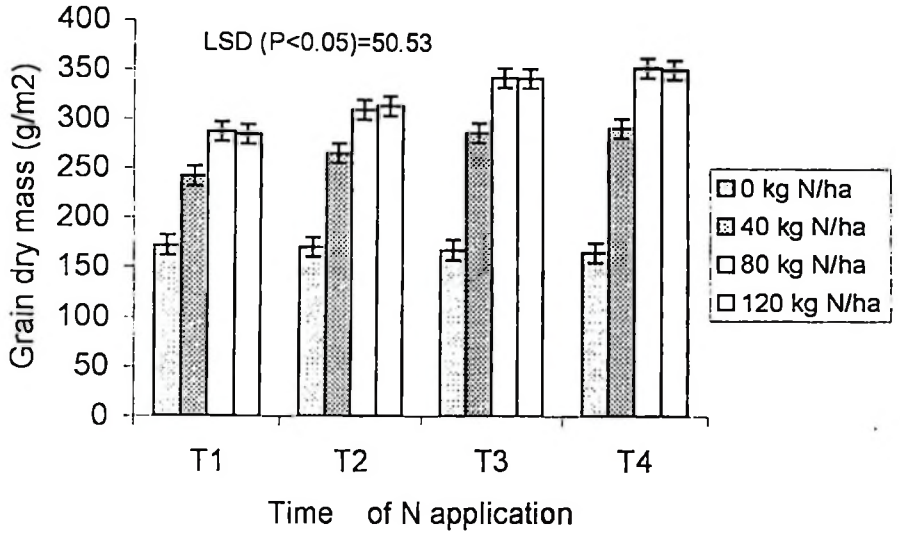

Figure 7. Effect of N rates and time of application on grain dry mass

4.3.3 Number of panicles/m^2

The number of panicles/m^2 differed significantly ($P<0.05$) among varieties. TXD 306 had the highest number of panicles/m^2 while Supa recorded the lowest. The varieties and rates of N interaction on number of panicles/m^2 were significant ($P<0.05$). All varieties gave highest number of panicles/m^2 with 80 kg N ha^{-1} (Table 14). Number of panicles/m^2 also varied among N rates. Highest mean values were recorded in treatments with 120 kg N ha^{-1}. The lowest values were recorded with 0 kg N ha^{-1}. Interaction of rates of N and time of N application on number of panicles/m^2 was also significant ($P < 0.05$). The highest number of panicles/m^2 was recorded in treatments with 120 kg N ha^{-1} applied as T4. The lowest values were recorded with low N rates, particularly when N was applied as T1 (Table 15).

4.3.4 Number of grains per panicle

While there were no differences in the number of grains per panicle in the treatments without N, large differences were observed when N was applied, regardless of the amount of N. Although it was not statistically significant, TXD 85 and TXD 306 had highest grains per panicle with 120 kg N ha^{-1}. Fewer grains per panicle were recorded in Supa with 120 kg N ha^{-1} than with 80 kg N ha^{-1} (Table14).

4.3.5 One thousand- grain weight

Increased N rates significantly ($P<0.05$) affected 1,000-grain weight. Grains weight was highest with 120 kg N ha^{-1} and lowest without N. Time of N application significantly ($P<0.05$) affected 1,000-grain weight. Interaction of N rates and time of application was significant ($P<0.05$) on 1,000-grain weight. In this case the highest grain weight was recorded in treatments with 80 or 120 kg N ha^{-1} applied as T4 .The lowest 1,000-grain weight was recorded in treatments with 40 or 80 kg N ha^{-1} applied as T1 (Table 15).

4.3.6 Panicle weight

Time of N application showed large effects on panicle weight ($P<0.05$). The highest panicle weight was recorded when N was applied as T4.The lowest panicle weight was recorded when N was applied as T1 (Table 14). Rates of N and time of N application had significant interaction effects on panicle weight. The highest panicle weight was realized in treatments with 120 kg N ha^{-1} applied as T4. The lowest panicle weight was recorded in treatments with 40 kg N ha^{-1} applied as T1 (Table 15). Interaction of varieties, rates of N and time of N application significantly

