SOIL FERTILITY STATUS AND RESPONSE OF RICE TO NITROGEN, PHOSPHORUS AND FARMYARD MANURE UNDER RAINWATER HARVESTING SYSTEMS IN SEMI ARID AREAS OF MASWA, TANZANIA

BY

GEOPHREY JASPER KAJIRU

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ABSTRACT

In semi arid areas of Tanzania, rainfed lowland rice production is constrained by inadequate plant nutrients and soil moisture thus restricting plant growth culminating into very low yields. With the adoption of appropriate rainwater harvesting (RWH) technologies the soil moisture stress is significantly alleviated. A study was conducted on the Ndala River Catchment comprised of Isulilo, Njiapanda and Bukangilija villages in Maswa district Tanzania.The objectives were to evaluate the fertility status of the soils and their suitability for rice production and the response of rice (*Oryza sativa* L. var. Supa India) to farmyard manure (F), phosphorus (P), nitrogen (N) and F-P-N applications over three cropping seasons (2002/03 to 2004/05) at Bukangilija village. The fertility status of the soils and their suitability for rice production were evaluated based on the local and technical indicators of soil fertility and land quality. Nitrogen was applied at the rate of 0, 50 and 100 kg N ha^{-1} as urea, phosphorus at 0, 30 and 60 kg P ha^{-1} as TSP and farmyard manure (kraal manure) at 0, 3.5 and 7 t ha^{-1}. The P and F rates were accordingly broadcasted and incorporated into the surface soils one week before rice sowing and N was applied at two equal splits, at tillering and panicle initiation stages. Sowing was done between December and early January based on the long term seasonal rainfall distributions. Based on local and technical indicators of soil fertility, the soils on the catchment were of low fertility status and moderately suitable for rice production under RWH. The major limitations included low total nitrogen and organic matter contents, available zinc, soil moisture retention and high exchangeable Ca: Mg and Ca: Mg: K ratios and high ESP. The F, P and N and F-P-N combinations significantly increased tillering, dry matter and grain yields and N, P and K contents in the rice plants and the main effect increases were in the order N>F>P. The ranges in the number of tillers per hill, dry matter yields, grain yields, N, P and K contents in the rice plants between the control and the highest F-P-N combinations were 10.6, 3522 kg ha^{-1}, 1342 kg ha^{-1}, 25.92 g kg^{-1}, 1.38 g kg^{-1}and 12.12 g kg^{-1} , respectively. The rice response to F, N and F and the FPN combinations were due to increased availability and uptake of plant nutrients particularly N, P and Zn. The long term seasonal rainfall amounts and distribution and El-Niño-Southern Oscillation (ENSO) indices gave good and reliable projections on the time of sowing rice seeds in the study area. Based on the generated data farmyard manure, P and N rates at 3.5 t ha^{-1} 30 kg P ha^{-1} and 50 kg N ha^{-1}, respectively could be adopted for increased and sustainable rice production where RWH technologies have been adopted on the Ndala River Catchment. Agro-climate extension service should be established.

DECLARATION

I, GEOPHREY JASPER KAJIRU, do hereby declare to the Senate of Sokoine University of Agriculture that this thesis is my original work and that it has never been submitted for a degree in any other University.

Signature: ....

Date: 26/10/2006

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LIST OF ABBREVIATION AND SYMBOLS

%	Percentage
<	Less than
>	Greater than
^{o}C	Degree Celcius
AD	Anderson-Darling test
Al	Aluminium
Al^{3+}	Aluminium ion
ANOVA	Analysis of variance
Ca	Calcium
CEC	Cation exchangeable capacity
cm	Centimetre
Cmol(+) kg^{-1}	Centimole(+) per kilogram
Cu	Copper
CV	Coefficient of variation
df	Degree of freedom
DTPA	Diethylenetriaminepentaacetic acid
EC	Electrical conductivity
ENSO	El Niño-Southern Oscillation
et al.	And others
FSR	Farming system research
g	Gram
ha	Hectare

ICRA	International Centre for Development oriented Research in Agriculture
IQR	Intra Quartile Range
IRI	International Research Institute
IRRI	International Rice Research Institute
kg	Kilogram
L	Litre
MEI	Multivariate index
Mg	Magnesium
mg	Milligram
Na	Sodium
OC	Organic carbon
P=0.05	Probability level of 0.05
pH	Negative logarithm of hydrogen concentration
ppm	Parts per million
Q	Quartile
RCBD	Randomized Complete Block Design
RWH	Rainwater harvesting
SFD	Stream flow diversion
SRF	Sheet rill flow
SST	Sea surface temperature
SUA	Sokoine University of Agriculture
TN	Total nitrogen

TSP	Triple super phosphate
USDA	United State Department of Agriculture
WARDA	West Africa Rice Research Development Association
Zn	Zinc

CHAPTER ONE

1.0 INTRODUCTION

It is estimated that Tanzania is endowed with 88.6 million hectares of arable land of which 60 million hectares are suitable for livestock rearing (Semboja *et al.*, 1998). Of this entire total, only 6 - 7 million hectares are used for rainfed agriculture while 24 million hectares are used for rearing livestock, the remaining 57.6 million hectares remain untapped. Of the 6-7 million hectares of land suitable for rainfed agriculture, 330,000 hectares are under rice production (FAO, 2005), of which 74 % are under rainfed lowland rice in the semi-arid areas of Tanzania (Kanyeka *et al.*, 1994).

On the basis of agricultural potential, it is estimated that more than 50 % of the land in Tanzania is semi-arid or arid (LRDC, 1987). The term semi-arid refers to conditions where rainfall ranges from 400 to 800 mm per year, and/or potential evapo-transpiration exceeds rainfall in most of the time and/or the rainfall regime is highly variable in quantity, timing, distribution and intensity (Hatibu *et al.*, 2006). Therefore, semi-aridity is characterized by three main conditions; namely i) low amounts of rainfall, ii) high evapotranspiration rates and iii) erratic temporal and spatial distribution of the rainfall (Nieuwolt, 1973; Mahoo *et al.*, 1999a). It has been reported that in most parts of Tanzania, potential evapotranspiration exceeds rainfall during more than nine months of the year. Further, about 22 % of the land in Tanzania, receives 570 mm or less of rainfall in 9 years out of 10 years (Nieuwolt, 1973). Often long dry spells occur during the growing season to the extent that crop and pasture production is significantly reduced even when total rainfall amount is higher than 800 mm per annum (Mahoo *et al.*, 1999a). Low and variable rainfall distribution, which is the main characteristics of semi-arid areas of Tanzania, should be given due consideration to ensure adequate availability and efficient use of soil moisture (or rainfall) by plants during their growth cycle. This can be achieved through the adoption of the appropriate technologies, strategies and practices of soil moisture conservation.

