

**RESPONSE OF RICE TO NITROGEN AND PHOSPHORUS APPLIED TO THE  
DOMINANT SOIL TYPE AT THE DAKAWA IRRIGATION SCHEME,  
MOROGORO TANZANIA**

**HALIMA RASHID MBAGA**

**A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE  
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**ABSTRACT**

A study was conducted to classify and establish the fertility status of the soil at the Dakawa Irrigation Scheme (DIS) and subsequent to this, a screen-house pot experiment was conducted to assess the response of rice (variety TXD 306) to nitrogen and phosphorus applied to the dominant soil type at the DIS. According to the Soil Taxonomy and the World Reference Base for Soil Resources, the soil of the study area classified as Inceptisol and Cambisol, respectively. Based on physical, chemical and biological properties of composite soil sample, the soil had low total N, low OC, organic matter and exchangeable Ca and Mg, and hence rated as marginally to moderately suitable for rice production. For the response of rice (variety TXD 306) to N and P, rates adopted were 0, 50, 100, 150, 200 kgNha<sup>-1</sup> and 0, 40, 80, 120, 160 kgPha<sup>-1</sup>, respectively. The sources of N and P used were (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> and (Ca(H<sub>2</sub>PO<sub>4</sub>)<sub>2</sub>), respectively applied in 5<sup>2</sup> factorial in CRBD. The number of tillers increased significantly (P < 0.05) with N and P levels from P<sub>0</sub>N<sub>0</sub> kg ha<sup>-1</sup> to P<sub>80</sub>N<sub>200</sub> kg ha<sup>-1</sup>. Biomass weight (g) increased significantly (P < 0.05) from 10.99 g pot<sup>-1</sup> to 93.04 g pot<sup>-1</sup> at P<sub>0</sub>N<sub>0</sub> kg ha<sup>-1</sup> and P<sub>160</sub>N<sub>200</sub> kg ha<sup>-1</sup>, respectively. Grain yield (g) increased significantly (P < 0.05) from 2.24 g pot<sup>-1</sup> to 33.06 g pot<sup>-1</sup> for absolute control and P<sub>160</sub>N<sub>200</sub> kg ha<sup>-1</sup>, respectively. Therefore, for optimum grain yield of TXD 306 for the DIS Cambisol, 80 kgPha<sup>-1</sup> should be applied as basal and N in two splits i.e. 100 kgNha<sup>-1</sup> close to tillering and 100 kgNha<sup>-1</sup> at panicle initiation. For appropriate N and P recommendations, further studies should be conducted to take onboard the integrated soil fertility management in rice cultivation based on soil types to allow extrapolation of the results to other similar soils.

**DECLARATION**

I, Mbaga Halima, do hereby declare to the Senate of Sokoine University of Agriculture, that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

-----  
Halima R. Mbaga  
(MSc. candidate)

-----  
Date

The above declaration is confirmed by

-----  
Prof. J.P. Mrema  
(Supervisor)

-----  
Date

-----  
Prof. B.M. Msanya  
(Supervisor)

-----  
Date

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## LIST OF ABBREVIATION AND SYMBOLS

$^{\circ}\text{C}$	degree centigrade
AE	Agronomic efficiency
AEZ	Agro-ecological zone
ARE	Apparent Recovery Efficiency
BC	Before Christ
C/N	Carbon nitrogen ratio
Ca	Calcium
CEC	Cation exchange capacity
$\text{CEC}_{\text{clay}}$	Cation exchange capacity of clay
$\text{CEC}_{\text{soil}}$	Cation exchange capacity of soil
cm	centimetre
CRBD	Complete Randomized Block Design
DCD	Diciandiamide
DIS	Dakawa Irrigation Scheme
EC	Electrical conductivity
ESP	Exchangeable sodium percent
<i>et al.</i>	and others
FAO	Food and Agricultural Organization of the United Nations
Fe	Iron
g	gram
ha	hectare
HIV	Human Immuno-deficiency virus
i.e.	that is
K	Potassium

kg	kilogram
MAFC	Ministry of Agriculture, Food and Cooperatives
Mg	Magnesium
mm	millimetre
Mn	Manganese
Na	Sodium
P	Phosphorus
pH	negative logarithm of hydrogen ion concentration
PSRPI	Principles of System of Rice Production Intensification
RLDC	Rural Livelihood Development Company
SA	Sulphate of ammonia
SCU	Sulphur coated Urea
SOC	Soil Organic carbon
SOM	Soil Organic matter
SUA	Sokoine University of Agriculture
TEB	Total exchangeable bases
TSP	Triple super phosphate
USDA	United States Department of Agriculture
WRB	World Reference Base for Soil Resources



## CHAPTER ONE

### 1.0 INTRODUCTION

Rice is a multipurpose crop as it is used both as food and cash crop and is the third most important cereal crop in Tanzania after maize and sorghum (Mghase *et al.*, 2009). In terms of food value, the crop ranks second after maize. Rice can be grown in a wide range of soil conditions from flooded to dry land fields and on hilly terraced to non-terraced landscapes. In Tanzania, rice is extensively grown in the lowlands of the Southern Highland Zone, Mwanza, Shinyanga, Manyara, Kilimanjaro, Morogoro and Coast regions. The majority of farmers who grow rice in Morogoro Region, prefer the traditional cultivars such as *Shingo ya mwali*, *Tule na bwana*, *Mbawa mbili*, *Kaniki*, *Afaa*, *Kahogo*, *Sindano* and *Kilombero (SuperIndia)*. These varieties are aromatic and have good milling and cooking qualities (Kalagho, 2013), but are genetically low yielding compared to the improved varieties such as TXD 306 (Kalagho, 2013). The yields of the aforementioned traditional or local varieties range between 2.5-4  $\text{tha}^{-1}$  compared to 8-10  $\text{tha}^{-1}$  for TXD 306 (SARO 5) variety (Ceesay, 2004).

It has been reported that, in spite of the efforts on the part of researchers and the Government of Tanzania to increase rice yields, the average yield of rice like SARO 5 is still lower than its genetic potential of 10  $\text{tha}^{-1}$  (Ceesay, 2004). There are a number of factors contributing to the low rice yields; namely deficiencies of nutrients especially N and P, improper nutrient management and pests and disease control, growing of poor quality seeds, poor soil water management, use of old seedlings ( $\geq 27$  days old) as well as inappropriate traditional transplanting methods (Ceesay, 2004). Inherent factors such as rainfall, temperature and soil conditions such as soil moisture, aeration (oxygen levels), pH and salt content affect the rate of nutrient uptake and the use efficiency of N and P by

the rice plants (Ahmad, 1992). For optimum rice production, it is mandatory to establish the optimum doses of N and P and uptake efficiencies as well as their influence on the components of yields (Tanaka *et al.*, 1964).

Dakawa Irrigation Scheme (DIS) has the potential area of 3000 ha for rice production, but only 2000 ha have been developed for rice production due to lack of appropriate infrastructure for irrigation. The soils of DIS are predominantly clayey and the water used for irrigation is of good quality. Both the soils and water favour rice production and the majority of the farmers capitalize on these qualities, but the yields obtained by the farmers are still very low due to low fertility status of the soils. Supplementation of nutrients like N and P is highly recommended.

The paddy crop requires more water compared to other cereals (O'Toole, 2004) like maize, hence adequate soil water throughout the active growing period is a must. In addition, the Principles of System of Rice Production Intensification (PSRPI) that integrates the aspects of water management, use of good quality rice seeds, transplanting young rice seedlings (8-12days old), mechanical weed control, appropriate spacing (25cmx25cm) and single seedling per hill (Roshan *et al.*, 2011) have to be given due consideration. However, in the adoption of the PSRPI aimed at attaining high yields, the appropriate rice varieties to be grown have to be taken onboard.

Efforts by the Government of Tanzania to establish irrigation and intensive system of TXD 306 rice variety production have increased yields from an average of 3.25 to 6  $\text{tha}^{-1}$  (Thiyagarajan and Gujja, 2013) which is still below its yield potential under optimum growing conditions. The main constraints to achieve the optimum potential yield of the TXD 306 rice variety at DIS could be attributed to the low fertility status of the soils and

application rates of the deficient plant nutrient elements like N and P that are below the nutrient requirement by TXD 306 rice variety for optimal yields. The proper dosage of N and P for TXD 306 rice at DIS can be achieved by conducting on site experiments. Therefore, the application of the appropriate nutrients from various sources as well as their management in the soil ecosystem is highly recommended for increased and sustainable production of the TXD 306 rice variety at the DIS. To improve rice productivity, adoption of high yielding varieties is crucial. Yields of rice varieties like TXD 306 are very low in most areas of Morogoro Region and particularly at DIS due to a combination of soil, climate and agronomic factors. N and P have been reported as the most limiting plant nutrients at the DIS. Currently, there are no established nutrient rates for the rice variety SARO 5 (TXD 306) at DIS, that have critically addressed the nutrient requirement particularly N and P, their use efficiencies and the cost-value ratios of the N and P applied (Abdul *et al.*, 2006). Therefore, this study serves as a guide for establishing N and P rates for SARO 5 at the DIS.

The purpose of the proposed study was to assess the response of the TXD 306 rice variety to N and P and consequently establish the optimal economic N and P rates for the rice variety TXD 306.

The overall objective of the proposed study was to increase yields of the rice variety TXD 306 through the establishment of the appropriate N and P application rates.

The specific objectives were:-

- i. To carry out detailed and comprehensive pedological and soil fertility characterization of the study area.
- ii. To assess of the response of TXD 306 rice variety to N and P in one of the dominant soils at DIS.
- iii. To determine of the optimum levels of N and P for TXD 306 rice.

## CHAPTER TWO

### 2.0 LITERATURE REVIEW

#### 2.1 Origin of Rice

*Oryza sativa* (Asian rice) or *Oryza glaberrima* (African rice) is one of the major cereal crops in the world. The two species fall under two subspecies which are *Japonica* and *Indica*. Several rice varieties have been developed from these two species whereby short grain and long grain rice represent *japonica* and *indica*, respectively (Carpenter, 1978). Rice production originated in China in the late stone age (about 3000 BC) and in about 500 BC spread to other countries such as Sri Lanka and India (Lihui *et al.*, 2005). In West Africa *O. glaberrima* was partly replaced by *Oryza sativa* varieties as from the 15<sup>th</sup> century onwards due to its high yielding ability and was then grown worldwide (Grist, 1986). In East Africa, *Oryza sativa* might have been introduced by traders from Sri Lanka and India through Oman to Somalia and finally to Zanzibar and Kilwa about 200 years ago (Carpenter, 1978).

#### 2.2 Importance of Rice

In Tanzania, rice is a major staple food and a mainstay for the urban and rural populations in the rice-producing areas. It is mainly cultivated by small scale farmers in holdings of less than one hectare. Rice is also a wage commodity for workers in the cash crop or non-agricultural sectors. It provides employment opportunities through labour, machines for cultivation and irrigation, transportation of paddy from the fields to the milling machines and rice from milling machines to the markets (Reuben, 2003).

### **2.2.1 Nutritional Attributes of Rice**

Rice is a good source of carbohydrate (Denny, 1998). In different areas of the world, rice is usually cooked by boiling or steaming to make it soft. It can be eaten plain or with a sauce of vegetables, meat or fish, or sweetened and baked into rice pudding (Denny, 1998). It is also crushed into powder which can be used to make rice noodles (Denny, 1998). In Japan rice is eaten in each of the three meals of the day (Yoshizawa, 1995). It is also made into an alcohol known as “sake” (similar to wine), which is typically served during meals at dinner parties and especially at celebrations such as weddings and birthdays (Yoshizawa, 1995).

In West Africa, rice bread, rice cake, and rice porridge are used at ceremonies such as funerals and weddings (Denny, 1998). Some “old” rice varieties (most likely *O. glaberrima*) are used in traditional religious ceremonies, while certain parts of some of the rice varieties are used as medicines in the traditional treatment of some diseases. Few examples of the diseases treated by rice are chronic constipation, heart burn, swells and skin blemishes, nausea, diarrhoea, stomach upset and ingestion (Umadevi *et al.*, 2012).

### **2.2.2 Economic Attributes of Rice**

Rice is also grown as a cash crop. Thailand is the world's major rice producer as a cash crop, exporting on an average 8 million tons of rice annually followed by Vietnam and India exporting a total of 7 million tons (FAO, 2008). A positive trade balance for rice has been maintained by Asia, Australia and the United States while Latin America, Africa, and Europe are net importers of rice because production is low in the respective continents (Pasquin and Witt, 2006).

### 2.3 Rice Production and Consumption Statistics

Worldwide rice production has increased steadily from about 200 million tonnes of paddy rice in 1960 to over 678 million tonnes in 2009 (FAO, 2013). The production increases are attributed to both the intensification of the rice production systems through the use of improved rice varieties, close spacing, use of fertilizers and extensification attributed to increased area under rice production (FAO, 2008; Mghase *et al.*, 2010 and Minot, 2010). The three largest producers of rice in 2009 were China (197 million tonnes), India (131 million tonnes) and Indonesia (64 million tonnes) (Shahidur *et al.*, 2008). As of 2009, world consumption of rice was 354,603 million metric tonnes and the largest consumers were China 29.4% and India 23.3% of the total world rice consumption (FAO, 2012). In Tanzania the total area under rice production is about 618,000 ha which is equivalent to 18% of the total area cultivated in the country (RLDC, 2009), where a total of 818,000 tonnes of rice are harvested making an average yield of 1.3 tonnes ha<sup>-1</sup> (FAO, 2008). Kibanda (2008) and Mghase *et al.* (2010) reported that the annual per capita consumption of rice in Tanzania is roughly 25 to 30kg accounting for 8% of the caloric intake among the Tanzanian population making rice the third most important source of calories after maize (33%) and cassava (15%) (FAO, 2008).

### 2.4 Growth Requirements of Rice

#### 2.4.1 Soils

Rice can be grown in all types of soils ranging from light soils (Regosols) to heavy soils (Vertisols), except in very sandy soils (White *et al.*, 1997). Clay soils are the most suitable for rice cultivation due to their high water retention capacities (Brady and Weil, 2008). Slightly acid soils of pH 6 to 7 are the most suitable for paddy cultivation, but some rice varieties like CSR27, NERICA 2 and IR 56 have been found to perform well in a

widerange of soil pH values from 4 to 8, attributed to breeding (Fageria and Zimmermann, 1996).

#### **2.4.2 Climate**

Rice is widely grown and distributed in the tropical regions where rainfall intensities are high, ranging from 1400 to 1800mmper annum (Yoshida, 1983). Rainfall hence soil moisture isthe critical determinant of rice productivity in upland areas where irrigation is not practiced or common (Beale, 2004).Development of rice at different growth stages depends on air, temperature, water and light. Low air temperature below 20<sup>0</sup>C interferes with the growth as it slows down the activities of the enzymes and hormones responsible forgrowth (Wopereis *et al.*, 1996) while higher temperatures above 35<sup>0</sup>C during panicle development and flowering stage contribute to spikelet sterility (Fageria *et al.*, 2008). The reproductive stage is the most critical stage for drought stress during the crop growth cycle, because of its strong impact on yield and seed quality. Moreover, drought stress affects crop growth performance by reducing grain yield and all other yield components (Fageria *et al.*, 2008).

#### **2.4.3 Nutrient Requirement by Rice**

High yielding rice varieties including hybrids have been introduced in many countries to increase food grain production. The essential nutrient elementspecially N and P requiredby hybrid rice is high, but most often fertilizersare recommended without evaluating the soil nutrient status or the yield potentials of the varieties in question (Pattanayak *et al.*,2008). The result is inadequate and unbalanced fertilization leading to low yields that are much lower than the expected achievable yield of 5to 7tha<sup>-1</sup> for the hybrids(Thiyagarajan and Gujja, 2013).

### 2.4.3.1 N Requirement by Rice

Tanaka *et al.* (1964) observed that the productive tillers, panicle length and number of filled grains per panicle increase with increase in N supply to the plant. However, significant increases were observed only for panicle length and number of filled grains per panicle up to 120 kgNha<sup>-1</sup> (Tanaka *et al.*, 1964). The number of panicles are associated with the extent of tiller production which is the most important yield limiting plant factor in rice (Ahmad *et al.*, 2007). It has been reported that nitrogen concentrations in grain increased significantly with increased nitrogen application levels from 90 to 120 kgN ha<sup>-1</sup> (Patro *et al.*, 2011). Perez *et al.* (1996) reported yield increases of rice of up to 5.8 and 6.3 tha<sup>-1</sup> for two rice varieties namely IR58185 and IR64616H, respectively in Philippines when 110 kgNha<sup>-1</sup> were applied. This was attributed to the high number of effective tillers, total spikelets and grains per panicle (Uddin *et al.*, 2013). Robert *et al.* (2010) also recorded optimum level of nitrogen for rice production between 150 and 168 kgN ha<sup>-1</sup> application rate which gave yields of 8.2 and 8.7 tha<sup>-1</sup>, respectively. For soils with high native N, the rice crop is able to optimize yield with significantly less N fertilizers by utilizing the N being supplied by the soils (Uddin *et al.*, 2013). Mnguu (1997) reported a similar trend of N application increments from 0 to 200 kgNha<sup>-1</sup> where 4 tonnesha<sup>-1</sup> in the control plot and 8.3 tonnesha<sup>-1</sup> when 200 Nkgha<sup>-1</sup> applied were realized. Semoka and Shenkalwa (1985) also recorded the highest rice dry matter and grain yield in a greenhouse experiment using Dakawa soil at 200 mgNkg<sup>-1</sup> equivalent to 400 kgNha<sup>-1</sup>. A significant increase in yield was attained when more N fertilizer was applied to supplement N in the soil (Jones *et al.*, 1982).



### **2.4.3.1.1 Symptoms of N Deficiency in Rice**

Many nutrient deficiency symptoms look similar because they interfere with the crop plant developmental processes. It is important to know the appearance of plant species when it is healthy in order to recognize symptoms of distress. For example some plants were bred to have variegated patterns in the leaves when they are healthy, which are the symptoms of N deficiency in plant (Dobermann and Fairhurst, 2000). Rice plants with N deficiency tend to exhibit chlorosis, stunted appearance, thin spindly stems, low protein contents and high sugar contents (Mghase *et al.*, 2010). All these contribute to poor performance of the plant attributed to the interferences of the metabolic processes hence low yields. The same symptoms may be observed when the plant is under sulphur deficiency (Mghase *et al.*, 2011). However, N deficiency symptoms occur near the bottom of the plant while S deficiency symptoms are found near the top (Mghase *et al.*, 2010). The minus one technique for the identification of nutrient deficiencies (Dobermann and Fairhurst, 2000) could serve as a guide for the assessment of N deficiency symptoms. The manifestation of N deficiency symptoms is a consequence of the antagonistic effects of the interactions of N and other nutrients on the metabolic processes in the rice plant.