Table 17. Effect of varieties, N rates and time of application on panicle weight

Variety	Time of N application	Panicle weight (g) 0 N	40 N	80 N	120 N	Mean
TXD 85	T1	2.5 p-s	3.6 lmn	4.0 klm	4.0 klm	3.5
	T2	2.9 n-r	4.5 ijk	5.4 fgh	5.9 c-f	4.7
	T3	2.8 o-s	5.4 fgh	6.3 b-c	6.9 ab	5.3
	T4	3.1 n-q	5.6 efg	6.5 bcd	7.3 a	5.6
TXD 306	T1	2.1 s	3.4 mno	4.4 ijk	4.9 g-j	3.7
	T2	2.4 qrs	4.4 ijk	5.2 f-I	5.8 c-f	4.4
	T3	2.7 o-s	4.8 h-k	5.8 c-f	6.6 abc	4.9
	T4	2.9 n-r	3.2 nop	3.2 nop	2.0 s	2.8
Supa	T1	2.3 rs	2.9 n-r	3.1 n-q	3.6 lmn	3.0
	T2	2.2 rs	3.4 mno	4.2 jkl	4.6 ijk	3.6
	T3	2.2 rs	4.7 h-k	5.8 def	5.9 c-f	4.6
	T4	2.2 rs	5.6 efg	6.6 abc	7.3 a	5.4
Mean		2.5	4.3	5.0	5.4	4.3
SE						0.2
CV						16.2

Means within rows or columns, followed by the same letter(s) are not significantly different at $P<0.05$ according to DNMRT. Definition of symbols as in Table 2.

($P<0.05$) affected panicle weight. In this regard, highest panicle weight was observed in TXD 85 and Supa with 120 kg N ha^{-1} applied as T4 (Table 17).

4.3.7 Percentage filled grains

In this study, neither the effect of varieties, rates of N nor time of N application had significant effect on percentage filled grains (Table 15).

4.4 Correlation Analyses

4.4.1 Correlation between yield and yield Components

In this study, grain yield was influenced by various morphological characteristics (Table 18). Variation in grain yield among treatments was associated with variations in the number of panicles/m^2, number of grains per panicle and panicle weight. The number of filled grains per panicle and 1000-grain weight were not associated with this variation. The number of grains per panicle depended on the number of panicles/m^2. Similarly, panicle weight depended on number of panicles/m^2, number of grains per panicle and 1000-grain weight.

4.4.2 Correlation between grain yield and dry mass production

The analysis results showed large and positive correlation between grain yield and various plant growth characters. Grain yield was significantly ($P<0.05$) influenced by grain dry mass, stem dry mass and total dry mass (Table 19).

Total dry mass, on the other hand, was influenced by grain dry mass, stem dry mass and leaf dry mass. But leaf and stem dry mass depended only on grain dry mass. Leaf dry mass had no direct contribution to the observed variation in grain yield.

Table 18. Correlation between grain yield and yield components

S/N	Parameters	1	2	3	4	5	6
1.	Panicles/m2	1.000					
2.	Grains/panicle	0.508**	1.000				
3	Filled grain %	0.141	0.090	1.000			
4.	1,000 grain weight	- 0.013	0.630**	0.081	1.000		
5.	Panicle weight	0.433**	0.856**	0.070	0.674	1.000	
6.	Grain yield	0.702**	0.736**	0.195	0.204	0.662**	1.000

**Significant at P<0.01.

Overall, grain yield variation among treatments was associated with variations among vegetative and reproductive plant characteristics (Table 18 &19). Correlation between grain dry matter with stem dry matter and leaf dry matter and grain yield was positively significant (P<0.01). Leaf dry matter was not significantly (P<0.01) correlated with grain yield.

4.5 Economic Analysis of Varieties and N Rates

Economic analysis of varieties and rates of N showed that TXD 85 gave optimum economic grain yield with 120 kg N ha^{-1} and TXD 306 with 80 kg N ha^{-1}. Supa gave optimum economic grain yield with 40 kg N ha^{-1}.

Table 19. Correlation between grain yield, grain dry mass, stem dry mass, leaf dry mass and total dry mass

S/N	Parameters	1	2	3	4	5
1.	Grain dry mass	1.000				
2.	Stem dry mass	0.722**	1.000			
3.	Leaf dry mass	0.568**	0.097	1.000		
4.	Total dry mass	0.925**	0.891**	0.515**	1.000	
5.	Grain yield	0.758**	0.823**	0.163	0.804**	1.000

**Significant at $P<0.01$.

There was a slight increase in grain yield with 120 and 80 kg N ha^{-1} in TXD 306 and Supa, respectively.