In spite of low and variable rainfall in the semi-arid areas of Tanzania, these areas account for about 35 % of the national rice production grown under rainfed lowland system through irrigation and harvested rainwater. The rainfed lowland rice is grown on level to slightly sloping bunded fields with non continuous flooding at various depths and durations (Zeigler and Puckridge, 1995). The system is characterized by variable crop performance due to differing seasonal rainfall conditions and spatial heterogeneity of soil types and topographic conditions (Wade *et al.*, 1999). Grain yields of rainfed lowland rice in semi-arid areas of Tanzania are often low ranging from 1.5 to 2.5 t ha^{-1} (URT, 2003). The low rice yields is caused by, among other things, drought (low rainfall) and hence inadequate soil moisture during the growing period and low soil fertility (Shepherd and Soule, 1998; Fukai *et al.*, 1999). Drought is a complex phenomenon that may set-in before transplanting to late in the growth stages of the rice plants. The variation in both timing and intensity of drought in semi-arid areas makes it particularly difficult to breed rice adapted to rainfed environments. Low soil fertility is also complex and very little progress has been made in rice breeding to overcome the large number of nutrients which may be in limited supply or the toxic levels of nutrients in acid soils like Al^{3+} and H^- and saline-sodic soil conditions nutrients like Na^+ , Mg^{2+} and Ca^{2+}, cause imbalance of other nutrients (Fukai *at el.,* 1999).

In semi-arid areas of Tanzania particularly Maswa district, inadequate soil – moisture for plant growth aggravates the problem of low soil fertility and hence rice production. In Maswa district, Shinyanga region rice grain yields ranged from 2.5. to 3 t ha^{-1} (Hatibu, *et al.*, 2005) compared to the FAO average of 4 t ha^{-1} (FAO, 2005). The rice grain yield levels have been increased significantly in areas where RWH is being practiced. The adoption of various RWH technologies in semi-arid areas of Dodoma, Singida, Shinyanga, Kilimanjaro and Tabora regions, Tanzania have reduced the constraint of soil – moisture to crop production by about 10 to 50 % (Gowing *et al.*, 1999), resulting into increased rice grain yields.

The consequences of adoption of RWH technologies are increased plant growth and nutrient demand due to intensification of rice production hence progressive decline in soil fertility, which lead to low rice yields. This is attributed to the fact that, there have not been parallel and equivalent efforts in the adoption of strategies to improve soil fertility so as to sustain the anticipated high rice yields. The gradual decline in rice yields and soil fertility has resulted into decline in farm income from rice production and land degradation. The low soil fertility status in most of semi-arid areas under rainwater harvested rice production systems is caused by nutrient imbalances, limited use of inorganic and organic soil amendments. In an attempt to sustain high rice production by replenishing the nutrients taken up by the rice crop.

about 10 % of households in Maswa district use inorganic fertilizer and organic soil amendments in crop production (SWMRG, 2003). However, the rates of inorganic fertilizers and manure used by the farmers are very low hence their contribution to sustainable soil fertility is insignificant.

The limited use of inorganic and organic soil amendments (like manures) is caused by poor extension service in educating farmers on the benefits of using the above amendments in rice production and high transport and fertilizer costs and prices, respectively. The problem of high prices of fertilizers and transportation costs could significantly be overcome if farmers opt to use the farmyard manure produced in the vicinity of the farmers' homesteads. Further, as a soil fertility management strategy, manures contain all the essential plant nutrient elements that are released gradually during the growing season. Further, manure positively improve the physical, chemical and biological soil fertility and productivity. About 50 % of the households in Shinyanga region have cattle that can provide farmyard manure that can be used as source of plant nutrients to supplement and in a certain instances substitute the use of inorganic fertilizers in crop production (Meertens *et al.*, 1999). However, it has been reported that only few of the farmers (10 % of the households) are using cattle manure in crop production due to lack of awareness of the benefits of using manures in soil fertility management strategies (SWMRG, 2003).

The inorganic N-fertilizers recommendation of 40 kg N ha^{-1} for rice production that is currently in use in Shinyanga region, Tanzania is based on blanket recommendations with limited soil analytical data and field experiments that were conducted in some of the rice growing areas (Mowo *et al*., 1993). Other studies on the effects of various combinations of inorganic and organic soil amendments in semi-arid areas of Tanzania on rice were conducted for one season thus the results were not conclusive hence no recommendations were made (Meertens *et al*., 2003).

Crop yields and particularly for rainfed lowland rice have been shown to decrease because of moisture deficiencies as a result of poor rainfall amounts and distribution during the growing period. Intensive input applications such as fertilizer may only be worthwhile if soil-moisture conditions are favourable. Farmers rely on receiving adequate rainfall throughout the growing season which is not the case in semi arid areas of Tanzania. However, input decisions are often made assuming average weather conditions would occur. Considering the variability of rainfall in the semi arid areas of Maswa district, there is a need to enhance the comprehension of variability in the long term seasonal rainfall distribution by farmers with the goal of reducing uncertainties and the risks of investment such as fertilizers and manure inputs in the rice production.

Similarly, there is a need to study the effect of organic and inorganic soil amendment in a systematic way so as to generate more reliable results that can be extrapolated to other areas. Use of both inorganic fertilizers and manures in optimal combinations can reduce the amounts of inorganic fertilizers that are to be used, hence improvement of soil fertility (Ghosh and Sharma, 1999) and farm income. This would in turn increase productivity of water in macro catchment RWH systems in Maswa district. In view of this, there is need to study the rainfall characteristics, soil fertility status, response of rice to inorganic and organic soil amendments and dynamics of nutrients in soils and develop soil fertility management strategies in macro catchment RWH systems for increased and sustained rainfed lowland rice production in semi-arid areas of Tanzania, so as to come up with realistic and economic fertilizers and manure recommendations.