### **2.4.3.2 Phosphorus Requirement by Rice**

Phosphorus (P) is a major macronutrient required for rice growth and development (Marschner, 1995). In addition to the P essential role in energy transfer and metabolic regulation, it is also an important structural constituent of many molecules such as nucleotides, phospholipids and sugar phosphates (Lim *et al.*, 2003). It has been reported that inorganic phosphates ( $\text{H}_2\text{PO}_4^{1-}$ ,  $\text{HPO}_4^{2-}$  and  $\text{PO}_4^{3-}$ ) are the primary sources of P in the soil and are the major forms of P which are actively absorbed by plants. The concentrations of the aforementioned phosphate ionic species in soils are dependent on the soil reactions

as manifested by the soil pH. At soil pH values below 6 and above 7.5, the concentrations and mobilities of phosphate in the soil are lower than those for the other major nutrients (Clarkson and Lüttge, 1991). Therefore, P availability is often limited in soils particularly in acid and alkaline soils because of the strong adsorption of P by the soil colloids, precipitation of insoluble  $\text{AlPO}_4$  and  $\text{FePO}_4$  and  $\text{Ca}_3(\text{PO}_4)_2$ , respectively. Phosphates are often classified as acid or alkaline (Vincent *et al.*, 1992; Marschner, 1995), depending on the ionic species produced during their dissolution and ionization processes.

Proper P nutrition is critical for attaining optimum rice yields, which contributes about 84% of the total food grains grown (Dobermann, 2000). It promotes vigorous, early plant growth and development with strong root systems and profuse tillering. It also enhances flowering, fruiting, and many other biochemical processes in the plant (Pattanayak *et al.*, 2008). Increase in yields of hybrid rice from 9.7 to 13.9  $\text{t ha}^{-1}$  as the P rate was increased from 25 to 100% of the recommended rate has been reported by Pattanayak *et al.* (2008), other growth factors and requirement being optimal and balanced.

#### **2.4.3.2.1 Symptoms of P Deficiency in Rice Plant**

P deficiency in rice plants is often referred to as a “hidden hunger” because its symptoms are hard to recognize unless deficient plants are directly compared to the P sufficient plants (Dobermann, 2000). The P deficiency symptoms in rice are the consequences of its low availability for plant growth and development. P affects the major functions in energy storage and transfer in plants (Marschner, 1995). In rice, common symptoms of P deficiency include retarded growth and development, reduced number of leaves, tillering, panicles and grain weights (Mghase *et al.*, 2010). Older leaves become narrow, darker, short and very erect. Maturity delays are common when P deficiency is severe, plants may not flower at

allhencecomplete grain losses (Dobermann, 2000; Dobermann and Fairhurst, 2000).Mild to moderate P deficiency symptoms are difficult to recognize in the field, but the deficiency is often associated with other nutrient disorders such as Fe toxicity at low pH as well as Zn and Fe deficiencies(Weir and Cresswell, 1993).

P deficiency is widespread in all major rice ecosystems and is the major growth limiting factor in highly weathered, clayey, acid upland soils where soil P-fixation capacity is often high for example in Ultisols and Oxisols (Dobermann, 2000).Availability of P in these soils is reduced by the reaction of soluble P with iron and aluminum oxides (Warren, 1992). Other soils particularly prone to P deficiency include sandy soils containing small amounts of organic matter and small P reserves, volcanic soils (Andisols), with high P-sorption capacity, peat soils (Histosols), and acid sulfate soils in which large amounts of active Al and Fe result in the formation of insoluble P compounds at low soil pH values (Warren, 1992).

Phosphorus (P) deficiency has been identified as one of the major limiting factors for crop production in highly weathered soils such as Oxisols and Ultisols in the tropics (Warren, 1992). Availability of P in these soils is reduced by the reaction of soluble P with iron and aluminum oxides (Mokwunye *et al.*, 1986).There are a number of ways to correct P deficiency in rice. Some of them include the use of rice cultivars that use P efficiently,replenishment of P removed in crop products by applying P fertilizers efficiently,use of farmyard manure and other materials such as compost (Hossain *et al.*, 2005).P can also be recycled by incorporatingthe rice strawin the field although the total amount of P recycled with the straw is small (1kg P t<sup>-1</sup> straw) (Zekri and Obreza,2009). This assists in maintaining a positive P balance in the soils in the long term.

### 2.4.3.2 The N and P Transformations in Soils and Interaction in Rice Production

N and P are fundamental nutrients to crop development as they form the basic component of many organic molecules, nucleic acids and proteins (Lea and Miflin, 2011). In irrigated rice systems, P fertilizer is generally applied only at the beginning of the season before or during transplanting (Hossain *et al.*, 2005). This is a common practice because P acquisition and requirement are high during the early growth stages for proper root development (Haefele and Wopereis, 2005; Hossain *et al.*, 2005). P in contrast to N is not transported with the soil solution (mass flow) but mainly by diffusion (Schachtman *et al.*, 1998). A large root surface area is therefore, particularly important for P uptake since plants gain access to a larger soil volume hence to P on the P adsorption sites (Lynch, 2007).

N in rice cultivation is applied in three splits (basal/after transplanting, maximum tillering and panicle initiation/booting (Russo *et al.*, 1991). N is mainly involved in vegetative development and preparation of the plant towards the reproductive phase. In a rice field up to two-thirds of the N absorbed by the plant is extracted from the soil, even in fertilized fields (Russo *et al.*, 1991). Therefore, natural sources of N, transformation and availability processes, markedly influence soil fertility in paddy fields and the efficiency of the fertilizer nitrogen for high yields (Moletti *et al.*, 1992).

Response of rice varieties to N in the field is generally recognized, but crop recovery of applied N is only 20 to 35% due to the losses in several ways (Ponnamperuma and Deturck, 1993). For example, nitrate in flooded soils moves into reduced soil zone where it is rapidly converted by denitrifying bacteria to  $N_2$  and  $N_2O$  gases unsuitable for the rice plant (Rich *et al.*, 2003). Denitrification is generally reported as a major reason for the low efficiency of applied ammonium fertilizers. Losses of nitrate by leaching can

also occur, especially if the submerged soil is sandy. Recent findings suggest that 15% to 45% of surface applied N fertilizers may be lost by nitrification-denitrification processes. Nitrate present in dry soil disappears within a few days after flooding (Mergel *et al.*, 2001). It was furthermore reported that ammonia volatilization may even cause losses up to 60% of urea ( $\text{CO}(\text{NH}_2)_2$ ) applied to flooded soils (Mergel *et al.*, 2001). Deep placement of  $\text{NH}_4^+$  fertilizers can reduce losses of N by denitrification and  $\text{NH}_3$  volatilization (Rich *et al.*, 2003; Rich and Myrold, 2004). In order to reduce N losses from the soil various slow-release, N fertilizers have been developed which provide a continuous and regular supply of nitrogen during the growth of the plant (Russo *et al.*, 1991). Among these fertilizers one of the best known is sulfur coated urea (SCU) (Moletti *et al.*, 1992). Other fertilizers are products of urea condensation with formaldehyde or several aldehyde types for example Isodur and Ureaform (Russo *et al.*, 1991).

Because denitrification is probably the most frequent cause of N losses in submerged soils, the use of nitrification inhibitors, like dicyandiamide (DCD), has also been recommended (Russo *et al.*, 1991). Another possibility for reducing losses and increasing N fertilizer use efficiency is splitting N application in two or three times as basal and topdressing, especially if the soil is sandy (Moletti *et al.*, 1990; 1992). The proper combination of N and P in rice field results in high rice yields. Dobermann *et al.* (1998) reported that the application of nitrogen from 50 to 180  $\text{kg ha}^{-1}$  and phosphorus from 20 to 30  $\text{kg ha}^{-1}$  significantly increased the dry matter yields at panicle initiation, grain and straw yields at harvest. N levels of 120  $\text{kg ha}^{-1}$  and P levels of 30  $\text{kg ha}^{-1}$  have been found to be the optimum doses for high yields of up to 10 tonnes of rice per hectare, other growth factors, like the supply of the other essential plant nutrients being constant and optimal. When P and N deficiency occur simultaneously leaves appear pale green with subsequent significant yield loss (Weir and Cresswell, 1993).

Jibrin *et al.* (2010) reported that the general fertilizer recommendation in rice is based on agroecological zones. For the humid forest soils, Savannah and Sudan Sahel, 60 kg N, 30-60 kg P<sub>2</sub>O<sub>5</sub> and 30 kg K<sub>2</sub>O, 60-80 kg N, 30-60 kg P<sub>2</sub>O<sub>5</sub> and 30 kg K<sub>2</sub>O and 100-120 kg N, 60 kg P<sub>2</sub>O<sub>5</sub> and 60 kg K<sub>2</sub>O per hectare, respectively have been recommended (Jibrin *et al.*, 2010). For the Sudan /Sahel, the aforementioned rates are for rice under irrigation.

## **2.5 Rice Farming and Cropping Systems**

Rice is grown in three agro - ecosystems namely rain-fed lowland (74%), rain-fed upland (20%) and irrigated lowland (6%) (Kanyeka, 1994). De Datta (1981) classified rice cultivation systems in accordance to the sources of water supply as either rain-fed or irrigated. Based on land and water management rice production systems have been classified as lowland rice and upland land rice cropping systems (De Datta, 1975).

### **2.5.1 Lowland Rice**

Rice is primarily a lowland crop because of its semi-aquatic characteristics. It is also referred to as bunded flooded rain-fed lowland rice system as determined by water availability (Kanyeka *et al.*, 1994). The flooded lowland system is widespread in the southern parts of Tanzania, where rainfall is higher than 800mm per annum and reliable (Beale, 2004). In Tanzania, of the 818,000 ha under rice production, 457,320 ha are under lowland rice production (Greig, 2009). Average yields of rice for the low land rice farming system range between 1.5 to 2 and 2.5 to 4 tonnes ha<sup>-1</sup> for rainfed and irrigated systems, respectively (MAFC, 2009).

Nitrogen use efficiency by flooded rice is less than 50% (Fageria *et al.*, 2001). The low N use efficiency of lowland rice is associated with the N loss by several processes in the soil-

plant systems. The main N loss processes are volatilization as ammonia ( $\text{NH}_3$ ), leaching loss mostly as nitrate ( $\text{NO}_3$ ), loss through denitrification ( $\text{N}_2$  and  $\text{NO}_2$ ) and soil erosion (Fageria *et al.*, 2001). Nitrogen use efficiency by crops, rice inclusive can be improved by adopting appropriate soil and plant management practices. Adequate application of N fertilizers form and methods of application are important management strategies for increased N use efficiency. Nitrogen use efficiency has been defined in various ways, but these definitions generally take into account the quantity of N accumulated in the plant, known as uptake efficiency and quantity of N utilized in grain production known as utilization efficiency (Mergel *et al.*, 2001).

### **2.5.2 Upland Rice**

De Datta (1975) defined upland rice as dry land rice grown on both levelled and sloping fields that are not banded, prepared and seeded under dry conditions. The major source of moisture in this system of growing rice is generally the natural precipitation. Upland rice is grown under a wide range of management intensities and systems, varying from shifting cultivation to permanent cultivation (De Datta, 1975). Upland rice areas in Tanzania are common in the areas with bimodal rainfall distribution with short, low intensity rains commonly known as *vuli* starting from October to December and long heavy rains (*masika*) from March to May. Average yields of rice grown in upland areas range between 0.5 to 0.8 tonnes  $\text{ha}^{-1}$  (MAFC, 2009), which is very low compared to the FAO (1999) average yield of one tonne  $\text{ha}^{-1}$  hence concerted efforts are needed to raise the yield levels.

### **2.5.3 Irrigated Lowland Rice**

Intensive, irrigated lowland rice based cropping systems are found on alluvial floodplains, terraces, inland valleys, and deltas in Asia (Maclean *et al.*, 2002). Belder (2007) reported that, in South Asia, Southeast Asia, and East Asia, irrigated lowland rice is

dominant in the vast, flat and lowlying flood plains and deltas of many of the world's major rivers, which are flooded annually during the rainy season. Irrigated rice is grown in puddled soil in banded rice fields with one or more crops planted each year. In this system of rice cultivation, irrigation is the main water source in the dry season and is used to supplement rainfall in the wet season (Bouman *et al.*, 2007). Irrigation systems vary widely, and include; (i) individual pump irrigation from shallow tube wells (down to about 15m depth), (ii) small to medium scale community based pump irrigation from deep wells (down to 200-300m depth), (iii) small to medium scale community based surface irrigation where water is diverted from ponds or reservoirs (for example, the tank system in southern India and Sri-Lanka), (iv) small to medium scale community based surface irrigation where water directly diverted from a river (run off the river irrigation), (v) large scale surface irrigation where water is diverted from reservoirs or lakes and (vi) conjunctive groundwater surface water irrigation schemes (can be small to large scale) (Bouman *et al.*, 2007).

Irrigated rice accounts for 55% of the global harvested rice area and contributes 75% of global rice production equivalent to 410 million tonnes of rice per year (Maclean *et al.*, 2002). This is an overall average rice grain yield of about 5 tonnes ha<sup>-1</sup>. Worldwide, the total harvested area of lowland irrigated rice is about 79 million ha, with 43% (34 million ha) in East Asia (China, Taiwan, Japan, Korea), 24 million ha in South Asia, and 15 million ha in Southeast Asia (Bouman *et al.*, 2007). The countries with the largest areas of irrigated rice are China (31 million ha), India (19 million ha), Indonesia (7 million ha), and Vietnam (3 million ha) (Maclean *et al.*, 2002; Bouman *et al.*, 2007).

The major irrigated rice cropping systems are double and triple crop monoculture rice in the tropics and rice - wheat rotations in the subtropics (Dawe *et al.*, 2004). Together, they cover



a land area of 36 million ha in Asia and account for 50% of global rice production (Timsina and Connor, 2001). For most irrigated lowland rice, land is planted to modern semi-dwarf *indica* and *japonica* varieties, which have a large yield potential and respond well to N fertilizer (Singh *et al.*, 2002; Nguyen *et al.*, 2008). In China, hybrid rice varieties are used in more than 50% of the irrigated rice area, and yields are about 10-15% higher than for the conventional rice varieties (Singh *et al.*, 2002).

## **2.6 Rice Production Constraints**

### **2.6.1 Pests and Diseases**

Rice pests are organisms or microbes with the potential of reducing the yield or value of the rice crop or rice seeds (Jahn *et al.*, 2007). Rice pests include weeds, nematodes, rodents, and birds. A few examples include wild rice and *Ipomea* spp., army worms and leaf hoppers as well as *qwelea qwelea*. There are a number of factors contributing to pest outbreaks which include climatic factors, improper irrigation and application of high doses of nitrogen fertilizer and inappropriate soil and land management practices (Jahn *et al.*, 2005). In high rainfall areas early in the wet season, the rice gall midge and army worm outbreaks are common because their larva feeds on cool season grasses of cereals including rice (Douangboupha *et al.*, 2006).

Common rice diseases include sheath blight, rice ragged stunt, rice yellow mottle virus (RYMV) and brown spot disease (Swain and Prasad, 1988). Several nematode species infect rice, causing diseases such as *ufra* (*Ditylenchus dipsaci*), white tip disease (*Aphelenchoides bessei*), and root knot disease (*Meloidogyne graminicola*) (Barsalote and Gapasin, 1995). Pests and disease tend to reduce the vigour of the rice plants and increase the plants susceptibility to other pests and diseases culminating into low yields (Swain and Prasad, 1988).

### 2.6.2 Climatic Conditions

The rice crop is best suited to tropical and sub-tropical humid climate but can also be grown in a variety of climates except in the extreme cold temperate zones (Peng *et al.*, 2013) and extremely arid zones. It has been pointed out that rainfall, temperature, day length and humidity are the major climatic factors that affect rice production (Peng *et al.*, 2013). Rice cultivation is possible only in areas with good rainfall, except where irrigation is practiced as the crop requires substantial amounts of water for growth. Aryals (2012) reported that rainfall of about 1400 to 1800 mm which is well distributed is required during the active growing stage of rice.

Rice being a tropical and sub-tropical plant requires fairly high temperatures, ranging from 20 to 40°C. Temperatures of 30°C during the day times and 20°C during night time are considered ideal for the rice plant growth and development (Aryals, 2012). During the ripening period of the last 35 to 45 days, adequate light is most essential (Aryals, 2012). Bright sunshine with low temperature during the ripening stage of the rice crop promotes or enhances the synthesis of carbohydrates in the grains (Peng *et al.*, 2013). The effect of solar radiation is more profound where water, temperature and nitrogen are not limiting (Aryals, 2012).

### 2.6.3 Rice Varieties

The rice varieties grown in Tanzania are grouped into local or traditional and improved varieties. Some of the local varieties are *Karamata*, *Kilombero*, *Mbawambili*, *Kahogo*, *Afaa*, *Sindano* and *Kaniki* whereas TXD 306, NERICA, Africa Rice, and Kyela 2011 are the improved varieties (Tusekelege *et al.*, 2014). The two groups differ in terms of their yield potentials, disease and drought tolerance, aroma, milling quality and maturation.

Most of the local varieties have low yield, good aroma, delayed maturation and susceptible to diseases for example *karamata*, *kahogo* and *mbawambili*. The improved varieties for example TXD 306 and NERICA are high yielding varieties and also resistant to diseases and drought (Kalagho, 2013).

Rice varieties such as NERICA 1,2,4,7, WAB-12-2, WAB450, BL1 and DV4 perform well in dry areas including Shinyanga, Musoma, Ifakara and Dodoma (Kalagho,2013). Water consumption by these varieties is very low and they produce  $\geq 3.5$  tons per hectare compared to the traditional varieties which can only produce 0.5 to 1.0 tons per hectare (Mongi - Henday, 2002). TXD 306 yields up to  $10\text{tha}^{-1}$  if properly managed in the same environment compared to the local variety yield of  $4\text{tha}^{-1}$  (Tusekelege *et al.*, 2014). Thiyagarajan and Gujja (2013) and Ceesay (2004) reported that, SARO is a potential variety in terms of yield although there is no agronomic package supporting this potential yield like for example the optimum rates of N and P which are the major nutrients limiting rice production, because of their inherent low contents in and availability from soils.

#### **2.6.4 Agronomic Factors**

There are several agronomic factors which affect the rice production process in Tanzania. These include land preparation, availability of improved seeds, soil fertility, diseases and insect pest management, insufficient knowledge on proper doses of fertilizers to be applied, time of planting and fertilizer application (Cassman, 1996). Most of the farming activities are done by traditional tools such as hand hoes, machetes and bush knives or commonly known as *panga* for land clearing and cultivation. Also sickles, knives and snail shells for harvesting rice are used in the traditional rice cultivation systems (Mghase *et al.*, 2010). It has further been reported that the use and application of fertilizers and

manure in rice production is very low. For example in Tanzania only 15% and 20% of farmers use fertilizers and manures respectively, in crop production, rice inclusive (Mghase *et al.*, 2010). The low use of fertilizers is attributed to their high prices whenever available hence not affordable to the small scale farmers who are the majority in rice cultivation in Tanzania. In addition, the number of livestock kept in the area under rice cultivation is very small and therefore can not produce enough manure for use in intensive rice production.