However, the yield increase was not significant compared to additional cost of N fertilizer incurred (Table 20).

Table 20. Economic analysis of performance of varieties and N rates

Variety	Rate of N (kg/ha)	Cost of N (kg/ha)	Yield (kg/ha)	Gross Revenue (T. Shs/ha)	Net Revenue (T. Shs/ha)
TXD 85	0	_	2232	334800	334800
	40	19118	3676	551850	532732
	80	38236	4505	67550	637514
	120	57354	5382	807300	749946*
TXD 306	0	_	2349	352350	352350
	40	19118	4082	612300	593182
	80	38236	5407	811050	772814*
	120	57354	4948	742200	684846
SUPA	0	_	1984	297600	297600
	40	19118	2533	379950	360832*
	80	38236	2774	416100	377864
	120	57354	2310	346500	289146

Cost of paddy =T. Shs 150/kg Cost of N (urea) =T. Shs 220/kg

*Economic optimum net returns.

CHAPTER FIVE

5.0 DISCUSSION

5.1 Crop Growth and Development

The variation in plant height was influenced by varieties, rates of N and time of N application. Time of N application significantly influenced plant height irrespective of the effects of varieties and rates of N. Since the tallest plants were recorded when N was applied as two equal splits at initial tillering and panicle initiation (T4) and as three equal splits: one- third dose each on dry soil before transplanting, at initial tillering and at panicle initiation (T3). The results suggest that these timing of N are proper time that N application promotes best plant growth and development. Leonard and Martin (1988) pointed out that; an increase in plant height was proportional to the amount of N applied. Rahman (1985) also reported similar increase in plant height with increasing N rates in rice genotypes.

The variation in days to 50% flowering was significantly affected by varieties, rates and time of N application. From this study, shortest days to 50% flowering were obtained with increasing N rates, implying that the amount of N reduced days to flowering. This in turn determined the days to maturity. These results support earlier reports by De Datta (1981) and Yoshida (1981) that genetic variation among genotypes for days to 50% flowering existed. These workers also emphasized that days to 50% flowering determined days to maturity. By shortening the growth duration it is possible to raise production per area per day (De Datta, 1981).

The number of tillers/m^2 was significantly influenced by varieties, N rates and time of N application. Application of N as T4 or T3 produced more tillers/m^2 than when was N applied as T1 or T2. In the latter which large amounts of N could have been lost before the plants utilized it completely for growth and development. However, the small increase in number of tillers/m^2 following application of N as T1or T2 might be attributed to indigenous soil N that promoted tillering.

The fact that number of tillers/m^2 was large even before N application, in the case of treatments without N, indicates that inherent soil N played a significant role in rice growth even before additional N as a fertilizer. However, most of the tillers produced without N supply did not form panicles, suggesting that the amount of N absorbed was not adequate for panicle formation. This could probably be due to low soil N at the experimental site (Table 1). Mae and Shoji (1984) reported that N absorbed during vegetative period mainly promoted early growth of the rice plant and increased the number of tillers. Hence increase in the number of tillers following application of N as T3 or T4 confirms reports by De Datta and Buresh (1990) that early N application is necessary for more tiller production.

The varieties, N rates and time of N application had a bearing on total dry mass variation. Total dry mass is the sums of leaf dry mass, stem dry mass and grain dry mass. The efficiency of the plant to accumulate dry mass depends on factors such as varietal differences in response to soil nitrogen supply, availability of soil moisture, intercepted solar radiation and air temperature (Yoshida, 1981; Wada, 1971). These factors are not only reflected on dry mass production as a whole but also in the

percentage of ripen grains and grain yields (Murata, 1969). The amount of solar radiation intercepted and nitrogen absorbed determine the rate of photosynthesis, hence the amount of dry mass accumulation.