The overall objective of the study was therefore to develop improved practices of soil fertility management that would improve and sustain rainfed lowland rice productivity in macro catchment rainwater harvesting systems in semi-arid areas of Tanzania. This has been promoted by the low rice yields in semi-arid areas where RWH systems and technologies are being practiced. The above general objective would be achieved through the following specific objectives;

i) To quantify the nutrient status of the rainfed lowland rice growing soils on the Ndala River catchment, Maswa, Tanzania.

ii) To characterize and categorize the soils on the Ndala River catchment for their suitability for rice production.

iii) To determine the response of rice to inorganic nitrogen (N), phosphorus (P) fertilizers and farmyard manures (F) as well as the combination of the three at various levels with respect to rice plant growth, straw and grain yields and nutrient uptake at Bukangilija village, on the Ndala River catchment Maswa, Tanzania.

iv) To determine the nutrient balances with respect to elemental nitrogen (N), phosphorus (P) and potassium (K) and sustainability of rainfed lowland rice at Bukangilija village, Maswa, Tanzania.

v) To determine rainfall characteristics and the potential for seasonal rainfall forecasting as an aid to strategic decision making in rainfed lowland rice cropping systems in Maswa, Tanzania.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Rainfed lowland rice

Rainfed lowland rice occupies about 46 million ha or about 35 % of the global land area suitable for rice production and is mostly grown in South and Southeast Asia (Maclean *et al.*, 2002). In West Africa, the rainfed lowland rice cultivation system occupies 82 % of the area under rice cultivation and accounts for 75 % of the rice produced in the region (WARDA, 1994). In Tanzania, of the 330,000 ha of the area under rice production, 74 % is under rainfed lowland rice where 20 % is used for upland rice, and 6 % is irrigated rice (Kanyeka *et al.*, 1994). Meertens *et al.* (1999) gave a detailed account of the introduction and characterization of rainfed lowland rice environment in Sukumaland (Northwest, Tanzania) where 35 % of Tanzania's rice is produced (Mdalila, 1998).

According to Carpenter (1978) the first appearance on the East African coast of *Oryza sativa* type of rice may have been brought by traders from Sri Lanka and India sailing via Oman to Somalia, Zanzibar and Kilwa some 2000 years ago. Introduction of *Oryza sativa* into the hinterlands of Africa was along the slave trading routes from the East African coast and Zanzibar to Zaire during the 19th century. The area inhabited by *Wanyamwezi* (the ethnic group) in central Tanzania became the inland base of the traders from 1852 onwards (Iliffe, 1979). From the headquarter at Tabora one route led to neighbouring Sukumaland, the area inhabited by *Wasukuma* (the ethnic group) bordering Lake Victoria in Northwestern Tanzania. Formally unknown crops such as maize, cassava and rice were introduced along the caravan routes to supplement the local diet of millet, soughum and banana. The cultivation of rice was mostly by Arab traders who settled in these areas. The local farmers were not initially interested in rice because its production turned out to be less reliable in comparison with millet and sorghum due to inadequate soil moisture. The cultivation of rainfed lowland rice in Sukumaland was not encouraged between 1960s to 1980s, because the Tanzanian Government regarded Sukumaland as semi-arid environment suited only for drought resistant crops such as cassava, sorghum and cotton (Meertens *et al.*, 1995). In semi arid areas, the construction of bunds to conserve water in the fields in the cultivation of rainfed lowland rice is essential. The function of the bunds is to catch and control the runoff water because of the highly unreliable rainfall and relatively low (700 – 1000 mm) total annual rainfall (Meertens *et al.*, 1999). This technology led to interest in rice cultivation in the semi-arid areas of Tanzania.

2.1.1 Environmental requirement of rainfed lowland rice

De Datta (1981) classified rice cultivation in accordance with sources of water supply as rainfed or irrigated. Based on land and water management practices, lands suitable for rice production are classified as lowland (wet land preparation of fields) and upland (dry land preparation of fields). Further, according to water regime, rice have been classified as upland with no standing water, lowlands rice with 5-50 cm of standing water and deep water rice with greater than 50 cm of standing water (De Datta, 1981).

Kanyeka *et al.* (1994) classified rice cultivation system in semi arid areas of Tanzania as rainfed lowland based on water availability. The lowland rice production system is characterized by water deficit at various stages of the growth cycle of the rice plants, hence limiting nutrient availability and nutrient uptake which in turn limits rice growth with consequent low yields.

The cultivation of rainfed lowland rice in Cambodia (Lando and Mark, 1994), Loas, Nepal, Thailand and Madagascar (Fujisaka, 1990) showed that the main management practices do not differ from those practiced in semi arid areas of Tanzania. These management practices include; land preparation, crop establishment (direct seeding or transplanting), weeding and harvesting. The only exceptions are rice fields in the flood plains near rivers which receive water from floods (Enserink *et al.*, 1994) and the rice fields are not bunded. This type of rice production is called unbunded flooded rainfed lowland rice system due to adequate water availability and is also common in the southern part of Tanzania (Kanyeka *et al.*, 1994) where the rainfall is greater than 800 mm per annum and reliable.

2.1.2 Rainfall pattern in semi-arid areas of Tanzania

In the rice growing areas in Northwest Tanzania, rains start in October and end in May. The rainfall pattern could be considered to be bimodal with peaks in November-December and March-April although rainfall patterns in the interland of Tanzania is categorized as unimodal. The rains are localized and unpredictable (Mahoo *et al.*, 1999a). Dry spells are common throughout the rainy season but are more pronounced in January-February. Potential evaporation rate of about 4.5 mm

day^{-1} occur during the rainy season due to high temperatures (ICRA, 1991). According to water balance as classified by Garrity *et al.* (1986) which is based on water retention potentials (slope and soil texture), rainfall amounts and length of the growing season, the rainfed lowland rice of Northwest Tanzania is drought prone. The production of rainfed lowland rice in semi arid areas of Northwest Tanzania is practiced along the toposequence in bunded fields so as to conserve the run off water (Kajiru *et al.*, 1998; Meertens *et al.*, 1999).

2.1.3 Soils along the toposequence in semi arid areas of Tanzania

The term toposequence or catena refers to the systematic arrangement of soils in a landscape and their associated moisture regimes (rainfall distribution) and the physical and chemical fertility properties (Stoop, 1987). The systematic nature of the catena provides a logical framework that can be used to understand crop system arrangements and related farmers' cropping strategies (Stoop, 1986; 1987).

Based on the regional map of Tanzania, Sukumaland includes Shinyanga, Mwanza, and part of Tabora regions. In the Sukumaland, different soil types and their extent of coverage along the toposequence have been identified in most of the semi arid areas (Fig. 1). There is a well-developed indigenous knowledge of the soils along the toposequence in many parts of the semi arid areas of Tanzania. For instance, knowledge of the *Sukuma* people (native ethnic group in Sukumaland) was popularized internationally by Milne (1947). The extent of coverage of different soil types along the toposequences in three locations of the Lake zone is portrayed in Table 1.