#### **2.6.5 Socio-economic Factors**

Low rice productivity is the result of a number of socio-economic factors such as lack of capital, low levels of education, technology adoption, labour shortage, diseases such as HIV and Malaria, irrigation systems and lack of reliable markets for the rice produce, small sizes of the fields and land ownership (Mghase *et al.*, 2009). In most of the rice producing areas, land ownership rights are not secured under emerging individualized tenure. Farmers who undertake long-term investments may not be able to win the future benefits due to inability to give the property to desired beneficiaries or to sell the land freely if the need arises. In this way, efficient farm management is hampered by tenure insecurity (Besley, 1995). Furthermore, farmers are unable to abandon their traditional networks which were granted on kin, neighbourhood and friendship relations. However, social and economic development has improved rural lifestyles but this has resulted in a lack of need for the social capital represented by those traditional relationships, especially for the rice farming practice (Tuan, 2009) hence contributing to low rice production.

## 2.7 Rice Response to Soil Amendments

### 2.7.1 Nutrient Applications

Most arable lands are not optimally productive due to deficiencies of certain plant nutrients and nutrient imbalances in soils associated with the chemical and biological equilibria in the soils. Nitrogen and phosphorus as primary macronutrients are the most limiting nutrients in rice producing areas. Calcium (Ca), magnesium (Mg) and sulphur (S) are also central in rice production (Imran and Gurmani, 2011). Other nutrients that are required by rice in small amounts (micro-nutrients) and central to rice production include zinc (Zn), boron (B) and molybdenum (Mo) (Belfield and Brown, 2008).

Both macro and micro nutrients taken up by rice plants originate from the organic and inorganic sources in the soil (Samonte *et al.*, 2006). Inorganic fertilizers like  $(\text{CO}(\text{NH}_2)_2)$  and  $\text{Ca}(\text{H}_2\text{PO}_4)_2$  contain high quantities of the essential nutrients namely N and P, respectively than the organic soil amendments like farmyard and compost manure (Samonte *et al.*, 2006). The rate of release of nutrients from inorganic sources is far much higher than from organic sources (Ceesay, 2004) due to the occurrence of the N and P in the later in complex forms. Therefore the nature, quantity and timing of soil amendment like fertilizer and manure applications are very crucial in rice production.

### 2.7.2 Microdosing Fertilizer Application Technology

Fertilizer microdosing is the localized placement of small amounts of mineral fertilizer (4 grams of TSP) in the planting hole at sowing, or at the base of newly emerged plants, instead of spreading fertilizers evenly across the field (Abdoulaye *et al.*, 2014). In hard soils, farmers open small holes before the rain starts, then fill them with manure if available. When rains begin, the water is captured instead of running off over the hard (compacted) soils. They put the fertilizer and seeds in the hole where the soil provide a

moist environment hence encouraging root growth. Farmers who use the microdosing technology apply 6 gram doses of fertilizer about a full bottle cap or a three-finger pinch in the hole where the seed is placed (at the time of planting) (Abdoulaye *et al.*, 2014). This technique uses only about one-tenth of the amount typically used on wheat, and one-twentieth of the amount used on corn in the USA. In the Sahel region, microdosing technique has proven to be the most efficient fertilizer use and ultimately improves productivity in maize, sorghum and legumes (Chauhan, 2006). Furthermore, in Western Africa about 25,000 smallholder farmers in Mali, Burkina Faso, and Niger have adopted the technique and obtained increases in sorghum and millet yields of 44 to 120%, along with an increase in their family incomes of 50 to 130%. Combining microdosing with rainwater harvesting is a good option in the Sahel, with the potential to substantially increase yields by 25 to 50% in rainfed legumes and cereal translating to an increase of about 50 to 130% of their family income (Chauhan, 2006). Hence the technique has shown great effect on food security. The microdosing fertilizer placement technology could also be adopted in rice cropping and farming systems.

Although the results have shown consistent yield increases, farmers have reported that microdosing is time consuming, laborious and difficult to ensure that each plant gets the right dose of fertilizer. In an attempt to address these issues, researchers are looking at packaging the correct dose of fertilizer as a tablet that aids in application. ICRISAT is also exploring the use of seed coating as another option of further reducing the quantity of fertilizer to be used as well as the labor constraint (Chauhan, 2006).

Several factors have been identified as major constraints to the widespread adoption of microdose technology. These include access to fertilizer, access to credit, insufficient flows of information and training to farmers, and inappropriate policies (Abdoulaye *et*

*al.*,2014). Experiences from both West and Southern Africa have shown that adoption of microdose technology requires supportive and complementary institutional innovation as well as input and output market linkages (Chauhan, 2006).

## **2.8 Pedological Characterisation in Relation to Plant Nutrient Recommendations**

Pedological characterization provides valuable information and knowledge on soil characteristics and gives clear understanding on soil genesis, morphology, classification and spatial distribution of soils in an area (Msanya, 2003; Kebeney *et al.*,2014). Soil information gathered by systematic identification, grouping and delineation of different soils is required when sound interpretations towards land use potentials are to be made (Msanya *et al.*, 2003). Thus, knowledge of site soil physical and chemical properties with other ecological conditions would aid in determining the correct type and amounts of fertilizer to be applied for optimum crop production and enhance improvement of soil fertility (Msanya, 2003). Soil fertility specialists need well characterized sites with similar soil and other ecological conditions in order to carry out meaningful fertilizer trials. There is also a strong feeling that fertilizer trials should be conducted on well characterized soils to enhance transferability of information from one place to another (Msanya *et al.*,2003; Kebeney *et al.*,2014).

### **2.8.1 Importance of the Pedological Characterisation in Crop Production**

Pedological information is important to land users especially farmers who use the data to make decisions on what crops and management practices are best suited for the optimal and sustainable production of crops including rice. According to Breimer *et al.* (1986), pedological studies provide a better understanding of spatial changes in the characteristics of the soil continuum so that soils may be used more efficiently for the benefit of mankind. In ecological studies, soil and land resource surveys provide geographical information or spatial

soils information which can be used to correlate with vegetation data to obtain more complex picture of a given ecosystem (Breimer *et al.*, 1986). Generally, the role of pedological characterisation is the application of soil science skills to clearly understand the genesis, morphology, types and spatial distribution of the soils in a given locality.

### **2.8.2 Soil Characteristics and Plant Nutrients Availability**

Plant nutrients in soils originated from the parent materials from which the soils were formed through the weathering of rocks and minerals (Agricultural Research Council, 2009). Plants obtain most of their nutrients and water from the soil through their root systems. Any factor that restricts root growth and activity has the potential to restrict nutrient availability even though the nutrients are available in the soil. These soil factors that can restrict ability of crop to absorb nutrients include soil compaction and soil moisture regime (Harvlin *et al.*, 2005). Understanding these factors that cause nutrient deficiency in crops is important to avoid the need for excessive fertilization beyond what is recommended (Harvlin *et al.*, 2005).

### **2.8.3 Influence of Soil Forming Factors on Soil Fertility**

The soil is a natural body, differentiated into horizons of mineral and organic constituents, usually unconsolidated, of variable depth, which differs from the parent material below in morphology, physical properties and constitution, chemical properties and composition, and biological characteristics. The soil forming factors include parent materials, climate, topography, vegetation, and time, which interact to form different soil types with different physical and chemical properties. According to Moustakas and Georgoulas (2005) the relative influence of each factor varies from place to place, but the combination of all five factors normally determines the kind of soil developing in a given location. Soil fertility is greatly influenced by these factors of soil formation. Nutrients are being continually



removed from minerals and rocks (parent materials), and added to the soil over time. The conditions of soil formation ultimately determine the amount and kind of nutrients the soil can naturally supply and hold.

### **2.8.3.1 Parent Material**

Parent material of a soil is the unconsolidated rock, mineral or organic matter in which soils are developing. It determines the mineralogical composition and contributes largely to the physical and chemical characteristics of the soil (Msanya, 2003). The type of parent material and how the soil is formed greatly influence the properties of the soil, for example, finely textured parent materials tend to weather into finely textured soils (Spector, 2001) while coarse textured parent materials tend to weather into coarsely textured soils. Basalt rock is finely textured and comprised of small crystals which cooled rapidly along the surface of the earth. Consequently the soil formed from weathered basalt tends to be finely textured, as well as fertile. In contrast to basalt, granite is coarse-textured rock that generally weathers into coarse-textured soils with low fertility.

Rocks of different origin, petrographic and mineralogical composition gives rise to different parent materials hence variation on nutrient contents (Spector, 2001). Also the type of parent material determines which minerals will predominate in the soil. Soils derived from ferromagnesian minerals such as olivine, pyroxene, forsterite, amphibole and biotite are rich in iron and magnesium and potassium (Msanya *et al.*, 2001). On the other hand soils derived from non-ferromagnesian (do not contain Fe and magnesium) minerals such as quartzs, feldspars, muscovites and plagioclase are rich in Na, Ca and K nutrients (Msanya *et al.*, 2001; Van Straaten, 2002).

### **2.8.3.2 Climate**

Climate is a fundamental force of weathering that interacts with all other soil forming factors. Climate, particularly temperature, precipitation and frost action have a profound influence on the soil formation processes through its effect on the nature (physical or chemical) and rates of the weathering processes, and the type of vegetation in an area, and extent of accumulation of soil organic matter (Msanya *et al.*, 2001). Warm and moist climates promote rapid plant growth and thus high organic matter production unlike cold and dry climates. Organic matter decomposition is also accelerated in warm and moist climates than in cold and dry climates (Meliyo, 1997). Through freezing, thawing, wetting and drying, the parent rock is broken apart. The nutrients released from primary minerals during weathering in high precipitation and temperature areas, can be removed or leached from the soil and transported deeper into the soil hence reduce its fertility. Soils of arid and semi-arid areas tend to have lower clay content, high pH, high base saturation and low soil fertility status and lower biomass productivity than humid region soils which have higher clay content, low pH, low base saturation and low soil fertility status and greater biomass productivity than arid region soils (Foth, 1984).

### **2.8.3.3 Topography**

Topography modifies the water relationships in soils and influences soil erosion to a considerable extent. The shape of the land surface, its slope and position on the landscape, greatly influence the kinds of soils formed. Soils that have formed in similar parent materials with the same climatic conditions differ as a result of their position on the landscape. These differences are largely a result of varying drainage conditions due to surface runoff or depth to water table. Soils that are developed on higher elevations and sloping areas are excessively drained or well drained (Spector, 2001). Soil profiles within

these areas commonly have a bright colored strong brown to yellowish brown upper solum grading to a lighter, grayer, unweathered substratum (Brady, 2008).

Soils that occur at lower elevations adjacent to drainage-ways and water bodies and within depressions generally receive surface runoff from higher elevations and often have a seasonal high water table at a shallow depth (Foth, 1984). Soil profiles within moderately well drained and poorly drained areas are mottled with irregular spots of brown, yellow and grey colors. In very poorly drained areas, where the water table is at or near the surface for prolonged periods, soil profiles characteristically have a dark-colored organic or organic rich surface layer underlain by a strongly mottled or gleyed (gray color indicating a reduced condition) subsoil and substratum (Brady, 2008). Therefore permeability of the soil material as well as the length, steepness, and configuration of the slopes, influence the kind of soil that is formed in an area.

#### **2.8.3.4 Soil Organisms**

Soil organisms are considered as one of the factor of soil formation because microorganisms (algae, bacteria, fungi), earthworms, and burrowing animals have directly been observed to influence soil development (Huang and Keller, 1972). The soil biotic community's processes including decomposition, nutrient cycling, soil organic matter formation and mineralization, soil aggregation, regulation of atmospheric trace gases and the biological control of soil-borne plant and animal pests and diseases are essential for soil formation and environmental soil services (Turco and Blume, 1999). The role of soil organisms in a range of essential ecosystem functions is well established, though it is not clear at what level of diversity is necessary to maintain these functions. Therefore the soil formation and development, fertility and quality depend on the biotic component (Carter, 2001).

### 2.8.3.5 Time

Soils change over time due to the process of evolution because soil formation is a continuous process. The formation of soils generally takes several thousand years for significant changes in physical and chemical properties to take place through the weathering process (Baba *et al.*, 2008). The relatively young soils with slight alteration of parent material and weak soil horizon development include Inceptisols, Entisols and Spodosols. The age of a soil is generally considered to be the length of time in years since the land surface became relatively stable, thus enabling soil development to proceed. The length of time required for a soil to form depends on the intensity of the other active soil forming factors of climate and organisms, and how topography and parent material modify their effects (Baba *et al.*, 2008).

A given period of time may produce change in one soil and the same time period will have little effect on another soil, due to the other four soil forming factors. Thus young soils have minimal soil development and few horizons while old soils have well developed and many horizons (Brady, 2008). In general, it takes less time for surface horizons to develop than subsoil horizons. A soil is said to have reached a steady state when its individual horizons and properties change over long periods of time (Brady, 2008).

### 2.8.4 Soil Classification

Soil classification is an essential operation of soil surveys. Soil classification is defined as the systematic arrangement of soils into groups or categories based on their characteristics (Msanya, 2003). Soils are grouped on the basis of their distinctive properties into segments, classes or taxa that can be conceived at various levels of abstraction. Grouping of soils into different classes requires that soils be fitted into several levels with evident relationships based on defined criteria for each category (Beinroth, 1978). Fitting of soils in several levels is necessary because soils belong to diverse a population. The advantages

of soil classification are: (i) it identifies, organizes and names soils in an orderly fashion and it stimulates the revelation and formulation of relationships within the soil population (Beinroth, 1978). (ii)it enables soil surveyors to maintain consistency in soil surveys from place to place and (iii) soil classification serves as a base for transfer and application of soil technology package (Beinroth, 1978) for sustainable land productivity.

## CHAPTER THREE

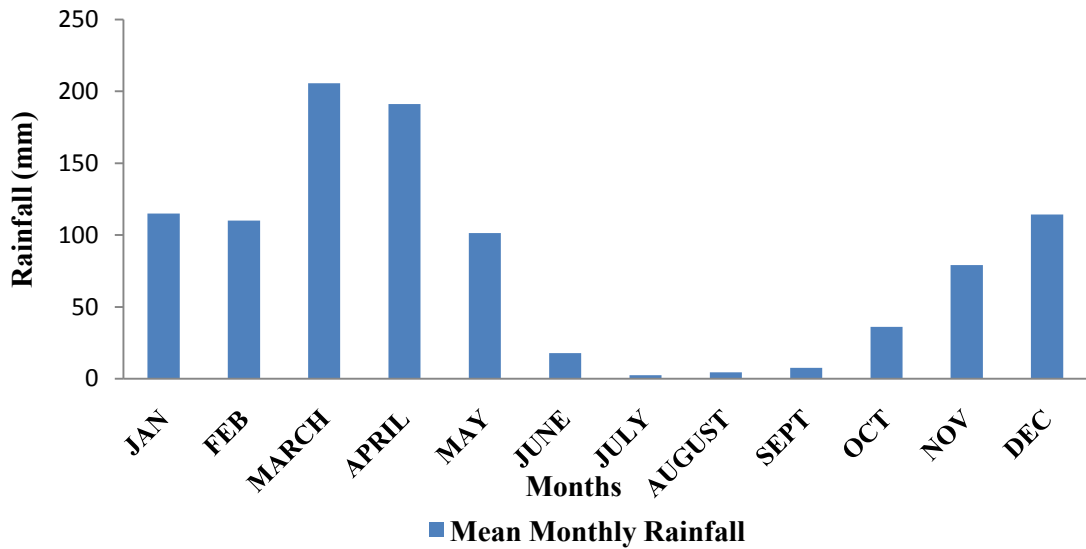
### 3.0 MATERIALS AND METHODS

#### 3.1 Description of the Study Area

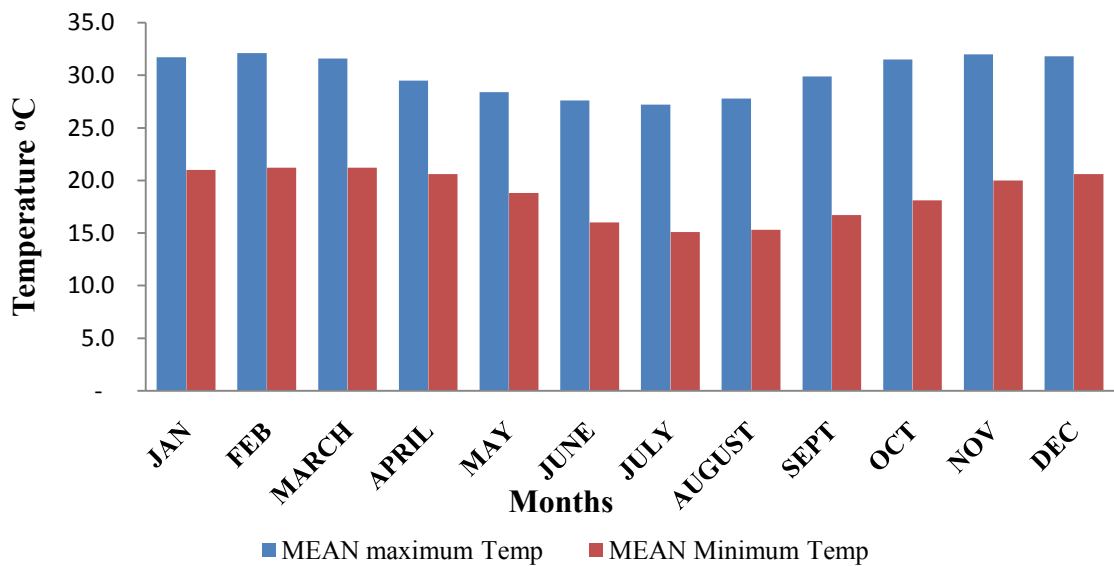
The scree house study was conducted on a Cambisol from the Dakawa Irrigation Scheme (DIS). The Scheme covers an area of 2000ha and is located in Mvomero District, Morogoro Region, Tanzania. It lies between latitude  $6^{\circ} 24'S$  and longitude  $37^{\circ} 33'E$ . It is about 45 km from Morogoro town, 7 km north east of Wami - Dakawa village and north - west of the Wami River. The area is almost flat with a very slight slope ranging from 0 - 1 percent, towards the east - north of the scheme area. The soils of DIS originated from alluvium derived from neogene rocks of the Mnguu mountains. Annual rainfall ranges between 580 mm and 1191 mm (Appendix 1). The rainfall distribution is bimodal with the short rains in October to January and the long rains in March to May (Figure 1). The long rains ranging between 74 mm to 410 mm are the most reliable for crop production compared to the short rain (50 mm to 387 mm). Seasonal variations in temperature at Dakawa are minimal with an average monthly maximum ranging between  $22^{\circ}C$  in February to  $32^{\circ}C$  in July and the mean monthly minimum temperature ranges from  $15^{\circ}C$  to  $22^{\circ}C$  for February and July, respectively (Figure 2).