In this study, the variation in dry mass production among varieties could be attributed to differences in their NUE. Lower dry mass production following application of N as T1 from 40 to 120 kg N ha^{-1} suggests that more N was lost before the rice plant had achieved a well developed root and shoot system for greater N absorption compared to application of N as T3 or T4. The accumulation of more dry mass resulting from N applied as T4 than N applied as T1 or T2, confirms earlier reports that N application at midseason increases total dry mass accumulation and grain yields compared to none midseason N application (Norman *et al.*, 1998).

Variation in dry mass among cultivars has been reported by Chandraratna (1984), that japonica varieties convert 50% of the total dry mass to grain and the dry mass utilized by indicas to grain was under 40% of the total dry mass. Therefore the lowest grain yield in Supa (which is an indica) with application of 120 kg N ha^{-1} could have also been attributed to its lower total dry mass production as compared to TXD 306 and TXD 85. Also, in this study, the higher increase in dry mass following application of N as T3 or T4 than as T1 or T2 could be attributed to greater availability of N throughout the growth period and low N loss. Similar increases in dry mass with three-split N application at planting, tillering and panicle initiation stages were also reported by Saheb *et al.* (1990).

5.2 Nitrogen Use Efficiency (NUE)

Timely application of N may improve NUE throughout the growing season as it provides specific amount of nutrients to the crop during peak periods of demand and may reduce leaching of nitrate - N in the soil (Fageria and Baligar, 1999). Several applications of small amount of fertilizer N during the growing season, therefore, could be a more effective way of supplying N for plant growth than one large dose at the beginning of the season (Peoples *et al.*, 1995).

Results of the study suggest that NUE is higher with lower N rates and is influenced by time of application. The results still suggest that application of N as T4 has the highest NUE regardless of variety and rate of N. It has been reported that for maximum efficiency, least N application should coincide with the stage of development that still permits N uptake (Olson and Kurtz, 1982). It is therefore possible that application of N as T4 is the best time where maximum NUE can be obtained in rice production. The variability in NUE among the rice varieties could have been attributed to their genetic capacity to absorb N in the soil. Also the existence of interaction between varieties and rates of N shows differential behaviour of varieties with increasing levels of N.

Increasing the number of fertilizer splits increased NUE particularly at higher N rates. Hence N application as T3 or T4 would be the best for lower rates e.g. 40 kg N ha^{-1}, while application as T4 would be the best for higher rates e.g. 80 or 120 kg N ha^{-1}. This observation suggests that N supply, as T4 or T3 would have significant influence on NUE than when applied as T1 or T2. Matsushima (1969) pointed out

that a large amount of N applied from tillering to early heading is important as these are the critical growth stages during which paddy utilizes large amounts of nitrogen.

Split applications of N enhance synchronization of N supply and demand that reduce residence time of the nutrient in the soil environment, and hence less fraction of N fertilizer is subject to loss. On the other hand, low NUE exhibited in treatments with N applied as T1 or T2 suggests that a substantial amount of N fertilizer was wasted since the crop uptake at this growth stage was lower than the amount of N supplied. Therefore, application interval as T3 or T4 would be long enough to minimize such N losses. Mae (1997) reported that N from a basal dressing is almost finished before the maximum tillering stage, and its major role is only promotion of early vegetative growth.

Apart from differences among varieties, N rates and time of N application, low NUE observed in this study also could be attributed to limitation of other nutrients, particularly P and K, which were generally low. De Datta (1981) mentioned some possibilities for low fertilizer use in rice crop that: plants do not take fertilizer nutrients because they are applied at the wrong time or in the wrong place or the transformations of nutrients make them unavailable. Although taken up by the crop, the nutrients are not used for grain production due to other growth limiting factors such as insufficient water or light or lack of other mineral elements.

Cassman *et al.* (1998) concluded that low fertilizer N use efficiency presently achieved by rice farmers results primarily from a lack of congruency between

effective indigenous N supply, applied N and crop demand. Bouman *et al.* (2001) pointed out that the recovery of fertilizer N depends on developmental stage of the crop with relatively low value at transplanting and high values at panicle initiation. A young crop takes less N than an older crop. Crop N demand is first met by indigenous soil N supply, and if this is insufficient, then N fertilizer is added.

In this study, NUE ranged from 18.2 to 48.8 g grain/g N. These results do not comply with observations made by Yoshida (1983) in which NUE of about 50 g grain/g N. Also higher NUE that were recorded with application of N as T3 or T4 were similar to those reported by Saheb *et al.* (1990) in which 41.4 kg grain/kg N was recorded. The findings of this study, therefore confirm that higher NUE could be achieved by use of better varieties and improving the field-specific N management strategies to match N supply to greater crop demand for the nutrient.