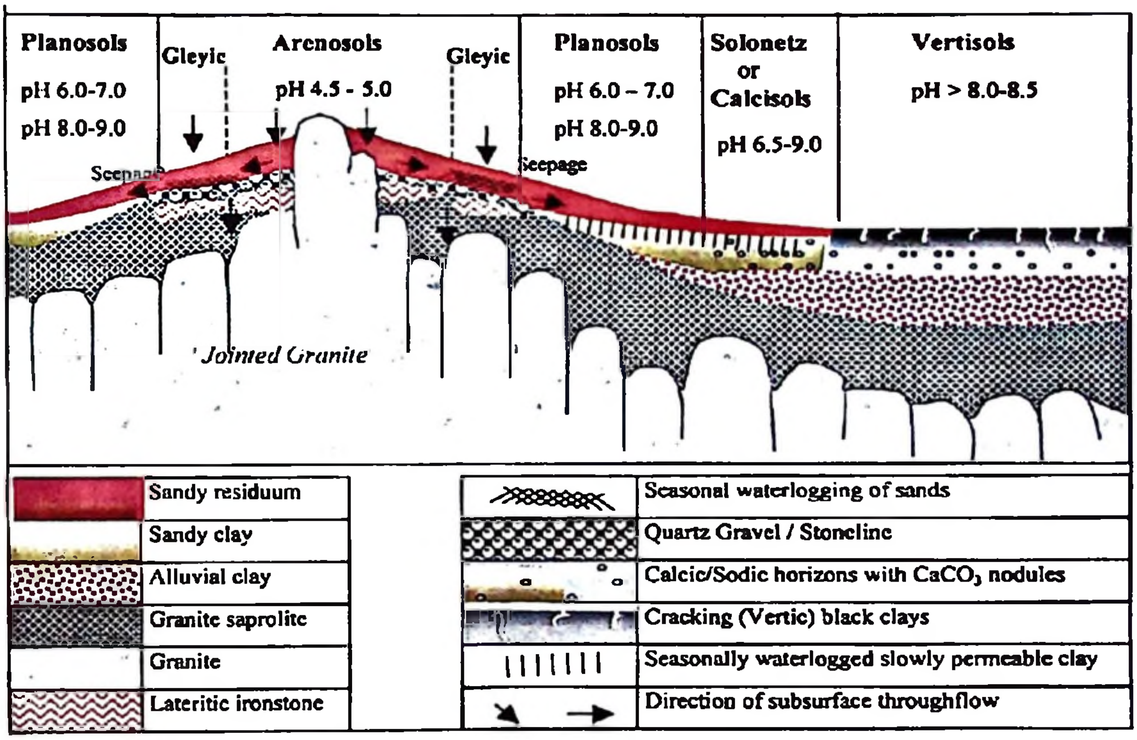


Figure 1: Idealized catena sequence in Northwest Sukumaland of Tanzania

Source: Payton, (2000).

Table 1: The extent of coverage and distribution of different soil types along the toposequence in three locations in the Lake zone, Tanzania.

Name		Area coverage (%)		
Local	Scientific (FAO-UNESCO-1990)	Tabora	Ngudu	Misungwi
Luguru	Lithosols	6	6	8
Luseni	Arenosols	45	15	5
Ibushi	Calcisols	2	1	17
Itogoro	Planosols	6	60	45
Mbuga	Vertisols	30	18	25

Source: Hatibu *et al.* (2000).

Hatibu *et al.* (2000) gave description of different local soil names in relation to run off generation found in most of the semi arid areas of Tanzania. These included;

a) *Luguru.* These soils are found on mostly exposed bare, rocky hilltops, dominated by granite boulders with interspersed gravely, loamy soils. This type of soil is good for run off generation as water infiltration is almost negligible due to presence of rocks.

b) *Luseni.* These soils are grey to reddish-brown, coarse sandy soils derived from granitic parent materials. These soils occupy the upper and mid-slopes next to *Luguru* in the toposequence (Sumnit). Soil depth is variable and sand content in the top soil generally exceeds 80 %. Due to their coarse texture, permeability is high while water holding capacity is 30 mm of water per metre of soil. This type of soil is not good for run off generation.

c) *Itogoro.* These are hard pan soils occupying lower slopes next to *Luseni* soils on the toposequences. They are also derived from granitic parent materials as the *Luseni* but have fine texture, that is, less sand than the *Luseni.* Their important feature is a hard pan layer at about 30-50 cm depth which restricts percolation of water. This encourages rapid saturation of the topsoils leading to high rates of run off. The soils have available water holding capacity ranging from 30 – 100 mm of water per metre depth of soil, categorized as high.

d) *Mbuga*. These are heavy, light grey to black cracking soils occupying the valley floors next to *Itogoro* soils. The majority of the fine fractions transported down slope are eventually deposited on the valley floors and in depressions where they developed to dark coloured clayey soils. These soils have high moisture retention compared to the other soils on the toposequence.

The toposequence, common in many parts of semi arid areas, is a naturally occurring RWH system. The Luguru parts at the top generate run off which flow through the *Luseni* and *Itogoro* parts picking plant nutrients before its concentration on the *Mbuga* soils. Maggogo (1990) gave some physical and chemical properties of three major soil type along the toposequence in Northwest, Tanzania (Table 2). Based on Landon rating of various soil attributes (Landon (1991) the *luseni* and *Itogolo* soils have high percent of sand while *mbuga* soils have high percent of clay content thus have high capacities to retain plant nutrients and water. The soils have very low (*Luseni and Itogolo*) to low (*mbuga*) total nitrogen while available phoshorus and exchangeable potasium were low to medium and CEC were very low (*luseni and Itogolo*) to very high *(mbuga)*. Exchangeable magnesium and calciaum ranged from very low (Luseni) to very high (*Mbuga*). Based on the analytical data the soils in Table 2 are rated as medium suitable (S2) for rice production. The main limiting factors are low total nitrogen, very low to medium organic carbon, exchangeable potassium and available phosphorus.

2.1.4 Production constraints to rainfed lowland rice

Boling *et al.* (2004) reported that moisture deficit, nutrient deficiencies (N and K) and pest infestation are the major determinants of high yields of rice in Philippines. Supplying adequate nutrients in the form of fertilizers and manures and good pest control are equally important as moisture deficit management for increasing productivity of rainfed rice (Boling *et al.*, 2004). The relative importance of moisture deficit, nutrient and pest management may vary in other rainfed rice cultivation areas, therefore, yield constraints analysis should be systematically carried out to identify appropriate soil and crop management strategies.

Table 2: Some characteristics of the dominant soil types along the toposequence in Northwest, Tanzania

Parameters	*Luseni*	*Itogoro*	*Mbuga*
Depth (cm)	0-13	0-24	0-17
Sand (%)	84.00	80.00	10.00
Clay (%)	10.00	8.00	72.00
Silt (%)	6.00	12.00	18.00
pH (water)	6.80	6.70	7.70
pH -KCl	6.10	5.10	7.00
% Organic carbon	0.40	0.60	1.50
% Total Nitrogen	0.03	0.06	0.12
P Bray (ppm)	6.00	3.00	13.00
K ($cmol_{(+)}$/kg soil)	0.11	0.20	0.53
Ca ($cmol_{(+)}$/kg soil)	0.90	2.60	37.00
Mg ($cmol_{(+)}$/kg soil)	0.10	0.70	7.60
CEC ($cmol_{(+)}$/kg soil)	3.40	4.90	62.70
Base saturation (%)	35.00	77.00	73.00

Source: Maggogo (1990).