Agricultural activities at the study area are mainly irrigated rice which is grown both as a food and cash crop. Water is usually pumped from the Wami Dakawa river for irrigation. Other crops grown in the scheme area include maize, beans and green gram which are grown during the long rains without irrigation. Based on local and technical indicators of soil fertility, the soils at the DIS have been previously categorized as of low to medium fertility status (Kisetu *et al.*, 2013) hence moderately and marginally suitable for rice production. The soils in the study area are mostly clayey which retain enough water for

rice production. The major soil fertility limitations at the DIS include high soil pH and deficient levels of N and P (Semoka and Shenkalwa, 1985).



**Figure 1: Mean Monthly Rainfall at Dakawa Irrigation Scheme (2004-2014)**



**Figure 2: Mean Monthly Maximum and Minimum Temperatures at Dakawa Irrigation Scheme(2005-2014)**

### **3.2 Pedological Characterization of the Study Area**

The purpose of undertaking the pedological characterization of the soils was to establish the type of soils at the study area, that is DIS.

#### **3.2.1 Soil Profile Excavation**

Reconnaissance field survey was carried out based on transect walks, auger observations and profile descriptions to establish the soil settings at the study site on the basis of landforms and other physiographic attributes (FAO, 2006). Data and information on landform, soil morphological characteristics, elevation, slope gradient, parent material (lithology), vegetation and land use/crops were collected from different observation sites that represented the major landforms and soils identified during reconnaissance survey. The data so gathered was entered on the field description forms according to the FAO Guidelines for Soil Profile Description (FAO, 2006). Based on the information gathered during the reconnaissance survey, the extent and magnitude of soil variation was minimal, hence justified the decision to open a single profile for the classification of the soil at the study area which covers about 8ha. A representative soil profile of 2.5m by 1.5m was excavated to the depth of 2m. The soil horizons were identified, demarcated, described and sampled according to FAO Guidelines for Soil Profile Description (FAO, 2006).

#### **3.2.2 Soil Sampling from the Profile**

Disturbed samples were taken from each of the horizon identified for laboratory determination of physical and chemical properties of the soil at the study area. Three undisturbed samples were also taken from the profile for the determination of bulk density and soil moisture characteristics.



### 3.2.3 Soil Analysis for Soil Classification

The disturbed and undisturbed soil samples were subjected to physical and chemical analysis. For the disturbed soil samples particle size analysis was determined by the Gee and Bauder (1986) method and the textural class by USDA (1975). Soil pH was measured potentiometrically in water and 1 M KCl at a ratio of 1:2:5 soil-water and soil-KCl suspensions (McLean, 1986). Organic carbon was determined by the wet oxidation method (Nelson and Sommers, 1982) and the organic carbon was converted to organic matter by multiplying by a factor of 1.724 (Duursma and Dawson, 1981). Total nitrogen was determined by the micro-Kjeldahl digestion – distillation method (Bremner and Mulvaney, 1982). Available P was determined by the Olsen method (Shio, 1996). Cation exchange capacity ( $CEC_{soil}$ ) was determined by the neutral buffered 1M ammonium acetate saturation method (Sommers and Miller, 1996). Cation exchange capacity of clay ( $CEC_{clay}$ ) was calculated using the formula outlined by Baize (1993) as follows:

$$CEC_{clay} = \{CEC_{soil} - (\% OM * 2)\} / \% clay * 100.$$

$Ca^{2+}$  and  $Mg^{2+}$  and  $K^+$  and  $Na^+$  in the ammonium acetate filtrates were quantified by Atomic Absorption Spectrophotometer and the flame photometer, respectively. Total exchangeable bases (TEB) were calculated arithmetically as sum of the four exchangeable bases ( $Ca^{2+}$ ,  $Mg^{2+}$ ,  $Na^+$  and  $K^+$ ) for a given soil sample. Formulas used for the calculation of sodium adsorption ratio, exchangeable sodium percent and base saturation were as given by Landon (1991). Plant extractable Cu, Zn, Fe and Mn were extracted by the DTPA method (Lindsay and Norvell, 1978). The electrical conductivity was determined in 1:2:5 soil:water suspensions, electrometrically (potentiometrically) using the electric conductivity meter (Rhoades, 1996).

The undisturbed soil samples were used to determine bulk density and the soil moisture characteristics. The bulk density was determined by the core method (Black and Hartge, 1986). Soil moisture retention characteristics was determined using sand kaolin box for low suction values and pressure apparatus for higher suction values National Soil Service (NSS, 1990).

#### **3.2.4 Classification of Soils**

Based on field and laboratory data, the soil at the study area was classified to the family level of the USDA Soil Taxonomy (Soil Survey Staff, 2006) and to tier-2 of the FAO World Reference Base (FAO-WRB, 2006).

### **3.3 Soil Fertility Evaluation**

The purpose of characterizing the soil was to establish the fertility status of the soil at the study site (DIS) before conducting the screen house pot experiment. By using an auger, 30 randomly selected points from the area covering 8ha, soil sampled at the depth of 0-30cm were gathered, thoroughly mixed to constitute composite sample for the fertility evaluation. The composite sample was air dried, ground to break soil aggregates and sieved through 2mm sieve for comprehensive laboratory analysis, for soil fertility evaluation. The parameters analysed for soil fertility evaluation were; particle size distribution which was determined by the hydrometer method (Gee and Bauder, 1986) and the textural class by USDA (1975). Soil pH was determined electrometrically in 1:2.5 soil: 0.01M CaCl<sub>2</sub> suspensions (Thomas 1996), organic carbon by the wet oxidation method (Nelson and Sommers, 1982) and total nitrogen by the micro-Kjeldahl digestion – distillation method ( Bremner and Mulvaney, 1982). Available P was determined by the Olsen method (Shio, 1996). Cation exchange capacity (CEC) was determined by the

neutral buffered 1M ammonium acetate saturation method (Sommers and Miller, 1996).  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{K}^+$  and  $\text{Na}^+$  in the ammonium acetate filtrates were quantified by Atomic Absorption Spectrophotometer and flame photometer, respectively. Plant extractable Cu, Zn, Fe and Mn were extracted by the DTPA method (Lindsay and Norvell, 1978). The electrical conductivity was determined in 1:2.5 soil:water suspensions, electrometrically (potentialmetrically) using the electric conductivity meter (Rhoades, 1996).

### **3.4 Pot Experiment**

The purpose of this experiment was to assess the response of the rice variety TXD 306 to N and P application rates. The outcome was finally used to chart out the N and P fertilizers rates for TXD 306 for optimal, sustainable and economical rice production at the Dakawa Irrigation scheme.

#### **3.4.1 Soil Sampling for the Pot Experiment**

About 6 kg soil sample portions were gathered from each of the 30 identified soil sampling sites for the soil fertility evaluation (Section 3.3). The sampling depth was 0-30cm. The 30, 8kg samples were thoroughly mixed to constitute the bulk composite soil sample used in the pot experiment. The bulk composite soil sample was air dried, slightly ground and sieved through 8mm sieve.

#### **3.4.2 Rates of N and P and Design of the Experiment**

The rates of N adopted in the glasshouse pot experiment were 0, 50, 100, 150 and 200kgNha<sup>-1</sup> as (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>. The P rates were 0, 40, 80, 120 and 160kgPha<sup>-1</sup> as Ca(H<sub>2</sub>PO<sub>4</sub>)<sub>2</sub>. The rates of N and P were designated as N<sub>0</sub>, N<sub>50</sub>, N<sub>100</sub>, N<sub>150</sub> and N<sub>200</sub> and P<sub>0</sub>, P<sub>40</sub>, P<sub>80</sub>, P<sub>120</sub> and P<sub>160</sub> respectively. The design of the experiment was 5<sup>2</sup> factorial in CRBD replicated twice. The N and P treatment combinations were as presented in Appendix 2.

### **3.4.3. Setting up and Conducting the Pot Experiment**

Fifty, 3.5kg soil sample portions of the 8mm sieved bulk composite soil samples were weighed into 4 litre capacity plastic pots with holes at the bottom, to facilitate drainage of excess soil solution from the pots. The holes were loosely plugged with cotton wool to control soil loss from the pots. Plastic saucers were placed under each pot for the collection of the soil solution oozing out of the soils in the pots. The solutions were subsequently returned to the respective plastic pots.

The different P rates as TSP, were accordingly mixed with the 3.5kg soils, in the pots as per the treatment combinations, and then water was added to the soils in the pots to just above field capacity moisture content and equilibrated at field capacity moisture status for 7 days. Any solutions oozing out of the pots were returned to the respective plastic pots. After the equilibration period, 8 paddy seeds were sown in each pot then thinning was done to remain with 4 plants per pot. N fertilizer was split applied two times after sowing whereby the 1<sup>st</sup> and 2<sup>nd</sup> splits were applied at the tillering and panicle initiation growth stages, respectively. Leaching was minimized by avoiding flooding during watering. Other management practices such as pests and disease control were maintained for proper growth of plants in the pots throughout the experimental period.

### **3.5 Data Collected**

The data collected during the experiment were; number of tillers per plant, plant height, biomass yields and grain yields. Except for biomass and grain yields which were taken during harvest, number of tillers and plant height were counted during the panicle initiation stage. During harvesting the plants were cut at the soil level in the pots and dried to lower the moisture content of the seeds to 14%. Then the whole plants were weighed for the determination of biomass yields. The seeds (grains) were then detached from

the panicles and weighed for grains yield. The plant materials (straw) were ground and analysed for N and P contents based on the procedures by Okalebo *et al.* (2002). The response curves of yield Vs N and P applied were developed. The optimum rates of N and P were derived from the response data.

### **3.6 Data Analysis**

The gathered data were statistically analyzed using Genstat software and the Duncan's New Multiple Range Test was used to separate the means at ( $P < 0.05$ ).

## CHAPTER FOUR

### 4.0 RESULTS AND DISCUSSION

#### 4.1 Pedological Characterization of Soils of Dakawa Irrigation Scheme

Pedological characterization of the soils at the Dakawa Irrigation Scheme was based on morphological characteristics, physical and chemical properties of the soil horizon samples from the profile. In addition environmental characteristics such as climate and socio-economic factors were also used in the pedological characterization of the soil (Baba *et al.*, 2008).

##### 4.1.1 Morphological Characteristics

Some key morphological properties of the soil profile at the Dakawa Irrigation Scheme are presented in Table 1. Based on the guideline for soil description (FAO, 1990), the profile was very deep (>150 cm), moderately well drained, with gray to very dark gray soil colour. The soil structure of the first three horizons were moderate, medium and coarse subangular blocky, very hard when dry, firm to friable when moist, sticky and plastic when wet. The three bottom horizons (61-175<sup>+</sup> cm) were very clearly differentiated from the top three horizons (0- 61 cm). The soil structures of the three bottom horizons were weak, fine and medium subangular blocky, friable when moist, sticky and plastic when wet. Presence of CaCO<sub>3</sub> concretions were common in these 3-horizons (61-175<sup>+</sup> cm). Roots were distributed throughout the profile although the intensity was decreasing with increasing depth. Soil horizon boundaries were quite distinct, ranging mostly from clear to abrupt with either smooth or wavy horizon topography due to the soil deposition sequence.

**Table 1: Key morphological characteristics of the Studied profile (DAK-P1)**

Profile	Horizon	Depth (cm)	Texture	Colour (Moist)	Consistence	Structure	Horizon boundary
DAK-P1	Ap	0-11	SCL	vdg (10YR3/1)	vh,fr,s&p	m m&c, sbk	cs
	BAw1	11-39	SCL	vdg (10YR3/1)	vh,fr,s&p	m m&c, sbk	cs
	BAw2	39 - 61	SCL	dg (10YR4/1)	h,fr,s&p	m m&c, sbk	as
	BCk	61-97/110	SCL	dg (10YR4/1)	fr, s&p	w f&m, sbk	cw
	Ck1	97/110-130	SCL	lbg (10YR6/2)	fr, s&p	w f&m,sbk	as
	Ck2	130-175+	SCL	g (10YR6/1)	fr, s&p	w f&m, sbk	

Soil profile: DAK P1 = Dakawa irrigation scheme profile one SCL= sandy clay loam; fr = friable; s = sticky; p = plastic, vh = very hard, h = hard, vdg = very dark gray,dg = dark gray, lbg = light brownisg gray, g = gray, m m&c sbk = moderate, medium and coarse, subangular blocky; w f&m, sbk = weak fine and medium subangular blocky, a = abrupt; c = clear; s = smooth; w = wavy

#### 4.1.2 Agro - ecological Zone of Dakawa Irrigation Scheme

Dakawa Irrigation Scheme is characterized by the lowland Agro ecological zone (River valley and basin) (MAFC, 2014). This zone is comprised of the Mgeta,Kafa, Ruvu, Wami, Msongozi, Mbulumi and Ngerengere river valleys in Morogoro and Mvomero District; the Wami-Mkata plains and Mkondoa valley in Kilosa District and the Luhombero Plains in Ulanga District (MAFC, 2014). The topography and climate of these areas is predominantly plain with rainfall ranging between 900mm and 1400mm annually, respectively. Temperatures in this zone are high with an average of 33<sup>0</sup>C due to its lowland nature. The zone is densely populated in the upper parts of the valleys, and sparsely populated in the inner parts of the valleys due to occurrence of floods during the rain seasons. The inner parts of the valleys are commonly used for rice cultivation (MAFC, 2014).

#### 4.1.3 SoilPhysical Properties

Some of the physical properties of the horizon soil samples generated through laboratory analysis were as presented in Table 2.

**Table 2: Physical properties of profile DAK-P1 at the DIS**

<b>Pedon</b>	<b>DAK- P1</b>					
<b>Horizon name</b>	Ap	BAw1	BAw2	BCK	CK1	Ck2
<b>Soil depth (cm)</b>	0-11	11-39	39-61	61-97/110	97/110-130	130-175
<b>Clay %</b>	24	26	30	32	32	32
<b>Silt%</b>	4	4	2	2	4	6
<b>Sand%</b>	72	70	68	66	64	62
<b>Texture</b>	SCL	SCL	SCL	SCL	SCL	SCL
<b>Silt/Clay Ratio</b>	0.17	0.15	0.07	0.06	0.13	0.19
<b>Bulk density</b>	1.81	NA	1.93	NA	1.92	NA

SCL=Sand Clay Loam, NA= Not Applicable

#### **4.1.3.1 Particle Size Distribution**

The particle size distribution of the soil at the study area was the result of the relationship between the three soil proportions namely clay, silt and sand. The trend shows that percent clay was increasing while the percent sand were decreasing with soil depth. Percentage silt content of the studied profile was generally low compared to sand and clay and did not show a clear trend with profile depth. High sand contents in the top horizon as compared to the subsurface horizons might be due to migration of finer soil particles in suspension from topsoils down the profile (clay eluviation and illuviation). Another reason for higher sand content in the topsoil may be due to surface runoff which washed away the finer soil particles and leave behind the large amounts of sand particles. Generally the soil textural class was sand clay loam (SCL) throughout the profile. Soil texture is the most stable physical characteristics which influence several other soil properties like soil structure, consistence, soil moisture regime and infiltration rate, runoff rate, erodibility, workability, permeability, root penetrability and fertility status of the soil (Landon, 1991). Based on the textural class of the soil with special reference to the percent clay contents, the soils at DIS have good water and nutrient retention capacities hence suitable for rice production.



#### 4.1.3.2 Bulk Density

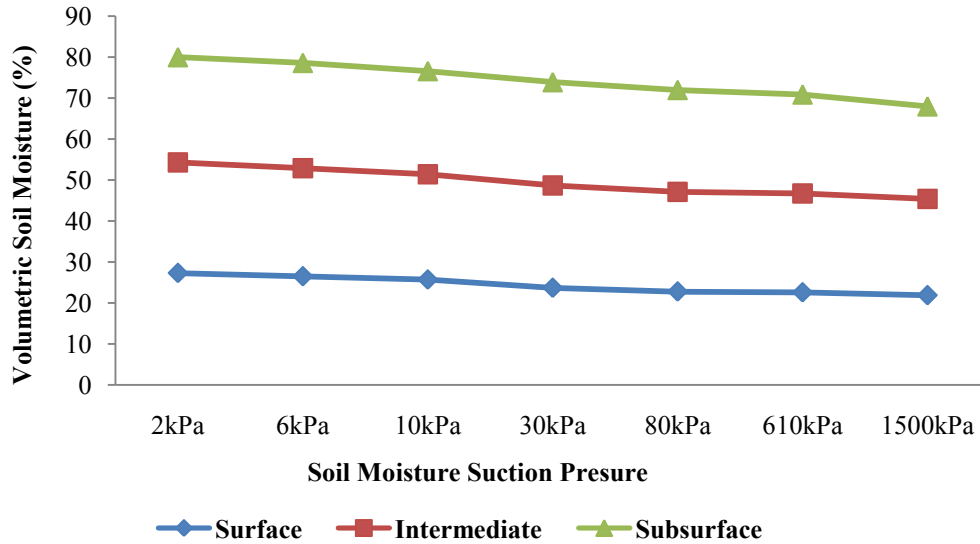
Bulk density is an important parameter for the description of soil quality and ecosystem function. The bulk densities of the horizon soil samples were as presented in Table 2. The bulk densities of the three horizons sampled (topsoil, intermediate and subsoil) were greater than  $1.8 \text{ g cm}^{-3}$ . These bulk densities could be rated as high ( $1.6\text{-}1.9 \text{ g cm}^{-3}$ ) for surface soil and very high ( $>1.9 \text{ g cm}^{-3}$ ) for the intermediate and subsoil (Hazelton and Murphy, 2007). A normal range of bulk densities for clay soil is  $1.0$  to  $1.6 \text{ g cm}^{-3}$  and for sand soil is  $1.2$  to  $1.8 \text{ g cm}^{-3}$  with potential root restriction occurring at  $\geq 1.4 \text{ g cm}^{-3}$  for clay soil and  $\geq 1.6 \text{ g cm}^{-3}$  for sand soil (Brady, 2008). High bulk densities of more than  $1.75 \text{ g cm}^{-3}$  for sands or  $1.46$  to  $1.63 \text{ g cm}^{-3}$  for silts and clays may impose many stresses such as mechanical resistance, poor aeration and changes in hydrological system in the soil such as poor infiltration of water (Landon, 1991).