5.3 Grain Yield and Yield Components

Grain yield is expressed as a function of number of panicles per m^2, number of spikelets per panicle, kernel weight and percentage filled spikelets. Each of the yield components differs not only in the time it is determined but in its contribution to grain yield (Yoshida, 1981). In this study, higher grain yields were closely related to higher N fertilizer rates, suggesting that grain yields increased proportionately as the pool of available N increased in the soil by addition of N up to 120 kg N ha^{-1} with exception of Supa which produced higher yield with 80 kg N ha^{-1} .The fact that N application as T4 produced significantly higher grain yield than all other timings indicates that soil N availability apparently matched the crop needs during that

growing period. This also might suggest that at this stage, the crop had achieved a well-developed and active root system for absorbing the fertilizer N when it was supplied.

Peoples *et al.* (1995), reported that matching nutrients to plant demand is likely to reduce both losses by processes competing with N uptake and provide optimal nutrition for plant growth and yield. Higher N rates (120 kg N ha^{-1}) applied, as T1 or T2 could not influence number of panicles/m^2, grains/panicle and grain yield. This suggests that there were substantial N losses before the yield determination stage was reached. This meant that there should be even supply of N at various growth stages. Secondly, the plant has an exact demand for N at a particular growth stage available in the soil indigenous N pool, and that this could not be altered by excess or minimum N application.

Yield components of rice such as number of panicles and panicle weight which determined the grain yield, increased with increasing N rates. Higher grain yield was therefore associated with number of panicles and panicle weight. Sharma and Choubey (1985) observed similar results that application of N in two equal splits (at tillering and booting) appeared significantly superior with respect to yield and yield attributes than application in single dose at planting, and two equal splits: half dose each at planting and at tillering. Similar results were also reported by Singh and Singh (1991).

Modgal *et al.* (1974) also reported the necessity of split N application. They observed that three split N application i.e. at planting, tillering and panicle initiation influenced yield contributory characters such number of panicles/m^2, number of grains per panicle and grain yield, compared to the whole amount of N at planting. In this study, increase in number of tillers/m^2 following application of N as T4 could therefore be attributed to indigenous soil N that was sufficient to promote tillering even before additional fertilizer N was applied. Similarly, increased number of panicles following application of N as T4 indicates that the applied N coincided with such a growth stage where N supply was able to influence panicle production.

Although an increase in levels of N is important for increased number of tillers/m^2, excessive N application could increase the incidence of lodging (Vergara, 1992). In this study it was observed that application of 120 kg N ha^{-1} in Supa resulted into lodging of plants. This lodging effect could have caused the observed yield decline in this variety, in spite of having higher number of tillers/m^2 with 120 kg N ha^{-1} compared with 40 or 80 kg N ha^{-1}.

Generally, panicle weight increased with increasing N rates. This was probably due to increased metabolite supply with higher N rates. The heavier panicles in treatments involving N application as T3 or T4 indicate that more N was allocated to panicle development than when N was applied as T1 or T2. Prasad and De Datta (1979) reported that at high N rate (120 kg N ha^{-1}), N absorbed by the plant during vegetative stage is stored for use at later growth stages and that the supply after

panicle initiation tends to decrease grain weight. Hence, higher panicle weight produced with N applied as T3 or T4 contributed to higher grain yield.

One- thousand grain weight was generally not affected by N rates and time of application. Variation in rice grain weight is usually small since seed size is rigidly controlled by the size of the hull. In most situations 1,000-grain weight of a field crop is a varietal character and that management aspects such as fertilizer rates, its time of application and water supply have minimum influence (Yoshida, 1981). However, the same worker also reported to exist differences in 1000-grain weight under different environments and cultural practices.

Temperatures at grain filling stage affect considerably the 1000-grain weight. A controlled–temperature experiment showed that optimum daily mean temperature for grain filling ranged from 19 to 25 °C for IR 20, an indica rice and from 16 to 22 °C for Fujisaka 5, a japonica rice (Yoshida, 1981). In this study, the grain filling period occurred in May with mean temperature of 28.2 °C. Hence any variation in 1000-grain weight could have been attributed to temperature and varietal differences.