In semi arid areas of Tanzania, the constraints to rainfed lowland rice production have been documented by Meertens *et al.* (1999). In their work, the rice farmers in the Maswa hardpan plain regarded weed infestation as the most important constraint to rice production. The problem of water availability ranked second and other problems included stem borer infestation, low soil fertility and high prices and low availabilities of agricultural inputs. The presence of hardpan in the subsurface layers of the soils restricted water infiltration consequently encouraging water ponding in bunded rice fields with frequent increase in rice growth performance.

For the rainfed rice ecosystem the amount and timing of water supply to rice crop in the field are considered the most severe constraints to productivity (Widawsky and O'Toole, 1990; Zeigler and Puckridge, 1995). Wade *et al.* (1999) reported that within a small area like for example, 10 ha, the hydrology of rainfed lowland rice differs greatly depending on the surrounding landscape hence variation in yields. Rice paddies are commonly grouped in accordance with their positions along the toposequence. Paddies in higher or upper terrace lose large amounts (volumes) of water readily after heavy rains through surface run off and seepage due to steep slopes and coarse soil texture. On the other hand, those in the lower part of the toposequence may intercept the water that flows in from paddies on the upper position resulting in ponding of the fields. This lateral water movement results in different periods of water availability and rice growing duration often by more than 30 days within a small area (Wade *et al.*, 1999). Consequently, the upper terraces may be classified into the drought prone subsystem as they can loose water easily due to coarse soil texture while the lower terraces may belong to the submergence-prone or drought-and-submergence prone sub ecosystem.

Homma *et al.* (2003) reported that there exist steep gradients in soil fertility variations along the toposequence of rainfed paddy fields in Northeast Thailand. In their study, it was concluded that although water availability is the main rice production constraint in rainfed culture areas, experiments under well watered conditions indicated that rice productivity can not be substantially improved by irrigation alone because of low soil fertility status common in semi arid areas. Thus improvement of soil fertility is evidently one of the key technologies for improving rainfed rice productivity. There is also variation in soil fertility status at different positions of a toposequence. Generally, upper terraces have soils with high sand content, whereas clay content increases at the lower terraces hence the variations both in the physical and chemical attributes of soil fertility and productivity.

Weed problem in rainfed lowland rice is directly related to water availability in the excavated bunded fields and the method of crop establishment (Williams *et al.*, 2005). Weed control is difficult in rainfed lowland rice partly because of erratic and unpredictable rainfall. The type of weeds that emerge is closely related to the moisture content of the soils and water depth (Williams *et al.*, 2005). In standing water, growth is always stressful during seedling establishment, and deep water jeopardizes the rice crop. It is important, then, to determine the safe limit for water depth that will maximize the suppression of weeds without unacceptable risk to the rice plants. When water control is poor labour required for weeding increases. Water management can therefore partly substitute weeding in rice fields. Grassy weeds such as *Hydrophila spinosa* may be completely eliminated if a flooding depth of 15 cm is maintained throughout the rice crop growth cycle (Bhan, 1983). Based on the above, it can be concluded that water availability is the primary constraint to rainfed lowland rice production as it influences the availability and uptake of nutrients and weed proliferation.

The Farming System Research (FSR) in the Lake Zone (1989) hypothesized that low yields in rainfed lowland rice in Maswa and Meatu districts, Tanzania is a result of low soil fertility caused by continuous cultivation of rice in the same field without the application of any form of soil amendments. Consequently, on farm soil fertility trials were conducted in rainfed lowland rice in Sukumaland, Tanzania (Enserink *et al.*, 1994; Kajiru *et al.*, 1998; Meertens *et al.*, 2003) with the main objective of determining soil fertility status and fertilizer recommendations. These trials were of short duration, especially on the response of the rice in terms of yield to combinations of farmyard manure, phosphorus and nitrogen, thus no conclusive results were obtained. Therefore, due to variability in rainfall and the interaction between water and nutrient availability, there is a need to address the problem of low soil fertility in a systematic manner. Thus, this research, among other things, addressed this gap.

2.1.5 Effect of moisture stress on growth stages of rainfed lowland rice

Moisture stress is one of the major problems that affect crop growth worldwide. The problem is complex in rainfed lowland crops, as it may occur early in the growing season or from flowering to grain filling, and may follow a period in which soils are flooded and anaerobic (Wade, 1999). Moisture stress affects almost all the growth processes but the stress response depends upon the intensity, rate and duration of exposure and the growth stages of the rice plants (Kramer, 1983; Brar *et al.*, 1990). The reduction of growth due to moisture stress is mainly through its influence on leaf expansion, which determines the potential photosynthetic productivity of plants (Chen *et al.*, 1993).

IRRI (2005) reported that the response of the rice plant to water stress on rice varied with its growth stage and other agronomic practices. It was noted that direct sown rice is less prone to moisture stress than transplanted rice at early stages of rice growth. During the growing season, rainfall amount of at least 100 mm is required per month by the rice crop (De Datta, 1981) for optimal productivity other factors being optimum as well.

Water requirement is low at the seedling stage (De Datta, 1981). It has been reported that unless there is severe water stress at seedling stage of the rice plants recovery of the effects of moisture stress by the rice plants is possible. Crop establishment depends on the onset of rainfall and De Datta (1981) observed that rainfall of at least 3 mm per day is sufficient to generate runoff in lowland rainfed rice fields. Moisture stress in any growth development phase of the rice plant has an effect on rice grain yields (De Datta, 1981; Rahman *et al.*, 2002; Pirdashti *et al.*, 2003; Hemmatollah *et al.*, 2004). Moisture stress in the first three months of the rice plant growth stage has an effect on crop establishment. De Datta (1981) reported that 150 mm of water is required for raising the seedling and 200 mm for land preparation (puddling).

Water stress during the vegetative stage reduces plant height, number of tillers and leaf area (IRRI, 2005). However, the effect during the rice plant vegetative stage varies with the severity of moisture stress (IRRI, 2005). Long duration rice varieties suffer less damage than short duration varieties as long vegetative period could help the plant to recover when water stress is relieved (IRRI, 2005).