The topsoil bulk density of the soil profile was  $1.814 \text{ g cm}^{-3}$ . This value was low compared to the intermediate and subsoil horizons. This might be attributed to relatively high organic carbon hence organic matter in topsoils (Dalal and Mayer, 1986). The highest value of the bulk density at the intermediate horizon (45-50 cm) as compared to bottom horizon might have been caused by the use of heavy machines in tillage, harvesting and hauling operations when the soil was moist hence caused compaction of the soil. This condition is potential in rice cultivation as it encourages water ponding in the field. High bulk densities indicate that the soils do not disintegrate easily into numerous fragments when weak pressure is applied on it. The bulk density determines the magnitude of particle to particle contacts and how they influence the total porosity and available soil moisture (Landon, 1991).

For the bottom horizon the slightly decrease in bulk density was observed as compared to an intermediate horizon. This might be attributed to the presence of  $\text{CaCO}_3$ . Many of the physical properties such as texture, slope, and soil depth, cannot be modified economically by the farmer but these factors determine the suitability of a soil for agricultural production. The physical properties of the soils such as texture, structure, consistency, porosity and bulk density influences fertility status of the soil as it influences nutrient losses through leaching, soil nutrients and water holding capacities, root penetration and drainage.

#### **4.1.3.3 Available Water Capacity**

Available water capacity at the surface, intermediate and subsoil horizons are given in (Figure 3 and Appendix 3). The available water content for the surface soil (1.8 %) and intermediate horizon (1.5 %) are generally lower than the subsoil horizon (2.6 %). The percent water content for the surface soil is attributed to the content of organic matter which was observed to decrease down the profile (Table 3). Klute (1986) also reported that organic matter influences soil water holding capacities of soils. Moreover, the high water content in the subsoil is a result of a substantial clay content present in the soil. In the intermediate horizon the available water content was low as compared to the two horizons (surface and subsurface) probably due to compaction effect caused by the use of heavy machines in different farm operations especially when the soil was moist. Generally the very low available water content in the pedon DAK-P1 was probably attributed to the type of clay mineral (smectite) which retain water tightly and therefore fail to release it for plant use.



**Figure 3: Soil Moisture Characteristic Curves for Pedon DAK-P1**

Moisture characteristic curve provide the actual trend of the soil moisture behavior in a soil profile(Figure3). The moisture characteristic curve shows that subsurface (95-100 cm) and surface (0-5 cm) soil retain more water than the intermediate soil. This was probably due to the fact that the amount of organic carbon in surface soil and the amount of clays present in the subsurface soil have ability to hold more water as compared to intermediate soil horizon (Table 5).Moreover the low water content in the intermediate horizon was probably attributed to the compaction effect which was observe in this layer. Therefore the trend of the available moisture for the three horizons sampled were subsurface soil > surface soil > intermediate soil. Furthermore, there was a big gap between the amount of water retained by both surface soil and intermediate soils and the subsurface soils in the profile.According to Lal (2005) the soil moisture characteristiccurve depends on soil particle size distribution and organic matter content which play an important role especially at low suctions.

#### 4.1.4 Chemical Properties of the Profile

Some of the chemical properties of the soil profile's horizonwise soil samples from the profile DAK- P1 are presented in Table 3 and Table 4.

##### 4.1.4.1 Soil pH

The pH of the soils at DIS were increasing with profile depth (Table 3). The lowest soil pH (in water) was observed in the top soil (Ap horizon) and the highest value in subsoils at the B<sub>ck</sub> and C<sub>k1</sub> horizons. Landon (1991) rated these pH values as medium (5.5-7) to very high (7-8.5) for topsoil and subsoil, respectively. The high soil pH of this soil could be attributed to the relatively high concentrations of Na, Ca and Mg ions which were also increasing with soil depth. The Na might be originating from surface evaporation of water in the Wami River containing substantial amount of Na due to alluvial deposition (Kisetu *et al.*, 2013). Ca and Mg might be originating from the underlying bedrock. For the profile most of the horizons, showed positive  $\Delta$  pH ( $\text{pH}_{\text{water}} - \text{pH}_{\text{KCl}}$ ) values, which indicates that the exchange complexes of the soil colloidal fractions of the soils are mostly negatively charged (Bohn *et al.*, 1985). Hence the ability to hold cations that are in equilibrium with the soil solution.

##### 4.1.4.2 Available Phosphorus

The trend shows that the available phosphorus in the soil at the DIS were decreasing with soil depth (Table 3). According to Landon (1991), the Olsen's phosphorus values of  $< 7$  mg P kg<sup>-1</sup> soil are rated as low, 7 to 20 mg P kg<sup>-1</sup> soil as medium and  $> 20$  mg P kg<sup>-1</sup> soil as high.

**Table 3: Selected chemical properties of the profile**

HORIZONS	DEPTH (cm)	pH	pH	Ec	OC	TN	AVAILABLE -P Olsen	
		1:2:5(H <sub>2</sub> O)	1:2:5(KCl)	dS/m	%	%	C/N	mgPkg <sup>-1</sup>
<b>Ap</b>	0-11	6.59	4.75	0.08	1.01	0.07	14	56.50
<b>BAw1</b>	11-39	7.72	5.73	0.15	0.48	0.03	16	56.05
<b>BAw2</b>	39-61	8.68	7.05	0.49	0.32	0.02	16	55.16
<b>Bck</b>	61-97/110	8.82	7.24	0.55	0.27	0.02	13	54.71
<b>Ck1</b>	97/110-130	8.82	7.35	0.85	0.24	0.01	24	54.56
<b>Ck2</b>	130-175+	7.26	7.36	2.21	0.24	0.01	24	53.21

**Table 4: Exchangeable Cations and the Related Properties**

HORIZONS	DEPTH (cm)	CEC <sub>soil</sub> [cmol(+)/kg]	CEC <sub>clay</sub>	EXCHANGEABLE BASES [cmol(+)/kg]				TEB	PBS
				Ca	Mg	K	Na		
<b>Ap</b>	0-11	17.52	73.00	1.4	2.27	0.37	0.30	4.33	25
<b>BAw1</b>	11-39 Cm	18.30	70.38	1.5	3.70	0.12	0.83	6.15	34
<b>BAw2</b>	39-61	10.76	33.68	4.8	6.93	0.11	1.92	13.75	128
<b>Bck</b>	61-97/110	18.16	60.53	3.9	7.00	0.09	2.69	13.69	75
<b>Ck1</b>	97/110-130	13.38	41.75	3.9	6.25	0.08	3.99	14.22	106
<b>Ck2</b>	130-175+	21.60	67.50	5.7	8.22	0.08	4.85	18.86	87

Since the P values obtained in all the six horizons of the profile were  $>20 \text{ mg P kg}^{-1}$ , then the available P of the profile would be categorized as high. High Olsen available P may be attributed to high P content in the soil's parent materials and or the continuous application of P fertilizers during rice cultivation.

#### **4.1.4.3 Organic Carbon**

The organic carbon contents ranged from 1.01% in the topsoil and the lowest value was 0.24% in subsoil (Table 3). According to Landon (1991) these values are rated as very low since they are  $< 2 \%$ . The trend shows that the percentage OC decreasing with soil depth. Percentage OC in the topsoil was high as compared to the other horizons probably because of the accumulation of plant root materials and other organic residues. The low OC percent in the profile could be attributed to the levelling process which led to the removal of the soil layers rich in OC during construction of the irrigation infrastructures.

#### **4.1.4.4 Total Nitrogen**

The percentage total nitrogen in the soil ranged from 0.07 to 0.01 % for topsoil horizon and subsoil respectively (Table 3). According to Landon (1984) these values are rated as very low. The Nitrogen levels in different horizons showed a clear decreasing trend with soil depth indicating that most of the N in the soil is contained in the soil organic matter.

#### **4.1.4.5 Cation Exchange Capacity (CEC)**

The CEC of the profile was ranged from  $17.52 \text{ cmol}(+) \text{ kg}^{-1}$  for topsoil and 10.76 to  $21.60 \text{ cmol}(+) \text{ kg}^{-1}$  soil for subsoils, respectively (Table 4). Landon (1984) rated these values as medium for the topsoil and low to medium for the subsoil. There was no clear trend of

increase or decrease in CEC with soil depth. The low to medium CEC of the soils could be attributed to the low organic matter content in the soils as well as the nature of the parent materials from which the soils were developed and the type of the layer silicate clay minerals in the soils. Koelling (1995) reported that organic matter and clay minerals of the soil have negative charged sites on their surfaces which adsorb and hold positive charged ions (cations) by electrostatic force. The electrical charge is critical to the retention and supply of nutrients to plants because many nutrients exist as cations dissolved in the soil solution and adsorbed on the surface of the soil colloids. The CEC might be viewed as reservoir of plant nutrients that is the higher the CEC, the larger the reservoir (Koelling, 1995).  $CEC_{clay}$  was high because the soil is dominated by 2:1 clay mineral.

#### **4.1.4.6 Exchangeable Bases**

The values of exchangeable bases (Ca, Mg, K and Na) horizon wise are presented in Table 5. The exchangeable calcium levels were increasing with soil depth. According to Landon (1991) these values were rated as very low ( $<2\text{cmol}(+)\text{kg}^{-1}$ ) to medium ( $5-10\text{cmol}(+)\text{kg}^{-1}$ ). The increase of exchangeable calcium levels was attributed to the presence of  $\text{CaCO}_3$  which were increasing with depth. The exchangeable magnesium in the profile ranged from 2.27 to  $8.22\text{cmol}(+)\text{kg}^{-1}$ . Msanya (2012) rated these values as high ( $2.1 - 4\text{cmol}(+)\text{kg}^{-1}$ ) and very high ( $>4.1\text{cmol}(+)\text{kg}^{-1}$ ) in loamy soils for top soil and subsoil, respectively. Similar to exchangeable calcium, magnesium values were also increasing with soil depth. The high values of exchangeable magnesium in the profile could be attributed to high magnesium contents in the soil's parent material.

Exchangeable K values ranged from  $0.37 \text{ cmol}(+) \text{ kg}^{-1}$  to  $0.08 \text{ cmol}(+) \text{ kg}^{-1}$  for topsoil and subsoil, respectively. According to Landon (1991) these values were rated as medium ( $0.3\text{-}0.6 \text{ cmol}(+) \text{ kg}^{-1}$ ) and very low ( $< 0.1 \text{ cmol}(+) \text{ kg}^{-1}$ ), respectively. The trend showed that exchangeable K values varied from horizon to horizon and decreased with soil depth. Exchangeable sodium ranged from  $0.3 \text{ cmol}(+) \text{ kg}^{-1}$  to  $4.85 \text{ cmol}(+) \text{ kg}^{-1}$  in topsoil and subsoil (Table 5), respectively. Landon (1991) rated these values as low ( $0.1\text{-}0.3 \text{ cmol}(+) \text{ kg}^{-1}$ ) and very high ( $>2 \text{ cmol}(+) \text{ kg}^{-1}$ ), respectively. The trend showed that the exchangeable sodium were increasing with soil depth. Low levels of exchangeable Na in the top horizon may be attributed to its solubility and mobility when soils are sufficiently moist which leads to leaching of sodium down the soil profile (Zonn, 1986).

#### **4.1.4.7 Base Saturation**

The base saturation of the studied soil varied from horizon to horizon. The lowest value was 25% for the top horizon (Ap) and maximum value of 128% for the subsoil horizon (BAw2) (Table 5) indicating the presence of soluble salts. The low base saturation in the top soil is an indication of intensive leaching of bases down the soil profile. The soil's analytical results don't show a clear trend of the base saturation down the profile.

#### **4.1.4.8 Electric conductivity**

The electric conductivity of the studied soil is as presented in Table 5. The trend shows that the Ec increased with soil depth probably due to increase in Na levels. The lowest value of Ec was  $0.08 \text{ dSm/m}$  and the highest value was  $2.21 \text{ dS/m}$  for topsoil and subsoil, respectively. Except for the bottom horizon, all other horizon values were  $< 1.7 \text{ dS/m}$



indicating that the Ec of the studied soil has no effect on rice yield reduction (Landon 1991).

#### **4.1.5 Soil Classification**

Soil morphological and laboratory analytical data presented in Tables 1, 2, 3, 4 and 5 and Figure 3 were used to define the diagnostic horizons and other features used for the classification of soil at DIS. Table 6 presents the diagnostic horizons and features for classifying the soils to family level according to USDA Soil Taxonomy (Soil Survey Staff, 2006). At the first level (order) of the USDA Soil Taxonomy the soils have been classified as *Inceptisols*. Similarly, Table 7 presents a summary of the diagnostic properties of the soil profile and identifies the prefix and suffix qualifiers, which allowed the classification of the soil up to the TIER-2 of the FAO World Reference Base Classification Scheme (FAO-WRB, 2006). According to the FAO-WRB for Soil Resources the soil of the study area would be classified as *Cambisol* at the Reference Soil Group level (TIER 2).

**Table 5: Field description and analytical data for the studied pedon**

Profile number : DAK-P1 Mapping unit: 84 (SOTER -Morogoro and Mvomero districts) Agro-ecol. zone:  
 River valley or basin (Lowland)  
 Region : Morogoro District : Mvomero  
 Map sheet no. : 166/3 Coordinates : 37° 33' 06.3" E/ 6° 24' 00.8" S  
 Location : Dakawa Irrigation Scheme, Block 13 plot 1.  
 Elevation : 361 m asl. Parent material: Alluvium derived from neogene rocks of the Mnguu mountains.  
 Landform: Alluvial plain; Slope: 0- 1 %; straight. Surface characteristics : presence of deep wide cracks.  
 Erosion: slight interrill erosion. Deposition: none.  
 Natural drainage class : Moderately well drained SMR: ustic STR: Isohyperthermic  
 Human influence: basin irrigation system after surface levelling; with inlet and outlet irrigation canals  
 Described by B.M. Msanya and H.R. Mbaga on 11/02/2015

Ap 0 - 11 cm: dark gray (10YR4/1) dry, very dark gray (10YR3/1) moist; Sandy clay loam; very hard dry, firm moist, sticky and plastic wet; moderate to strong medium granular structures and moderate medium to coarse subangular blocks; many fine and very fine pores; many very fine roots; clear smooth boundary to

BAw1 11 - 39 cm: dark gray brown (10YR4/2) dry, very dark gray (10YR3/1) moist; sandy clay loam; very hard dry, firm moist, sticky and plastic wet; moderate medium to coarse subangular blocks; common fine and many very fine pores; common very fine roots; clear smooth boundary to

BAw2 39 - 61 cm: gray brown (10YR5/2) dry, dark gray (10YR4/1) moist; sand clay loam; hard dry, firm moist, sticky and plastic wet; moderate, medium to coarse subangular blocks; common fine and very fine pores; few very fine medium roots; abrupt smooth boundary to

Bck 61 - 97/110 cm: dark gray (10YR4/1) dry, dark gray (10YR4/1) moist; sand clay loam; friable moist, sticky and plastic wet; weak fine to medium subangular blocks; few very fine pores; common fine and medium spherical CaCO<sub>3</sub> concretions; few very fine roots; clear wavy boundary to

Ck1 97/110 - 130 cm: light brownish gray (10YR6/2) moist, sand clay loam; friable moist, sticky and plastic wet; weak fine and medium sub angular blocks; few very fine and common fine pores; few fine and medium spherical CaCO<sub>3</sub> concretions; very few very fine roots; abrupt smooth boundary to

Ck2 130 - 175+ cm: gray (10YR6/1) moist; sand clay loam; friable moist, sticky and plastic wet; weak fine and medium sub angular blocks; few very fine and common fine pores; few fine and medium spherical CaCO<sub>3</sub> concretions; very few very fine roots.

**ANALYTICAL DATA FOR PROFILE DAK-P1**

Horizon	Ap	BAw1	BAw2	Bck	Ck1	Ck2
Depth (cm)	0 - 11	11 - 39	39 - 61	61- 97/110	97/110- 130	130 - 175+ 97/110

Clay %	24	26	30	32	32	32
Silt %	4	4	2	2	4	6
Sand %	72	70	68	66	64	62
Texture class	SCL	SCL	SCL	SCL	SCL	SCL
Silt/clay ratio	0.16	0.15	0.06	0.06	0.13	0.19
Bulk density g/cc	1.814		1.926		1.923	
pH H <sub>2</sub> O	6.59	7.72	8.68	8.82	8.82	7.26
pH KCl	4.75	5.73	7.05	7.24	7.35	7.36
Organic C %	1.01	0.48	0.32	0.24	0.27	0.24
Total N %	0.07	0.03	0.02	0.02	0.01	0.01
C/N	14.42	16.00	16.00	13.50	24.00	24.00
Avail. P mg/kg	56.50	56.05	55.16	54.71	54.56	53.21
CEC NH <sub>4</sub> OAc cmol(+)/kg	17.52	18.3	10.76	18.16	13.36	21.6
Exch. Ca cmol(+)/kg	1.4	1.5	4.8	3.9	3.9	5.7
Exch. Mg cmol(+)/kg	2.27	3.71	6.93	7.00	6.25	8.22
Exch. K cmol(+)/kg	0.37	0.12	0.11	0.09	0.08	0.08
Exch. Na cmol(+)/kg	0.30	0.83	1.92	2.69	3.99	4.85
TEB cmol(+)/kg	4.33	6.15	13.75	13.69	14.22	18.86
Base saturation %	25	34	128	75	106	87
CEC clay cmol(+)/kg	73	70.38	33.63	60.53	41.75	67.5
EC (dSm/m)	0.08	0.15	0.49	0.55	0.85	2.21
SAR	0.15	0.37	0.56	0.82	1.25	1.52
ESP	1.7	4.55	17.82	14.84	29.82	22.45

Mineralogy: possibly montmorillonitic

Particle size distribution class: loamy

**SOIL CLASSIFICATION:**

USDA Soil Taxonomy (Soil Survey Staff, 2006):

World Reference Base for Soil Resources (WRB)(FAO, 2006)

**Table 6: Summary of the diagnostic horizons, other features and classification of the soil profile at the DIS (USDA Soil Taxonomy- Soil Survey Staff, 2006)**

Profile Name	Diagnostic epipedon and subsurface horizon	Other diagnostic features	Order	Soil Taxonomy Taxa			Family
				Suborder	Great group	Subgroup	
DAK- P1	Ochric epipedon; cambic B horizon; calcic horizon	Ustic SMR; Isohyperthermic STR, Slope 0 -1% - almost flat; loamy (sand clay loam particle size distribution); calcareous; very deep; presence of wide deep cracks,	Inceptisols	Ustepts	Calcustepts	Vertic Calcustepts	<i>Almost flat, very deep, loamy (sand clay loam), calcareous, ustic, isohyperthermic Vertic Calcustepts</i>

**Table 7: Diagnostic horizons, other features and FAO-WRB soil names for the soil profile at the DIS (FAO-WRB, 2006).**

Profile name	Diagnostic horizon	Other diagnostic features/ materials	Reference Soil Group (RSG)	Prefix Qualifiers	Suffix Qualifiers	WRB soil name
DAK- P1	Cambic horizon Calcic horizon	Vertic characteristics; very hard consistence; Calcareous.	Cambisols	Vertic, Haplic	Calcaric, Endoeutric, Greyic	<b><i>Haplic Vertic Cambisols</i></b> ( <i>Calcaric, Endoeutric, Greyic</i> )

#### 4.2 Soil Fertility Evaluation of the Study Area (DIS)

Some of the chemical and physical properties of the composite soil sample from the study area (DIS) gathered for the purpose of evaluating the fertility status of the soil (Cambisol) are as presented in Table 8.