In addition the lack of significant difference for percentage filled grains might be due to higher levels of N application among treatments. Some varieties have been reported to have lower percentage filled grains than others at high levels of N. Also at higher levels of N, lodging decreased the percentage filled grains. It also reduces the cross sectional area of vascular bundles and disturbs the movement of assimilate and absorbed nutrients via the root. In addition lodging disturbs leaf display and

increases shading (Yoshida, 1981). This was true with Supa, which failed to yield more in response to increased N application due to increased lodging with higher N levels.

Vergara (1992) reported that, when the plant lodges the empty spikelets on panicles will float when placed in water hence hindering male cells to unite with egg in the ovary (fertilization). The hindrance to fertilization could have contributed to some extent, the development of unfilled grains observed in Supa. However, for the case of TXD 306 and TXD 85 that did not lodge, the lack of significant difference for that parameter among the treatments suggests that the character was not influenced by N rates and time of N application. Rahman (1985) observed similar results in varieties, IR 747, P_3C_{26} and Zhu Lian.

5.4 Correlation Between Yield and Yield Components

Correlation analysis results agree with those reported by Miller and Roberts (1991) as well as Sharma and Choubey (1985) that production of panicles is highly correlated with grain yield. The fact that yield was positively correlated with these yield components indicates that rice grain yield could be appreciably increased by increasing number of panicles/m^2, panicle weight and number of grain per panicle. Therefore, from the results of the study it is likely that increased rice yield can be achieved through adoption of proper rates of N as well as timing of N application.

Grain yield is positively correlated with leaf dry mass, stem dry mass, grain dry mass and total dry mass. Hence it is suggested that an increase in N rate will lead to both increases in dry mass and grain yield. De Datta (1981) pointed out that grain

production, which is the final product of growth and development, is controlled by dry mass production during ripening phase. The dry mass in turn is controlled by potential ability of population to photosynthesize (the source) and the capacity of spikelets to accept the photosynthates (the sink). Sundaram *et al.* (1990) also reported the existence of positive correlation between grain yield and dry mass production. These reports are in conformity with this study that grain yield is positively correlated with leaf dry mass, grain dry mass, stem dry mass and total dry mass. Also, these results suggest the importance of selection based on characters, such as dry mass, which is highly correlated with grain yield for development of high yielding rice varieties.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

On the basis of these findings, the following conclusions were made:

1. Dry mass accumulation varied significantly among varieties, rates and time of fertilizer N application. More dry matter was obtained with higher N rates (120 kg N ha^{-1}) applied in two equal splits; half dose each at initial tillering and panicle initiation (T4).

2. Nitrogen use efficiency (NUE) depends on variety, rate and time of N application. NUE decreases with increasing N rates.

3. Split applications of N as three equal splits i.e. one-third dose each in dry soil before transplanting, initial tillering and panicle initiation (T3) or two equal splits i.e. half dose each at initial tillering and panicle initiation (T4) improved NUE at higher N rates.

4. Higher economic optimum for grain yield in TXD 85 was obtained with 120 kg N ha^{-1} while in TXD 306 was with 80 kg N ha^{-1}, both applied as T4. Supa produced higher economic optimum grain yield with 40 kg N ha^{-1}, also applied as T4.

Varieties with high NUE produced higher grain yield than those with lower

NUE. TXD 306 and TXD 85, which had the highest NUE produced higher grain yield than Supa, which had lower NUE.

6.2. Recommendations

1. Large application of N as single dose before transplanting should be discouraged. Most of fertilizer N applied in this way is wasted through denitrification and leaching.

2. Two equal splits of N applied at initial tillering and panicle initiation (T4), will result into higher grain yields than single dose before transplanting (T1) or two equal splits half dose each before transplanting and initial tillering (T2).

3. Losses of organic N are slower than those of inorganic N. Increasing indigenous N source by addition of organic N would reduce the need for inorganic N application before transplanting.

4. Since grain yield, dry mass and nitrogen use efficiency are genotype and environment specific characters; further studies should be conducted to characterize a range of genotypes in different agro-ecological zones. This will lead to environment and genotype specific N management recommendations that would result into increased rice yield.

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