Rice is most susceptible to water stress during the reproductive stage (IRRI, 2005). It was observed that water stress at or before panicle initiation reduces panicle number significantly, but all stresses regardless of crop stage or duration substantially reduce panicle numbers. Anthesis and ripening stages are the most sensitive to water stress. Water stress during anthesis increases the likelihood of unfilled spikelets while stress during grain filling decreases translocation of assimilates to the grain, which decreases grain weight and increases the likelihood of empty grains. Hemmatollah *et al.* (2004) reported that yield reduction as a result of moisture stress were 21%, 50% and 21 % at vegetative, flowering and grain filling stages, respectively when compared to the control (6 t of rice grain ha $^{-1}$) where soil moisture and other growth factors were optimal.

2.2 Measures to alleviate moisture constraints in rainfed lowland rice

In rainfed lowland rice production, measures to alleviate moisture constraints have been implemented through various rainwater harvesting techniques. From crop production point of view, rainwater harvesting (RWH) has been defined as the process of concentrating, collecting and storing water for plant use at a later time in the same area where the rain falls or in another area during the same or later time (Hatibu, 2000; Gould and Nissen-Petersen, 1999; Oweis *et al.*, 1999; Frasier, 1994; Reij *et al.*, 1988; Pacey and Cullis, 1986). RWH is commonly practiced in semi arid areas for rainfed lowland rice production through in-situ, micro and macro rainwater harvesting techniques under small scale rice production system.

Rainwater harvesting basically involves all the conventional approaches of soil and water conservation and management designed to enhance infiltration of rainwater into the soil, prolonged storage and consequently availability to plants. These include approaches such as ridging, tie ridging and contour bunding (tillage practices). Rainwater harvesting for crop production is therefore a continuum that ranges from conventional soil and water conservation such as ridging at one end to irrigation at the other medium to large scale farming.

Hatibu (2000) observed that RWH is justified by the nature of rainfall in the semi arid areas where if not managed, it quickly evaporates or runs as flash floods into saline sinks. Thus, the starting point of RWH is to capture rain where it falls for the purposes of meeting the water needs of the area such as livestock and crop production. Any excess can then be directed for the use in the downstream areas. In relation to plant growth, capturing rain where it falls is called in-situ RWH.

2.2.1 Practices of rainwater harvesting

Evenari *et al.* (1971) reported that runoff has been concentrated on lands to grow crops in arid and semi arid areas in some parts of the world for centuries. However, the surface storage in the form of small reservoir in conjunction with runoff concentration on lands has not been extensively used because of the high costs and labour involved. Rainwater harvesting is practiced in several countries in the world such as Israel, India, Pakistan and China for crop production and animal consumption. In Africa it is mainly practiced in North Africa and is relatively new in the Sub-Saharan Africa countries in areas where rainfall is low and highly unreliable such as in semi arid and arid areas (Reij *et al.*, 1990).

RWH for crop production also known as runoff agriculture constitutes four major categories (Reij *et al.*, 1990) and these include, RWH on short slopes or micro-catchment water harvesting, RWH on long slopes or macro-catchment, flood water harvesting within the streambed and flood water diversion. The RWH basin plus catchment systems from short (less than 100 m) slopes for trees or cereals varies between 0.5 – 1000 m^2 (Boers and Ben-Asher, 1982). The most well known systems of RWH are the demi-lunes (small semi-circular hoops) in West Africa and Kenya (Fig. 2) and 'Meskat' micro-catchment in Tunisia (Fig. 3) with slopes ranging from 1% to 7 %. RWH from long (greater than 100 m) slopes also referred to as external catchment RWH systems receive external runoff through earth bunds enclosing relatively large areas and collects large quantities of water (Finkel *et al.*, 1987).

Floodwater harvesting within the streambed comprises those techniques that concentrate runoff in the streambed by blocking the water flow. The valley bottom is cultivated and the water is utilized on the spot (UNEP, 1983). Cross - Wadi walls built of stones in Jordan and the silt trap in Mexico are examples of the forms of in-bed floodwater harvesting system (Gilbetson, 1986). Floodwater diversion comprises those techniques that force water to leave its natural course. Warping is one typical example of RWH practiced in China (UNEP, 1983). Its main purpose is to fertilize the soil with nutrients contained in the water and simultaneously irrigate the crops/land.

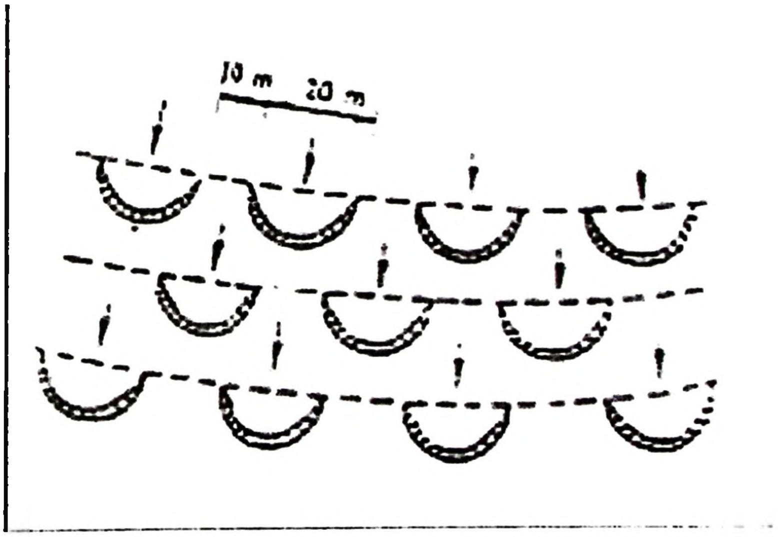


Figure 2: Rainwater harvesting with semi-circular bunding (demi-lunes)

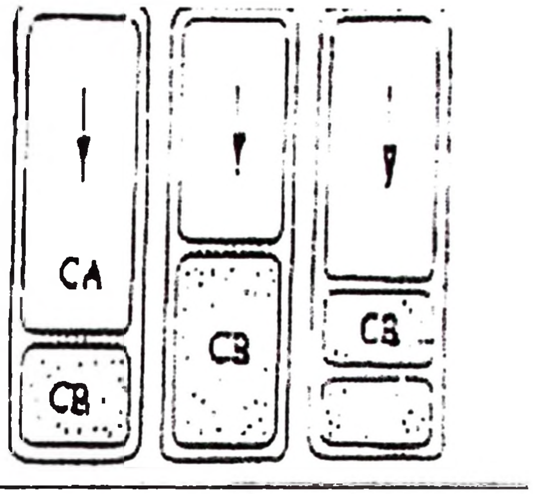


Figure 3: Rainwater harvesting with Masket- type bunding

2.2.2 Practices of rainwater harvesting in Tanzania

Rainwater harvesting for rainfed lowland rice production in Tanzania is mainly practiced in Shinyanga, Tabora, Mwanza, Singida, and Dodoma regions. Mwakalila (1992) reported that RWH is mainly used for rainfed rice production in which rainwater is collected from diversion of water from ephemeral streams and stored in excavated bunded basins (EBB) locally known as "*majaluba*" which are rectangular in shape. The basins are built with simple provision for entry and outlet of water. The EBB wall heights vary from 25 to 100 cm for the purpose of conserving ponded water during rice growing period.