**Table 8: Chemical properties of the composite soil sample from the study area at the DIS**

Soil Parameters	Value	Rating(Landon,1991)
pH (H <sub>2</sub> O)	7.93	H
Organic carbon (%)	0.81	L
Organic matter (%)	1.39	L
Total nitrogen (%)	0.07	VL
C/N	11.6	GQ
Extractable P (Olsen mg kg <sup>-1</sup> )	69.06	H
Exchangeable Na (cmol (+) kg <sup>-1</sup> )	0.43	M
Exchangeable K (cmol (+) kg <sup>-1</sup> )	0.84	M
Exchangeable Ca (cmol (+) kg <sup>-1</sup> )	1.52	L
Exchangeable Mg (cmol (+) kg <sup>-1</sup> )	0.25	L
BS (%)	10.8	dystic
PSD (sand, silt, clay)	72, 2, 26	SCL
CEC (cmol(+) kg <sup>-1</sup> )	28.2	H
DTPA extractable micronutrients (mg kg <sup>-1</sup> )		
Fe	13.7	VH
Cu	1.4	H
Zn	6.4	VH
Mn	42.7	VH

Note: MA=Moderately Alkaline, L= Low, VL= Very Low, H= High, VH= Very High, M=Medium, GQ= Good quality, SCL= Sand Clay Loam

#### 4.2.1 Soil pH

The soil pH of the composite sample from the study area, was 7.93. Landon (1991) categorize the soils with pH of 7.9 to 8.4 as moderately alkaline. The optimum soil pH for rice production under irrigation or flooded environment range between 5.5 to 7.2 (Landon, 1991). De datta (1981) reported that rice cultivation is even possible in soils with  $\text{pH} \geq 9.0$  although yields are affected. The high pH values of the soils could negatively influence the availability of most of the micronutrients such as zinc and copper as well as phosphorous. It is reported that at high pH, phosphate combines with Ca to form compounds which are not readily available to plants. In soils with pH of less than 5.5 and in high soil pH, available P may be fixed or precipitated as Fe and Al phosphates and calcium phosphates, respectively (Landon, 1991). It may also affect some of the physical, chemical and biological properties of the soils that contribute to soil fertility. The application of gypsum material is recommended to lower the pH of the soil for optimum crop production and also improve soil aggregation and stability.

#### 4.2.2 Particle Size Distribution

Textural class of the soil at the study area was sand clay loam. It has been reported that soils with high clay contents are suitable for rice production because of their high capacities to retain water and plant nutrients (De datta, 1981). The high clay contents in such soil further restrict the percolation of the water through the soil hence encourage water ponding for rice cultivation. Landon (1991) reported that rice perform well in soil texture ranging between medium to fine (sand clay loam to sand clay or clay). The particle size distribution of these soils are 20 - 35 % clay, < 28 % silt, and > 45% sand for sand clay

loam;  $\geq 35\%$  clay and  $\geq 45\%$  sand for sand clay and  $\geq 40\%$  clay,  $\leq 45\%$  sand and  $< 40\%$  silt for clay (Soil Survey Staff, 1993).

#### **4.2.3 Total Nitrogen**

The total nitrogen content in the soil of DIS would be rated as very low ( $< 0.1\%N$ ) according to the rating by Landon (1991). The very low values of total N in the soil may be caused by continuous practice of monoculture or cultivation of high N demanding crops without replenishment. Furthermore low soil organic matter due to low incorporation of plant debris and crop residues to the soil and low application of both organic manures and inorganic fertilizers might have contributed to the very low level of nitrogen into the soil. However, nitrogen is a dynamic nutrient in soil, which frequently needs replenishment because it is at high risk of being lost from the soil either by leaching, erosion, volatilization and plant uptake. Therefore N should be added to the soil as fertilizer or manure to supplement the deficient levels of N in the soil. Total nitrogen though not a good index of N availability to plants is a soil fertility constraints to optimize rice production at the DIS.

The C/N ratio of the composite sample was 11.6. According to the rating by Landon (1991) C/N ratios between 10 and 12 indicate satisfactory mineralization of organic nitrogen into nitrates. The C/N ratios greater than 12 and/or less than 10 indicate that nitrification is inhibited (EUROCONSULT, 1989). Thus, the soil need high application of both organic and inorganic sources of N so as to enhance its productivity.

#### 4.2.4 Organic Carbon

The organic carbon content of the soil at the study area was 0.81%. According to Landon (1991) this is rated as low (0.6-1.25 %). The low organic carbon content translates to the low organic matter content in the soil. Organic matter influences the physical, chemical and biological properties of the soil, such as soil structure, water retention, nutrient content and retention and microbiological activities in the soil. To improve and sustain rice productivity in the Cambisols at the DIS, organic materials like manure or crop residues have to be incorporated into the soil.

#### 4.2.5 Available Phosphorus

The plant available phosphorus in the soil at the DIS was 69.06 mg kg<sup>-1</sup>. According to Landon (1991), the level of P in soils of the study area would be rated as high (46-70 mg kg<sup>-1</sup>). The availability of P in ponded rice field is the function of the soil pH (Msolla *et al.*, 2005). In high soil pH, available P may be fixed or precipitated as calcium phosphate. Based on rice P requirement, the P value found in the soil would satisfy the phosphate demand or requirement by rice crop, hence no dramatic response by rice to phosphate applications to the soil as organic or inorganic fertilizers, would be expected. However with continuous rice production under irrigation the phosphorus that would be lost through various processes must be replenished. Phosphorus availability to plants is strongly influenced by soil pH and optimal when pH is between 5.5 and 7.5 (Shelukindo *et al.*, 2014). Available P of 7.0 mg P kg<sup>-1</sup> and above is considered optimum, below this level P deficiency symptoms are likely to appear in most crops (EUROCONSULT, 1989; Landon, 1991). The high available P in the study soil indicates possible positive effects of P to rice tillering ability and improved yield under optimal soil properties. However, high pH and Ca level in this soil indicate susceptibility of P to precipitation as Ca-phosphates (CaHPO<sub>4</sub> or Ca<sub>3</sub>(PO<sub>4</sub>)<sub>2</sub>) hence its low availability for plant uptake. A study by Msolla *et al.* (2005)

generated similar possibilities of susceptible P to plant absorption to be affected by soil properties as determined by soil pH. A study on the P sorption and its bioavailability conducted by Kisetu and Mrema (2010) reports that high pH (>7.0) levels of the soil accelerate P retention through precipitation and the soil's P retention capacities increase with the time of P contact with the soil's exchange sites. Phosphorous is thus not a limitation to rice production at the DIS.

#### **4.2.6 Cation Exchange Capacity**

The Cation exchange capacity (CEC) of the soil from the study site was 28.2 cmol (+) kg<sup>-1</sup>. Landon (1991) categorized CEC as follows: 5 to 12.0 cmol (+) kg<sup>-1</sup> as being low, 12.1 to 25.0 cmol (+) kg<sup>-1</sup> as medium and 25 to 40 cmol (+) kg<sup>-1</sup> as high. Based on this categorization, the CEC of the soil in the study site was rated as high. High CEC of the soil is attributed to the nature of the parent materials from which the soil was developed and the type of the layer silicate clay minerals in the soil. The high CEC of the soil is an indication of the high capacities of the soil to retain nutrients added to the soil as fertilizers. CEC protects soluble cations from being lost through leaching and helps soils to resist changes in pH. The soil nutrient (cations) retention at DIS is not a limitation to rice production. However, replenishment of the cations removed from the soil through plant uptake must be given due consideration.

#### **4.2.7 Exchangeable Bases**

##### **4.2.7.1 Calcium (Ca)**

The value of exchangeable calcium in soil from the study site was 1.52 cmol (+) kg<sup>-1</sup>. This level has been categorized as very low (<2 cmol(+) kg<sup>-1</sup>) (Landon, 1991). However, indices of plant available Ca is of little value, since calcium availability varies greatly from soil to soil (Meliyo,1997). Soils are considered to be deficient in Ca when the



exchangeable calcium is less than  $0.2 \text{ cmol kg}^{-1}$  soil (Landon, 1991). The low level of exchangeable Ca in the soil could be attributed to leaching processes, losses by runoff and mining by cropping systems.

#### **4.2.7.2 Magnesium (Mg)**

The exchangeable magnesium in the soil was  $0.25 \text{ cmol (+) kg}^{-1}$ . According to Landon (1991), this value is rated as very low ( $<0.5 \text{ cmol (+) kg}^{-1}$ ). Similar to calcium the very low values of exchangeable magnesium in the composite soil sample might also indicate leaching losses, losses by runoff and or mining through plant uptake. Sanchez (1976) reported that  $0.2$  to  $0.64 \text{ cmol (+) kg}^{-1}$  levels of exchangeable magnesium are sufficient for most crops. Therefore, soils of the study areas have sufficient levels of exchangeable magnesium for crop production including rice.

#### **4.2.7.3 Sodium (Na)**

The level of exchangeable Na in soil from the study area was  $0.43 \text{ cmol (+) kg}^{-1}$ . The level has been rated as medium ( $0.3$ - $0.7 \text{ cmol (+) kg}^{-1}$ ) (Landon, 1991). Based on the analytical results ESP of the soil was 1.5% indicating that the soil was not sodic. Rice is moderately tolerant to sodic soil conditions (ESP 20-40) hence the rice grown in the study area will not be affected by the level of the exchangeable Na in the soil. The low ESP contradicts with the high pH value of soil in water indicating that exchangeable  $\text{Na}^+$  had very little effect on ESP. Therefore based on the pH of the soil and the exchangeable  $\text{Na}^+$ , the soils in the study area could be categorized as suitable for rice production.

#### 4.2.7.4 Potassium (K)

The exchangeable K of the soil in the study area was  $0.84 \text{ cmol (+)K kg}^{-1}$ . According to Landon (1991), the K content in the soil of the study area was rated as high ( $0.6\text{-}1.2 \text{ cmol(+)\text{Kkg}^{-1}}$ ). Tazaki (2006) reported that the main source of K for plants growing under natural conditions come from the weathering of K bearing minerals and organic K sources such as composts and plant residues. It has also been reported that the soils with large amount of K loose some of the K through fixation. For soils with high contents of exchangeable K, the exchangeable K could be transformed into unavailable forms through fixation. It has further been reported that the minimum absolute exchangeable K in soils ranges between  $0.07$  and  $0.2 \text{ cmolkg}^{-1}$  soil (Pillai, 2005). Therefore the K value of the soil at the study area was above the minimum levels hence rice would perform well.

#### 4.2.8 Extractable Micronutrients

The DTPA extractable Zn of the soil from the study area was  $6.4 \text{ mg kg}^{-1}$ . According to Landon (1991) and Motsara and Roy(2008), the Zn values of the soil at study area was sufficient ( $>1.0 \text{ mgZnkg}^{-1}$ ) The adequate value of Zn in the soil could be attributed to inherent high Zn content in the soil parent materials. De Data (1989) gave the critical Zn levels (DTPA) at pH of 7.3 to be between  $0.5$  to  $0.8 \text{ mgkg}^{-1}$  for most crops including rice. The extractable Mn value was  $42.7 \text{ mgkg}^{-1}$ . According to Landon (1991) and Lindsay and Norvell (1978), the extractable Mn in the soil from the study area was rated as sufficient ( $> 1.5 \text{ mgkg}^{-1}$ ). Hence the soil has adequate amount of available Mn for rice production.

The extractable Fe level in the soil from the study site was  $13.7 \text{ mg kg}^{-1}$ . The value was very high ( $>10 \text{ mg kg}^{-1}$ ), as reported by Motsara and Roy (2008). Hence, the soil from the study site has abundant Fe for rice growth and production.

The extractable Cu value was  $1.36 \text{ mgkg}^{-1}$ . According to Landon (1991) and Lindsay and Norvell (1978), the extractable Cu in the soil from the study area was rated as sufficient ( $> 0.75 \text{ mg kg}^{-1}$ ). Hence the soil has adequate amount of available Cu for rice production. De Data (1989) gave the critical levels for Cu (DTPA) at 7.3 pH be  $0.2 \text{ mgkg}^{-1}$  for most crops including rice.

#### **4.2.9 Soil Fertility Constraints to Rice at the DIS**

Soils fertility constraints at the DIS based on the soil analytical results as presented in Table 8 include low percent total N, percent OC, exchangeable Ca and Mg. The low level of N in the soil would interfere with the vegetative growth of the plant hence contributing to low rice yields. The very low organic carbon in the Cambisol is an indication of the low organic matter content in the soil. This was attributed to burning of the crop residues (rice straw and weed gathering), collection of rice straw for feeding livestock and grazing. The removal of top soil which is rich in organic materials through leveling during construction of irrigation infrastructures also contributed to the low soil organic matter in the soil. The low OM in Cambisol would negatively affect the moisture and nutrient retention capacity, soil structure and biological activities in the soil, hence poor growth performance. The low exchangeable Ca and Mg could be attributed to their losses through leaching, runoff and mining through continuous plant uptake. Furthermore, the DIS soils have high pH due to dissolved salts.

#### **4.2.10 Soil Management Approach and Strategies for Enhanced and Sustainable**

##### **Rice Production at DIS**

Some of the deficient nutrients in the Cambisol at the Dakawa irrigation scheme can be corrected by the use of both organic and inorganic fertilizers, application of gypsum and the use of improved rice production systems such as system of rice intensification (SRI). Application of organic matter in the soil is very critical. Some of the beneficial aspects of organic matter in the soil involve soil structure improvement, increase water infiltration as well as water holding capacity (Reeves, 1997). Organic matter also increase cation exchange capacity (CEC), nutrient retention and microbial diversity and activities. Organic soil amendment represents the main source of nitrogen, whilst for conventional growers, it can be used as a way of minimizing fertilizer inputs. In the rice cropping and farming systems organic matter can be amended through incorporation of cover crops as green manures as well as additions of composts, animal manures, and crop residues (Reeves, 1997). Application of inorganic fertilizers such as  $(\text{NH}_4)_2\text{SO}_4$ ,  $\text{CaSO}_4$  and  $\text{MgSO}_4$  are good supplement of the soil deficient nutrients such as N and exchangeable cations (Ca and Mg) Ca is an important component in aggregate stability of the soil (Korcak, 1993).

System of rice intensification (SRI) in rice production system minimize water loss. It uses minimum amounts of water for irrigation and the frequencies of irrigation are also minimum as compared to conventional systems (Thiyagarajan and Gujja, 2013). The system encourage the use of organic fertilizers as a supplement of deficient nutrients to the plant. It also encourage mechanical weeding which in one way or another increases

organic matter in the soil and encourages their decomposition as the application of herbicides are very minimal (Thiyagarajan and Gujja, 2013).

### **4.3 Screen House Pot Experiment**

#### **4.3.1 The Response of Rice (TXD 306 / SARO 5) Variety to N and P applied to the Cambisol from the DIS**

The response of rice to N and P as sulphate of ammonia ( $(\text{NH}_4)_2 \text{SO}_4$ ) and triple super phosphate  $\text{Ca}(\text{H}_2\text{PO}_4)_2$ , respectively applied to the Cambisol from the DIS in terms of plant height, number of tillers, biomass yield and grain yield are as presented in Table 9 and Appendix 4.

##### **4.3.1.1 Plant Height**

The plant height increased with increasing rates of N from 60.5 cm for the absolute control to 80.00 cm for the highest rate ( $\text{N}_{200} \text{ kgNha}^{-1}$ ) (Table 9 and Appendix 4), but decreased with increasing rates of P. The increase in plant height was statistically significant ( $P < 0.05$ ). The increase in plant height with increased N application might be primarily due to enhanced vegetative growth with adequate nitrogen supply to the plants. This observation concur with the study conducted by Bahmanyar and Mashae (2010). Furthermore, rice plants that received no N and low N rates ( $\text{N}_0$  and  $_{50}$ ) showed some N deficiency symptoms such as chlorosis, few number of tillers and delayed maturity.

The positive increase in height was due to the effect of N as the native N content in the soil was very low (Table 8). Similar findings were reported by Kisetu *et al.* (2013), where plant height increased from 52.2 cm for absolute control to 64.9 cm for  $60 \text{ mgNpot}^{-1}$ .

**Table 9: Response of TXD 306 Rice Variety to N and P applied to a Cambisols from****DIS**

<b>Treatments</b>	<b>Plant Height (cm)</b>	<b>Tillers pot<sup>-1</sup></b>	<b>*Biomass yield gpot<sup>-1</sup></b>	<b>Grain yield gpot<sup>-1</sup></b>	<b>%N</b>	<b>%P</b>
<b>P<sub>0</sub>N<sub>0</sub></b>	60.50 de	4.00 abc	10.99 a	2.24 a	1.58 a	0.16 a
<b>P<sub>0</sub>N<sub>50</sub></b>	65.50 g	6.00 cde	15.18 b	2.55 a	1.83 abcd	0.20 bc
<b>P<sub>0</sub>N<sub>100</sub></b>	70.00 hi	7.00 def	19.70 c	4.64 b	2.10 dfgh	0.23 fg
<b>P<sub>0</sub>N<sub>150</sub></b>	73.50 ij	8.50 fgh	42.10 f	11.89 e	2.20 ghi	0.23 fg
<b>P<sub>0</sub>N<sub>200</sub></b>	80.00 k	10.00 hi	48.97 h	17.65 g	2.31 hij	0.24 ghi
<b>P<sub>40</sub>N<sub>0</sub></b>	60.50 de	4.00 abc	10.99 a	2.24 a	1.58 a	0.16 a
<b>P<sub>40</sub>N<sub>50</sub></b>	61.50 ef	5.00abcd	11.89 a	2.41 a	1.71 ab	0.19 b
<b>P<sub>80</sub>N<sub>0</sub></b>	55.00 bc	4.00 abc	16.04 b	3.94 ab	1.80 abc	0.21 de
<b>P<sub>120</sub>N<sub>0</sub></b>	53.00 b	4.00 abc	18.41 c	4.46 b	1.83 abcde	0.22 def
<b>P<sub>160</sub>N<sub>0</sub></b>	46.00 a	3.00 a	20.12 c	5.03 b	2.01 cdefg	0.24 ghi
<b>P<sub>40</sub>N<sub>50</sub></b>	67.50 gh	7.50 efg	29.54 d	8.10 c	1.70 ab	0.21 cd
<b>P<sub>40</sub>N<sub>100</sub></b>	70.50 hi	9.00 fgh	42.75 f	12.94 e	2.22 ghi	0.23 fgh
<b>P<sub>40</sub>N<sub>150</sub></b>	75.50 j	10.50 hi	48.46 h	15.00 f	2.40 ijk	0.24 gi
<b>P<sub>40</sub>N<sub>200</sub></b>	80.00 k	9.50 ghi	65.65 k	20.66 h	2.51 jkl	0.27 kl
<b>P<sub>80</sub>N<sub>50</sub></b>	68.00 gh	7.50 efg	32.91 e	9.66 cd	1.93 bcdef	0.23 efg
<b>P<sub>80</sub>N<sub>100</sub></b>	60.00 de	8.00 j	46.10 g	16.54 fg	2.25 ghij	0.25 ij
<b>P<sub>80</sub>N<sub>150</sub></b>	64.50 fg	10.50 hi	65.86 k	21.98 hi	2.42 ijk	0.27 kl
<b>P<sub>80</sub>N<sub>200</sub></b>	68.50 gh	11.50 i	76.16 l	29.78 k	2.64 klm	0.28 lm
<b>P<sub>120</sub>N<sub>50</sub></b>	55.00 bc	4.50 abc	34.93 e	9.95 d	2.07cdefgh	0.26 jk
<b>P<sub>120</sub>N<sub>100</sub></b>	57.00 cd	5.00 abcd	55.04 i	17.04 g	2.42 ijk	0.28 mn
<b>P<sub>120</sub>N<sub>150</sub></b>	61.50 ef	9.00 fgh	67.90 k	22.90 ij	2.51 jkl	0.29 no
<b>P<sub>120</sub>N<sub>200</sub></b>	65.00 fg	9.50 ghi	84.07 m	31.82 l	2.74 lm	0.29 no
<b>P<sub>160</sub>N<sub>50</sub></b>	54.50 bc	3.50 ab	41.86 f	12.97 e	2.23 ghij	0.26 k
<b>P<sub>160</sub>N<sub>100</sub></b>	52.00 b	5.50 bcde	60.26 j	20.94 h	2.51 jkl	0.30 op
<b>P<sub>160</sub>N<sub>150</sub></b>	67.50 gh	7.50 efg	75.39 l	24.11 j	2.70 lm	0.31 p
<b>P<sub>160</sub>N<sub>200</sub></b>	68.00 gh	10.50 hi	93.04 n	33.06 l	2.89 m	0.32 q
<b>Cv%</b>	<b>2.2</b>	<b>13</b>	<b>1.8</b>	<b>2.9</b>	<b>5.4</b>	<b>2.7</b>

\*Mean values in a column having same letter(s) do not differ significantly using DNMRT at 5% level of probability.

\*Biomass = straw + grain

These findings are also in line with the study conducted by Uddin *et al.* (2013) where the application of 80 kg Nha<sup>-1</sup> gave the optimum plant height (105.01 cm) as compared to the absolute control (95.19 cm). Likewise Singh and Sharma (1987) reported that the application rates of N up to 180 kgha<sup>-1</sup> resulted in increased plant height of rice. Maqsood (1998) and Meena *et al.* (2003) also reported similar results. Manzoor *et al.* (2006)

reported that maximum plant height of 139.8 cm was recorded in the treatment where 225 kg ha<sup>-1</sup> nitrogen was applied and remained statistically at par with that obtained by nitrogen application rates of 175 and 200 kg ha<sup>-1</sup>. Furthermore they also reported that the minimum plant height (128.0 cm) was achieved in control treatment where no N was applied.

The plant height increased at the low P rates but decreased when the P rates were further increased. The highest plant height recorded in this experiment was 61.5 cm when 40 kg P ha<sup>-1</sup> applied and the lowest height (46 cm) at 160 kg P ha<sup>-1</sup>. Furthermore, plant height increased significantly ( $P < 0.05$ ) with increasing applied P rate up to 40 kg P ha<sup>-1</sup> but further increase beyond 40 kg P ha<sup>-1</sup> resulted to a negative effect on plant height. This was due to high native P level in the soil (Table 8). The plants did not show any signs of P deficiency symptoms during growth indicating that the amount of native soil available P was sufficient for roots and plant development hence plant growth. This might be attributed to the synergistic and antagonistic effect of P on plant nutrients (Table 9 and Appendix 4). Similarly, Raju and Reddy (1993) and Zaman *et al.* (1995) reported the increases in rice plant height due to increasing P fertilizer application rates and decrease when the P rates were increased beyond 40 kg P ha<sup>-1</sup>.

The response of rice to the N\*P interactions for the TXD 306 rice variety is also presented in Table 9 and Appendix 4. The interaction did not follow a well defined trend in plant height. The plant height were significantly increased with the increase N application rates. Since one of the most important functions of N is the promotion of vegetative growth, application of N increased height of rice crop more than P. The highest plant height recorded in this experiment was 80 cm at (P<sub>40</sub>N<sub>200</sub> kg ha<sup>-1</sup>) and the lowest plant height was

52.00cm at  $P_{160}N_{100}kg\ ha^{-1}$ . This height was low as compared to absolute control (60.50 cm) due to imbalanced effect of the nutrients (N and P) to the plant.

Among all of the N\*P treatment combinations, statistically similar plant height were recorded at  $P_{40}N_{50}kg\ ha^{-1}$ ,  $P_{80}N_{50}kg\ ha^{-1}$ ,  $P_{80}N_{200}kg\ ha^{-1}$ ,  $P_{160}N_{150}kg\ ha^{-1}$  and  $P_{160}N_{200}kg\ ha^{-1}$  (Table 9). Plant height responded highly significantly and positively to the increased application levels of both N and P. With regards to the interaction between N and P, the responses of all N levels significantly ( $P \leq 0.05$ ) increased the plant height. This was attributed to the high level of native P in the soil observed during the soil analysis prior to the experiment (Table 8). The promotion of rice plant height in the present study due to applications of N and P is apparent as N is essential nutrient for plant growth since it is a constituent of all proteins and nucleic acids, whereas P is essential for the production and transfer of energy in plants. Thakur (1993), Hari *et al.* (1997) and Behera (1998) have also observed that rice plant height was enhanced by combined N and P applications. The synergist effect of the N\*P interaction was evident in this study as well as the antagonistic effects, where N and P requirement were in the appropriate and inappropriate balances, respectively.

#### **4.3.1.2 Response in Terms of Number of Tillers**

The response of TXD 306 to N and P applied in Cambisol from DIS in terms of number of tillers is presented in Table 9 and Appendix 4. The number of tillers per plant increased with the increasing rates of N. The increased number of tillers per hill was statistically significant ( $P < 0.05$ ). The highest number of tiller was 10 when  $200\ kg\ N\ ha^{-1}$  applied, and the lowest number of tillers (4) was recorded in absolute control where no N and P were



applied. The increase in number of tillers with N application was attributed to the increase in soil N as the soil from DIS was deficient in N (Table 8). N deficiency symptoms such as thin and weak tillers were also observed in pots where low rates of N were applied (0 and 50kgNha<sup>-1</sup>). Furthermore, from the applied soil amendment, N is among other things responsible for the promotion of rapid plant growth which in turn increased the number of tillers per plant (Hasanuzzaman *et al.*, 2009). Likewise, Manzoor *et al.* (2006) reported that rice plants produced more productive tillers per hill (23.42) when 225 kg Nha<sup>-1</sup> was applied which remained statistically at par with that obtained by nitrogen application levels between 125 to 200 kg ha<sup>-1</sup> due to different native N levels in the experimental soils. Moreover the lowest number of productive tillers per hill (18.17) was recorded in control treatment receiving no fertilizer. These results were in line with those reported by Singh and Sharma (1987), Rafey *et al.* (1989), Munda (1989), Maqsood (1998) and Meena *et al.* (2003). Enhanced tillering by increased nitrogen application might be attributed to more nitrogen supply to plant at active tillering stage. Similar findings were also reported by Hasanuzzaman *et al.* (2009) that application of N at the rates exceeding 50 kgNha<sup>-1</sup> facilitated high vegetative growth and tillering in most plants.

The number of tillers were also high at the low P rates (0 to 40 kgPha<sup>-1</sup>). The highest number of tillers (5) recorded at the P application rate of 40 kgpha<sup>-1</sup>. Increasing the P rates significantly reduced the number of tillers to 3 when 160kgPha<sup>-1</sup> was applied (Table 9). There were no significant response (P<0.05) of P with increased P application rates. Lack of response to P application for the DIS soils was attributed to their relatively high contents of initial P in the soil (69.06 mg kg<sup>-1</sup>) observed at the start of the experiment (Table 8). Similar observations were also reported by Semoka and Mnguu (2000) in

Kilangali, Mkindo, Mgomba and Majengo soils when assessing N, P, and K status of selected paddy growing areas in Tanzania.

The interaction between the two nutrients (N and P) in tillering of TXD 306 rice variety is as presented in Table 9 and Appendix 4. The highest number of tillers (11.5) was recorded at  $80\text{kgP ha}^{-1}$  and  $200\text{kgN ha}^{-1}$  and the lowest number (3) was recorded when  $\text{P}_{160} \text{N}_0 \text{ kg ha}^{-1}$  applied. These findings imply that the increase in number of tillers relates to the role of N in growth and development of a crop and ability of N to synergistically enhance availability of in-situ P from soil exchange sites, which is a primary nutrient in formation of tillers in rice.

#### 4.3.1.3 Biomass Yield

The response of N, P and the interaction between N and P on biomass yields (straw and grain) are presented in Table 9 and Appendix 4. The biomass yield increased significantly ( $P < 0.05$ ) with increased N rates in the soil. The results showed that the highest biomass yield ( $43.97 \text{ g}$ ) was obtained when  $200 \text{ kg ha}^{-1}$  applied and the lowest biomass ( $10.99 \text{ g}$ ) recorded in absolute control where no N and P were applied. The increase in biomass with N application was attributed to the increase in soil N as the soil at the trial site were deficient in N (Table 8). This is due to the fact that N is one of the important nutrient for the vegetative development of the plant. Similar findings were also reported by Irshad *et al.* (2000) that N application increased biomass yield over the absolute control.

Similarly the biomass yield increased significantly ( $P < 0.05$ ) with increasing levels of applied P (Table 9 and Appendix 4). The highest biomass yield ( $20.12 \text{ g pot}^{-1}$ ) was

recorded when 160 P kg ha<sup>-1</sup> applied. The lowest biomass yield (10.99 g pot<sup>-1</sup>) was recorded where no P fertilizer was applied. This also concurs with the study done by Irshad *et al.* (2000) and Kisetu *et al.* (2013). The interaction between the two nutrients in rice (N and P) significantly increased biomass yield ( $P < 0.05$ ). The highest biomass weight (93.04 g pot<sup>-1</sup>) was recorded at P<sub>160</sub>N<sub>200</sub> kg ha<sup>-1</sup> and the lowest biomass yield was 10.99 g pot<sup>-1</sup> observed in absolute control. The highest biomass weight recorded could be due to the influence of N and P on establishment and vigorous vegetative growth of rice. Additionally P<sub>80</sub>N<sub>50</sub> and P<sub>120</sub>N<sub>50</sub> kg ha<sup>-1</sup> combination rates also gave statistically similar biomass weight. These findings suggest that nutrient N and P induced optimum vegetative growth at the higher rates. These findings are in line with those reported by Hasanuzzaman *et al.* (2009) and Uddin *et al.* (2013).

#### 4.3.1.4 Grain Yield

The weights of dry grain per pot of rice TXD 306 variety are as presented in Table 9. The weight of the grain increased significantly ( $P < 0.05$ ) with increasing N, P and N\*P combination rates. Increased rate of N application significantly increased the grain yields of rice (TXD 306). The highest grain yield of TXD 306 was 17.65 g obtained when N was applied at the rate of 200 kg ha<sup>-1</sup>. In the contrary the lowest grain yield (2.24 g) was recorded in absolute control. This result was statistically similar with the grain yield from the treatment P<sub>0</sub>N<sub>50</sub>. Similar findings were reported by Uddin *et al.* (2013) that the highest grain yield was obtained when 80 kg N ha<sup>-1</sup> was applied and the lowest in absolute control where no fertilizer was applied. In addition, Uddin *et al.* (2013) reported that the increase in grain yield for application of N is mainly due to improvement in yield components such

as number of effective tillers and grains per panicle. Similar findings were reported by Tabar (2012).

According to Tabar (2012), N deficiency in rice results in stunted growth and chlorotic leaves caused by poor assimilate formation that leads to premature flowering and shortening of the growth cycle, which in turn reduce grain yield. In contrast, the presence of N in excess promotes development of the above ground organs with abundant dark green (high chlorophyll) tissues of soft consistency and relatively poor root growth and poor grain yield. Mohammadin-Roshan *et al.* (2011) also insisted that excessive vegetative growth in plants increases the risk of lodging and reduces the plant's resistance to harsh climatic condition and foliar diseases. Increased grain weight at the higher nitrogen rates might be primarily due to increase in chlorophyll content of leaves which led to higher photosynthetic rate and ultimately plenty of photosynthates available during grain development. Kanade and Kalra (1986) and Spanu and Pruneddu (1997) also reported highest paddy grain yields as a result of nitrogen application at  $150 \text{ kg ha}^{-1}$  and  $250 \text{ kg ha}^{-1}$ . The higher paddy grain yield at higher nitrogen rates was due to high number of grains per panicle and 1000 grain weight (Marazi *et al.*, 1993; Dixit and Patro, 1994; Bali *et al.*, 1995; Meena *et al.*, 2003).

Further increased P rates also increased the grain yields (Table 9). The highest grain yield ( $5.03 \text{ g pot}^{-1}$ ) was recorded at  $160 \text{ kg P ha}^{-1}$  and the lowest ( $2.24 \text{ g pot}^{-1}$ ) at the absolute control where both N and P were not applied. The response of rice in terms of grain yield above  $0 \text{ kg P ha}^{-1}$  was possibly affected by the higher amount of inherent extractable (available) P of the experimental soil (DIS Cambisol) (Table 8). The availabilities of both

native and applied P have also been reported to increase grain yield on soils under flooded rice production in Pakistan (Zia *et al.*, 1992). Yoefi *et al.* (2011) reveals that grain number per panicle significantly influenced by phosphorous fertilizer. Similar results were also noted by Awan *et al.* (1984) and Rafey *et al.* (1989).

However, the highest grain yield of rice TXD 306 variety in Cambisols from the DIS (33.06 g pot<sup>-1</sup>) obtained at the highest combination rate of N and P (P<sub>160</sub>N<sub>200</sub>kg ha<sup>-1</sup>). This result was statistically at par with that obtained at P<sub>120</sub>N<sub>200</sub>kg ha<sup>-1</sup> (Table 9). The lowest grain yield from the combination of N and P (2.24 g pot<sup>-1</sup>) was recorded for the absolute control. The importance of N to grain yield of rice is in line with a study of Kisetu *et al.* (2013) who reported that basal application of P at sowing and top dressing with half dose of N fertilizer (50 kg ha<sup>-1</sup>) at the beginning of tillering and the remaining half (50 kg ha<sup>-1</sup>) at about panicle initiation was practically a viable option to increased rice grain yields.

#### **4.3.2 N and P Contents in Biomass Straw**

The contents of N and P in biomass (straw) are presented in Table 9. The percent N in biomass straw increased with increasing N application rates. The highest N (2.31 %) was recorded when 200 kg N ha<sup>-1</sup> was applied and the lowest (1.58 %) in the absolute control where no nutrient was applied. This increase was statistically significant (P < 0.05). Thiagalingam (2000) categorized these biomass straw N as deficient (< 2 %) and optimum when it is ranging between 2.25-3.30 %. Therefore, based on Thiagalingam (2000). Percentage N observed was deficient in absolute control but sufficient when 200 kg N ha<sup>-1</sup> was applied. Furthermore, Havlin *et al.* (2003), reported the general sufficient or optimal range of nitrogen in most cereal plants range between 2.0 to 5.0%. According to

Tandon (1995), deficiency was observed when recently matured leaves, that means third leaf of any plant contain  $<3.8\%$ , sufficient when they contains 3.8 to 4.8% and high when they contain  $> 4.8\%$  N. This implies that, for rice production N fertilizer application in soil is important while at the same time nutrient balance should be considered in order to achieve high yields (Jones *et al.*, 1982).

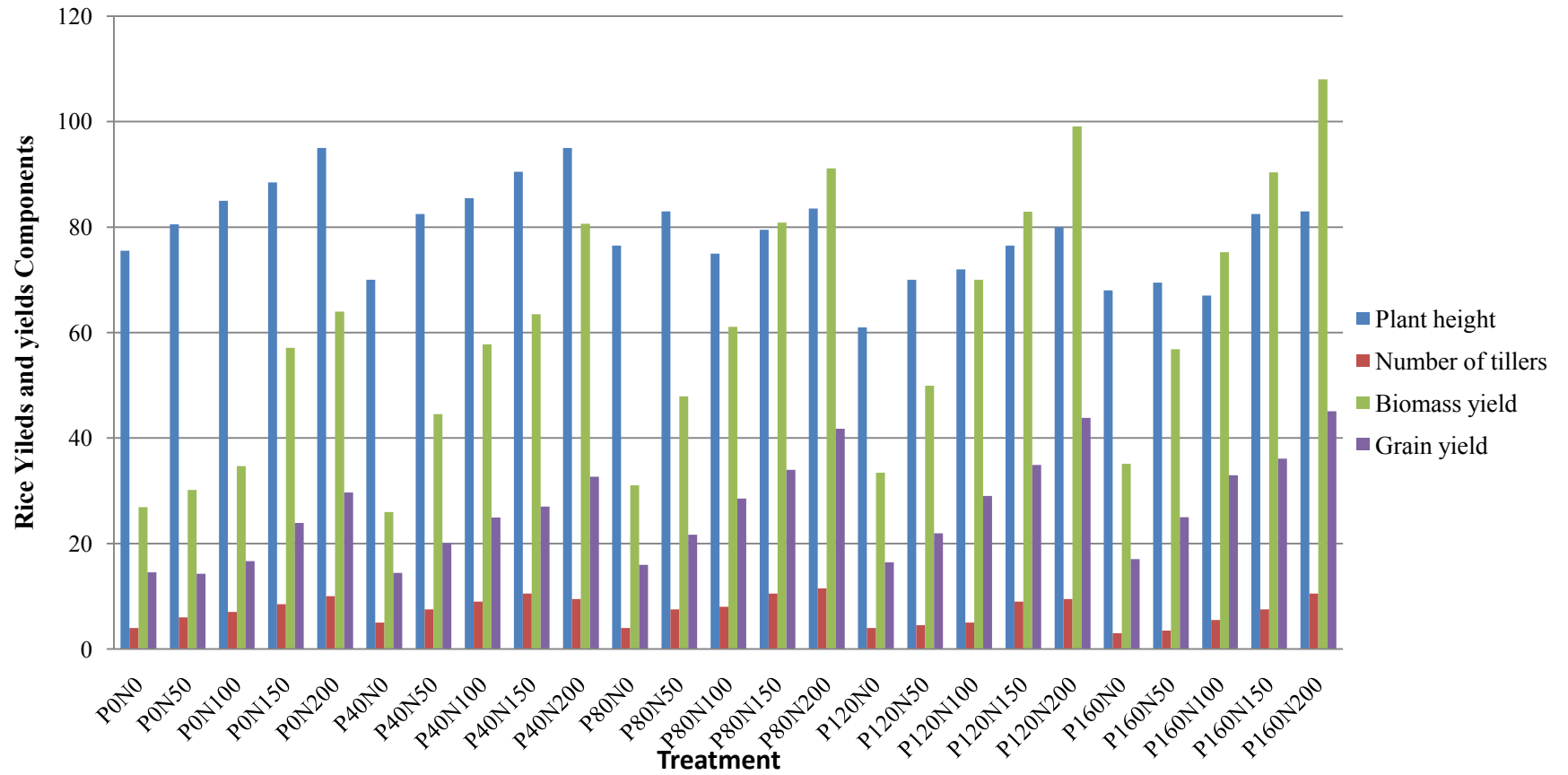
Moreover, percent P increased with increasing P rate. The highest P content in biomass straw was 0.24% recorded in  $160\text{kgP ha}^{-1}$  and the lowest (0.16%) in absolute control. Similar to N this increase was statistically significant ( $P < 0.05$ ). According to Thiagalingam (2000) these values are rated as sufficient ( $> 0.15\%$ ) but optimum when the values range between 0.18- 0.32%. Havlin *et al.* (2003) reported P deficiency to occur when a recently matured leaf (third leaf of a plant), contains  $< 0.15\%$  and above 0.17% the plant is considered adequately supplied with P. Other workers reported that the critical levels of P in plant leaves are as follows; Landon (1991) classified P contents ranging from 0.36 - 0.44% as sufficient and above 0.44% as high while Bonheure and Wilson (1992) reported values of critical levels of P and observed a deficiency level when plant leaves contain  $< 0.35\%$ , at 0.35 - 0.40% as subnormal and at 0.40 - 0.50% as normal and above 0.50% as excess. The sufficient P content in the absolute control indicates that available P in the Cambisols from the DIS was adequate for rice production.