Two sources of run off in the semi arid areas of Tanzania have been identified, namely, macro (external) catchment and flash floods from seasonal streams (Hatibu and Mahoo, 1999; Mahoo *et al.*, 1999b). The catchment length is divided into three major parts (Mahoo *et al.*, 1999b), namely;

i). steep slopes (up to 20°) on the rocky ground at the top of the catena consisting of numerous hills,

ii). medium slopes of between 4 – 10°, that consist of light textured soils (sandy soils) and are normally covered by scattered bushes and

iii). gentle slopes (up to 4°) on sandy to sandy loam soils of shallow depth at valley bottom.

These catchment characteristics coupled with the intense storms received in the area lead to high run off yields in some years resulting into floods and sedimentation of fields on the gentle slopes and plains. The flash floods from seasonal rivers are another source of run off (Mahoo *et al.*, 1999b). The main differences in run off management in the semi arid areas of Tanzania are related to the techniques used in the control of run off water, of which three have been identified in semi arid areas. These include stream flow diversion (SFD), sheet rill flow (SRF) and sub surface sand river bed (Mahoo *at al.*, 1999b).

a) Stream flow diversion (SFD)

The SFD technique involves diverting water from its natural ephemeral stream and conveying the water to arable cropping areas where it is distributed as spate irrigation (Fig. 4). In this technique, cultivated fields close to an ephemeral stream are first divided into excavated bunded basins (fields) and by means of small weir, water is diverted from the stream into the top most basins. The water fills this basin and the surplus spills to the next basin through purposely-designed openings until all basins are fully wetted.

The system is constrained by the small amounts of water conveyed into the cropped land. In addition, the channels are susceptible to frequent damage and siltation caused by run off water as the water flow speed decreases. The basins are filled with water sequentially leading to the tail-end syndrome (whereby the fields at the tail-end get little or no water at all). Due to slope being very low, the canal flow does not command substantial irrigatable area due to short distance of the canal. The fields located near the stream have higher risks of being damaged by floods.

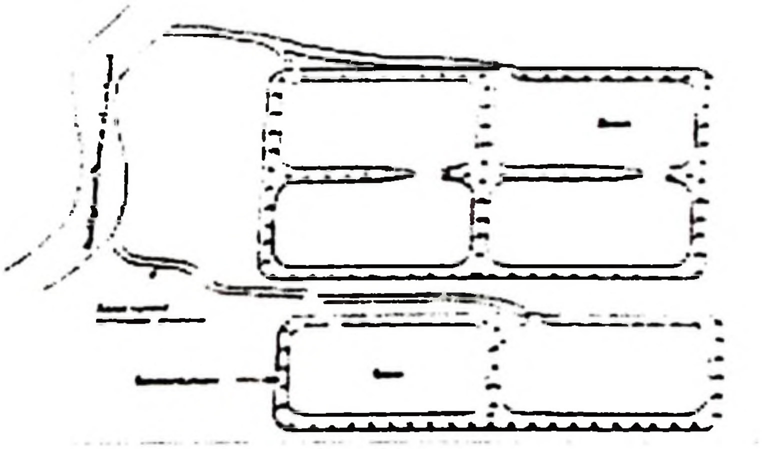


Figure 4: **Ephemeral stream flow diversion with distribution canals in Maswa district**

Regardless of the above limitations, the technique has received attention and Maswa District Council is implementing a stream flow diversion project at Bukangilija village so as to address the problem of moisture deficit in rice production.

b) Sheet rill flow (SRF) run off

This technique is practiced at upper, middle and lower parts of the Ndala river catchment, Maswa District. The technique involves harnessing the natural occurring surface run off (Fig. 5). The flat to gently sloping characteristics of the catchment do not allow concentration of run off to form gullies. Therefore, the run off moves in the form of sheet flow and is harnessed by constructing bunds across the directional of the flow and water is directed into the cropped fields using short channels/canals.

The technique is still crude and a lot of water (about 75%) is not captured (Mahoo *et al.*, 1999b). The main problem involves the location of interceptor bunds and channels. Sometimes these are not located along the contour, leading to their collapse and loss of the harnessed water. It was further reported that there is under utilization of the generated run off due to shortage of good land, poor interception of run off and lack of intervention to further develop this technique in Maswa district (Mahoo *et al.*, 1999b).

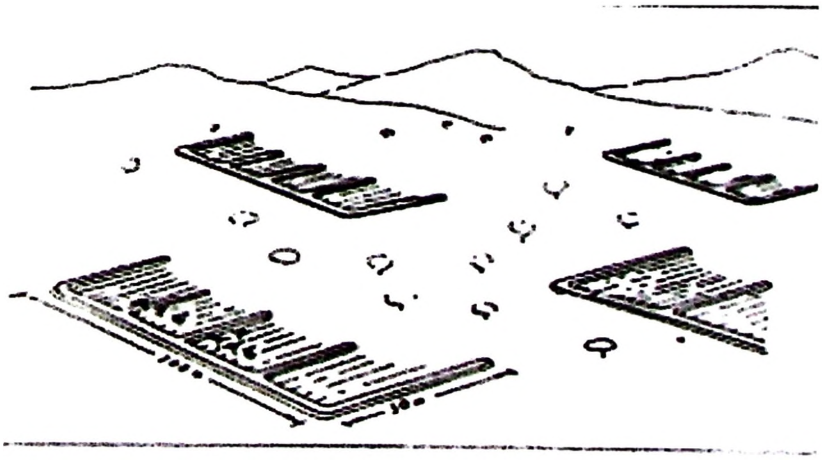


Figure 5: Hillside sheet/rill run off utilization in Northwest, Tanzania

c) Sub surface sand riverbed

This technique is practiced at upper, middle and lower parts of the Ndala River catchment, Maswa district. The technique depends on the water, which accumulates under the sand in the riverbeds with little intervention. Water is obtained by digging the sand riverbeds during the dry season. The technique is used opportunistically as a major source of water throughout the year for livestock and domestic use during the dry season.

The Kilimanjaro Agricultural Training Centre (KATC) (1995) reported that the distribution of rainfall in the paddy growing areas of Kilimanjaro and Northwest of Tanzania is very unreliable and frequent occurrence of dry spells in these areas make paddy cultivation risky. Some of the farmers are reported to have adopt various coping measures which include (i) establishing low plant densities in the paddy fields (less competition for water during dry spell), (ii) growing drought tolerant rice varieties of indica type and (iii) allowing for flexibility in transplanting time and water depth regulation in their rice field as an attempt to make the best of the little soil-moisture for rice production. These measures are profitable compared with the situation in areas where attempts to harvest rainwater and to conserve soils are not being practiced.