For the N\*P combination treatments receiving adequate supply of nitrogen had a positive impact in improving availability of P for plant uptake. Results of the combination showed that the highest P rate without N ( $P_{160} N_0 \text{ kg ha}^{-1}$ ) and zero P with higher level of N ( $P_0 N_{200} \text{ kg ha}^{-1}$ ) statistically gave similar P content in biomass straw ( $P < 0.05$ ). These results are also

supported by the findings by Jones *et al.* (1982) that N supply increased P uptake due to its effect on root growth.

#### **4.3.3 Optimum rates of N and P by rice (TXD 306) at the DIS**

The performance of different combined rates of N and P fertilizers applied to the rice (TXD 306) to the Cambisol from the DIS are as presented in Figure 4. Increased rate of N and P significantly increased grain yield from 2.24g to 33.06g pot<sup>-1</sup>. The lowest grain yield was recorded in absolute control (P<sub>0</sub>N<sub>0</sub>) and the highest mean grain yield per pot (33.06g) was recorded when the highest combination rate (P<sub>160</sub>N<sub>200</sub>kg ha<sup>-1</sup>) was applied. Based on observations made, the optimum rates of N and P for rice for Cambisols from the DIS was P<sub>160</sub>N<sub>200</sub> kg ha<sup>-1</sup> however, the economic analysis of rice production for the DIS calls for field experiments and trials.



**Figure 4: Optimum rates of N and P on Yields and Yields Components of Rice TXD 306**



## CHAPTER FIVE

### 5.0 CONCLUSIONS AND RECOMMENDATIONS

#### 5.1 Conclusions

The soil of the study area was characterized as a Cambisol, having moderate fertility and marginal suitability for rice production. The grain yield and yield components of the rice crop responded more to N than to P fertilization at the DIS. The optimum grain yield and yield components were obtained with a combined application of N and P fertilizers. In this study, height, number of tillers per plant and the straw biomass were the most important yield forming attributes causing significant variation in grain yield of rice (TXD 306).

The results of the study indicated that in order to improve the grain yield and yield components of rice grown on the soils at the Dakawa Irrigation Scheme, the optimum rate of N and P was  $P_{160}N_{200}$   $kg\ ha^{-1}$ . Based on the results of study it may be concluded that treatment  $P_{80}N_{200}kg\ ha^{-1}$  is economically suitable for rice cultivation in Cambisols at the DIS. Therefore, the marginal farmers who are unable to invest more might go for  $P_{80}N_{200}kg\ ha^{-1}$  and large scale farmers may be advised to adopt  $P_{160}N_{200}$   $kg\ ha^{-1}$  which supply balanced fertilization as the suitable one provided that the costs of input and market price of rice justify the profit pending verification by field experiment or trial.

Moreover, fertilizer application rate should consider the pedological and fertility characterization of the soil. This is important because each soil type behave differently in terms of fertility management. The optimum rate of fertilizers should be studied for each soil type and specific crop in order to give an appropriate fertilizer recommendations.

In irrigated rice production systems soil-water relation and the related factors that affect the availability and evaluation of nutrients should be considered as an integral parts of efforts to improve rice production and soil fertility.

## **5.2 Recommendations**

Based on the findings in the current study, it is recommended that:-

- i. Further studies are required in the light of significant fertilizer recommendations for both N and P fertilizers, aimed at promoting integrated soil fertility management in rice cultivation based on other soil types so as to extrapolate the results to other places with similar type of the soil.
- ii. Further studies should also be undertaken on economic use of fertilizer in order to maximize a farmer profit on rice production at the DIS and other places of similar soils
- iii. This study should however be confirmed by field experiments and thus generate site specific fertilizer recommendations.

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## APPENDICES

### Appendix 1: Weather data ( Collected from Dakawa Research Weather Station, Dakawa Wami Prison and Wami Ruvu Basin Office)

#### ( a) Rainfall data

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
<b>2004</b>	240	4.5	3.5	12.6	50	.5	0	0	.0	10	.0	193.5	1191.1
<b>2005</b>	73.5	9.0	3.5	16.5	4.5	9	0	2	.5	.3	.0	2.1	738.1
<b>2006</b>	91.0	1.0	2.2	13.2	1.3	0	5	.7	1.1	14	1.1	154.1	1081.2
<b>2007</b>	38.0	0.6	2.5	14.1	0.7	.9	3	.7	0	1.2	1.2	84.1	1160.3
<b>2008</b>	138	2.4	1.2	12.5	.8	1	0	0	.6	1.2	1.4	24.0	1089.1
<b>2010</b>	221	.4	4.0	79	1.5	3	2	0	.0	7.6	3.8	221	1404.8
<b>2011</b>	111.3	1.4	8.0	-	1.7	0	5	0	.0	.0	.5	214.5	868.9
<b>2012</b>	106.3	1.4	1.7	30	4.7	0	7	4	.0	5.1	.9	150.2	770.4
<b>2013</b>	63.2	14	1.1	18.3	1.3	0	0	0	.5	.0	.7	0.05	80.1
<b>2014</b>	67.8	1.2	4.5	13.4	2.2	.5	0	0	3.9	.0	.4	99.4	838.3
	<b>115.01</b>	<b>0.09</b>	<b>5.62</b>	<b>1.067</b>	<b>1.32</b>	<b>82</b>	<b>12</b>	<b>5</b>	<b>66</b>	<b>.14</b>	<b>.1</b>	<b>114.299</b>	<b>85.0</b>

**(b)MeanMaximumTemperature**

<b>YEAR</b>	<b>JAN</b>	<b>FEB</b>	<b>MAR</b>	<b>APR.</b>	<b>MAY</b>	<b>JUN</b>	<b>JUL</b>	<b>AUG</b>	<b>SEP</b>	<b>OCT</b>	<b>NOV</b>	<b>DEC</b>	<b>ANNUAL</b>
<b>2005</b>	32.2	31.8	31.7	31.0	28.6	28.0	27.8	27.3	30.3	32.1	31.5	29.8	30.2
<b>2006</b>	32.4	31.1	31.8	29.5	28.1	27.4	26.9	29.5	29.7	31.4	30.4	31.8	30.0
<b>2007</b>	33.6	33.7	33.5	29.1	28.4	28.3	27.9	28.4	29.7	29.8	33.2	30.5	30.5
<b>2008</b>	31.5	33.4	33.4	30.8	29.3	28.0	28.4	28.0	30.2	31.3	33.5	32.7	30.9
<b>2009</b>	30.4	31.0	31.5	29.5	27.9	27.5	26.9	27.3	30.3	31.7	29.7	31.7	29.6
<b>2010</b>	32.9	30.7	32.6	29.7	28.8	28.1	27.7	28.2	30.3	31.3	31.5	32.8	30.4
<b>2011</b>	31.3	33.7	31.4	30.1	28.3	27.8	27.4	28.5	28.7	32.0	31.5	30.8	30.1
<b>2012</b>	30.3	32.1	32.4	30.5	28.9	28.4	28.1	28.8	30.5	31.5	32.4	33.8	30.6
<b>2013</b>	33.7	33.0	32.4	30.5	29.7	28.7	28.8	28.9	29.7	32.2	31.8	31.5	30.9
<b>2014</b>	29.3	31.2	31.4	29.1	28.3	27.3	27.2	28.7	29.5	32.1	31.6	32.4	29.8
<b>MEAN</b>	<b>31.7</b>	<b>32.1</b>	<b>31.6</b>	<b>29.5</b>	<b>28.4</b>	<b>27.6</b>	<b>27.2</b>	<b>27.8</b>	<b>29.9</b>	<b>31.5</b>	<b>32.0</b>	<b>31.8</b>	<b>30.1</b>

**(c) Mean Minimum Temperature**

<b>YEAR</b>	<b>JAN</b>	<b>FEB</b>	<b>MAR</b>	<b>APR</b>	<b>MAY</b>	<b>JUN</b>	<b>JUL</b>	<b>AUG</b>	<b>SEP</b>	<b>OCT</b>	<b>NOV</b>	<b>DEC</b>	<b>ANNUAL</b>
<b>2005</b>	21.9	20.7	20.7	20.6	19.1	14.2	15.2	16.2	16.1	18.0	22.0	20.8	18.8
<b>2006</b>	20.9	22.9	20.7	20.7	18.5	15.1	14.2	15.7	16.5	18.5	20.4	21.0	19.0
<b>2007</b>	21.9	22.0	20.1	18.2	18.9	16.8	15.8	16.7	17.4	19.3	20.1	21.3	19.4
<b>2008</b>	21.4	21.7	21.7	21.7	19.5	16.9	15.9	16.2	16.9	18.5	20.8	21.7	19.2
<b>2009</b>	20.9	20.6	26.2	20.2	18.5	15.9	16.8	15.9	15.9	17.9	20.1	21.0	18.7
<b>2010</b>	21.0	20.6	20.3	20.3	18.2	19.2	15.2	14.1	16.6	17.8	19.6	21.3	18.7
<b>2011</b>	20.8	20.5	20.6	20.2	19.6	15.3	14.2	15.4	16.5	18.9	20.5	21.5	18.7
<b>2012</b>	20.9	21.1	21.6	21.0	19.2	15.3	15.7	17.2	17.7	19.1	20.4	22.1	19.3
<b>2013</b>	22.3	22.2	21.8	21.3	18.5	18.5	16.6	10.3	17.8	18.8	20.6	21.1	19.2
<b>2014</b>	20.8	21.3	20.4	20.6	19.4	16.4	15.4	11.9	17.4	18.3	19.8	20.7	18.5
<b>MEAN</b>	<b>21.0</b>	<b>21.2</b>	<b>21.2</b>	<b>20.6</b>	<b>18.8</b>	<b>16.0</b>	<b>15.1</b>	<b>15.3</b>	<b>16.7</b>	<b>18.1</b>	<b>20.0</b>	<b>20.6</b>	<b>18.7</b>



**Appendix 2: Combination of P and N for Rice (TXD 306)for the Pot Experiment**

	<b>N<sub>0</sub></b>	<b>N<sub>50</sub></b>	<b>N<sub>100</sub></b>	<b>N<sub>150</sub></b>	<b>N<sub>200</sub></b>
<b>P<sub>0</sub></b>	P <sub>0</sub> N <sub>0</sub>	P <sub>0</sub> N <sub>50</sub>	P <sub>0</sub> N <sub>100</sub>	P <sub>0</sub> N <sub>150</sub>	P <sub>0</sub> N <sub>200</sub>
<b>P<sub>40</sub></b>	P <sub>40</sub> N <sub>0</sub>	P <sub>40</sub> N <sub>50</sub>	P <sub>40</sub> N <sub>100</sub>	P <sub>40</sub> N <sub>150</sub>	P <sub>40</sub> N <sub>200</sub>
<b>P<sub>80</sub></b>	P <sub>80</sub> N <sub>0</sub>	P <sub>80</sub> N <sub>50</sub>	P <sub>80</sub> N <sub>100</sub>	P <sub>80</sub> N <sub>150</sub>	P <sub>80</sub> N <sub>200</sub>
<b>P<sub>120</sub></b>	P <sub>120</sub> N <sub>0</sub>	P <sub>120</sub> N <sub>50</sub>	P <sub>120</sub> N <sub>100</sub>	P <sub>120</sub> N <sub>150</sub>	P <sub>120</sub> N <sub>200</sub>
<b>P<sub>160</sub></b>	P <sub>160</sub> N <sub>0</sub>	P <sub>160</sub> N <sub>50</sub>	P <sub>160</sub> N <sub>100</sub>	P <sub>160</sub> N <sub>150</sub>	P <sub>160</sub> N <sub>200</sub>

**Appendix 3: Soil moisture characteristics(Pedon DAK-P1 at the DIS)**

<b>Bars</b>	<b>kPa</b>	<b>Surface soil</b>	<b>Intermediate soil</b>	<b>Subsoil</b>
0.02	2	27.3	27	25.7
0.06	6	26.5	26.4	25.7
0.1	10	25.7	25.7	25.2
0.3	30	23.7	25	25.2
0.8	80	22.8	24.3	24.9
6.1	610	22.6	24.1	24.2
15	1500	21.9	23.5	22.6
<b>AWC %</b>		<b>1.8</b>	<b>1.5</b>	<b>2.6</b>

**Appendix 4: Response of Rice (TXD 306) to N and P at the DIS Cambisol**

Treatment	Replication I							Replication II							
	Plant height	Plants/pot	No. of Tillers	Biomass yield	Grain yield	%P	%N	Plant height	Plants/pot	No. of Tillers	Biomass yield	Grain yield	%P	%N	
<b>P0N0</b>	76	4	4	26.11	14.07	0.16	1.69	<b>P0N0</b>	75	4	4	27.68	15.03	0.15	1.71
<b>P0N50</b>	80	4	6	29.71	14.50	0.20	1.82	<b>P0N50</b>	81	4	6	30.65	13.99	0.19	1.83
<b>P0N100</b>	84	4	7	35.26	16.04	0.22	2.09	<b>P0N100</b>	86	4	7	34.14	17.24	0.23	2.11
<b>P0N150</b>	86	4	8	56.59	24.54	0.22	2.19	<b>P0N150</b>	91	4	9	57.61	23.24	0.23	2.21
<b>P0N200</b>	95	4	10	63.54	28.14	0.23	2.30	<b>P0N200</b>	95	4	10	64.40	31.16	0.24	2.32
<b>P40N0</b>	71	4	5	26.70	14.55	0.18	1.69	<b>P40N0</b>	69	4	5	25.29	14.28	0.19	1.72
<b>P40N50</b>	82	4	8	44.23	20.54	0.21	1.97	<b>P40N50</b>	83	4	7	44.85	19.66	0.20	1.19
<b>P40N100</b>	86	4	9	58.00	25.39	0.23	2.20	<b>P40N100</b>	85	4	9	57.50	24.50	0.22	2.23
<b>P40N150</b>	90	4	10	62.43	26.77	0.24	2.39	<b>P40N150</b>	91	4	11	64.49	27.23	0.24	2.40
<b>P40N200</b>	96	4	9	81.40	33.22	0.26	2.49	<b>P40N200</b>	94	4	10	79.91	32.10	0.27	2.52
<b>P80N0</b>	77	4	4	30.84	15.93	0.20	1.79	<b>P80N0</b>	76	4	4	31.24	15.95	0.22	1.80
<b>P80N50</b>	82	4	8	47.75	21.25	0.22	1.91	<b>P80N50</b>	84	4	7	48.07	22.07	0.23	1.94
<b>P80N100</b>	73	4	18	60.93	28.62	0.25	2.21	<b>P80N100</b>	77	4	22	61.27	28.46	0.24	2.28
<b>P80N150</b>	78	4	9	80.26	33.26	0.27	2.40	<b>P80N150</b>	81	4	12	81.46	34.71	0.26	2.43
<b>P80N200</b>	82	4	10	91.68	41.59	0.28	2.60	<b>P80N200</b>	85	4	13	90.65	41.97	0.27	2.68
<b>P120N0</b>	59	4	3	33.91	16.94	0.21	1.80	<b>P120N0</b>	63	4	5	32.91	15.99	0.22	1.85
<b>P120N50</b>	68	4	3	50.22	22.05	0.25	2.01	<b>P120N50</b>	72	4	6	49.64	21.86	0.26	2.12
<b>P120N100</b>	70	4	5	69.66	29.66	0.28	2.39	<b>P120N100</b>	74	4	5	70.43	28.43	0.28	2.44
<b>P120N150</b>	74	4	9	83.33	35.33	0.29	2.50	<b>P120N150</b>	79	4	9	82.47	34.47	0.29	2.51
<b>P120N200</b>	78	4	10	99.54	43.54	0.29	2.70	<b>P120N200</b>	82	4	9	98.61	44.10	0.29	2.77
<b>P160N0</b>	68	4	3	34.72	17.52	0.23	1.90	<b>P160N0</b>	68	4	3	35.52	16.55	0.24	2.12
<b>P160N50</b>	69	4	3	56.76	24.76	0.26	2.22	<b>P160N50</b>	70	4	4	56.96	25.18	0.26	2.23
<b>P160N100</b>	68	4	6	74.80	32.80	0.29	2.49	<b>P160N100</b>	66	4	5	75.72	33.09	0.30	2.52
<b>P160N150</b>	82	4	7	90.88	36.88	0.30	2.69	<b>P160N150</b>	83	4	8	89.91	35.34	0.31	2.71
<b>P160N200</b>	80	4	11	110.84	45.84	0.32	2.89	<b>P160N200</b>	86	4	10	105.25	44.29	0.32	2.88