2.3 Use of El-Niño-Southern Oscillation (ENSO) index for weather forecasting in semi arid areas

2.3.1 El-Niño-Southern Oscillation (ENSO)

IRI (2005) observed the interaction among El Niño, La Niño and El Niño-Southern Oscillation (ENSO) phenomenon. ENSO is a coupled oceanic atmosphere mechanism occurring in the tropical Pacific basin. During an El Niño event, also known as a warm event, the normally cool coastal waters off the Peruvian coastal are replaced by abnormally warm surface water. The warm water extends to form a tongue along the equator as far as the dateline. The depth of the thermocline increases and the cold water upwelling off the coast of South America becomes less or ceases completely.

The changes in sea surface temperatures (SST) is coupled with changes in atmospheric pressure and circulation. The South Pacific high and Indonesian low pressure areas, which constitute the Walker circulation, weaken and in some cases the Walker cell can reverse completely. These atmospheric and oceanic changes have an impact on rainfall and temperature around the Pacific basin. A La Niña, or cold event, is typified by an intensification of normal conditions. The Walker circulation strengthens and the area of normal cool water off Peruvian coast expands. For this research, the phrase ENSO refers to the overall phenomenon whilst the terms El Niño and La Niña refer to warm and cold episodes, respectively. A La Niña event often, but not always, follows El Niño and vice versa. The interaction of El Niño, La Niña and Southern Oscillation is quantified as a Multivariate Index (MEI) (Wolter, 1987; Wolter and Timlin, 1993). Negative values of MEI represent the cold ENSO phase (La Niña) while positive MEI values represent the warm ENSO phase (El Niño).

El Niño-Southern Oscillation is the strongest source of natural climatic variability in the global climate system (Philander, 1990). The strongest effects of an event are felt ten degrees either side of the equator (Horel and Wallace, 1981) but can extend into temperate regions. The swings of rainfall associated with ENSO contribute to the large interannual variability in the tropics (Bradley *et al.,* 1987). These linkages between ENSO and weather anomalies are known as teleconnections (Glantz, 1991). Teleconnections are normally generalized on a regional scale. For instance, during the El Niño event, Western South America and Eastern Africa normally experience excessive rains, whilst Indonesia, Australia and Southern Africa may experience dry conditions. La Niña events are generally perceived to have the opposite impact to El Niño. Understanding ENSO and how it affects climate around the globe is the key element to providing an effective means of response to climate related anomalies (Glantz *et al.*, 1997).

The rainy season in South-eastern Africa generally extends from October or November to May reaching the peak in March or April. Detailed account of rainfall in semi arid area of Northwest of Tanzania was given by Meertens *et al.* (1995; 1999). In general, the distribution of rainfall during the rainy season is variable. Fluctuations of Southern and Eastern Africa rainfall patterns are linked to regional SST and global ENSO phenomenon (Jury, 1999). Use of models can predict ENSO a year in advance (Cane *et al.,* 1994) with a correlation coefficient of 0.61 between predicted and observed SSTs (Kirtman *et al.*, 2000). Mason (1998) noted that using ENSO in predicting Southern African rainfall may be achieved at lead times up to five months. Thus the World Climate Research Program (WCRP, 1994) showed that there is a coherent pattern of associations of regional rainfall patterns and ENSO promoting the necessity of using ENSO index in forecasting seasonal rainfall, hence the approximate data to initiate planting of annual crops.

Given the strong teleconnections, it has even been possible to link changes in ENSO directly with changes in crop yields. Cane *et al.* (1994) found a strong correlation between an El Niño index and both rainfall and maize yields in Southern Africa. Surprisingly, the correlation with maize yields is stronger than that with rainfall. This may be due to fluctuations in maize yields being amplified in the drier areas, or other climatic factors that influence maize plant growth. Eastern Equatorial Pacific SST accounts for more than 60 % of the variation in maize yields (Cane *et al.*, 1994).

2.3.2 Seasonal rainfall forecast

Climatic variability exert a strong influence on a variety of economic sectors (Easterling and Mjelde, 1987) including agriculture, forestry, water resource management, road maintenance, construction, tourism and public transport (Taylor, 1972). Agriculture is the most frequently cited human system likely to be affected by climate variation (Smit *et al.*, 1996). Climate is the primary driving force of agricultural production (Hollinger, 1994; Adam *et al.*, 1999). Climate affects a wide range of agricultural activities, output and input resources like yields, land quality, on-farm storage, water supplies, labour migration rates of urban and rural communities, population growth, farm income and farmers skills (Washington and Dawning, 1999). Climatic variations have widespread agricultural effects that affect every production management practice from seedbed preparation to harvesting (Hollinger, 1994). Crops and particularly rainfed lowland rice in semi arid areas have been shown to suffer severely because of moisture deficit and abnormally high temperatures during the growing season. Intensive input applications such as fertilizers may only be worthwhile if climatic conditions are favorable (Mjelde *et al.*, 1993). The limited use of fertilizers in crop production in semi arid areas of Tanzania is thus, among other things, due to unreliable rainfall. Farmers expect to receive adequate rainfall at key times throughout the growing season, but input decisions are often made assuming average weather conditions during the cropping season. (McNew *et al.*, 1991).

Valuations in the economic consequences of climatic events and forecasts can be useful to policy makers and farmers in particular in determining whether events, such as ENSO, are important relative to other processes. Economic analysis has a role in identifying where the greatest returns in seasonal forecasting research are likely to lie (Marshall *et al.*, 1996). Also, ENSO can show whether the potential damage from the event, such as developing La Niña, warrant vulnerability actions (Adams *et al.*, 1999). Many scientists agree that ENSO forecasts have, potentially, a substantial economic value (Adams *et al.*, 1999; Stern and Easterling, 1999). Several studies have analyzed the costs of ENSO related impacts, which suggested that predictable savings could be made if accurate warnings of the onset of the phenomenon could be used in weather forecasting (Glantz *et al.*, 1997). Hill *et al.* (2000) reported that economic studies have shown ENSO events to be of value to the decision maker because of the resulting ability to forecast climate conditions. Glantz *et al.* (1997) argued that the ENSO whether model based or not and the knowledge about climate variability, such as teleconnections, although not always totally reliable, can provide users with enough information to make appropriate decisions. Jury (1999) noted that for Southern Africa a reduction in societal stress could be achieved by the reliable prediction of seasonal rains. Beyond the immediate concern of individual season, the process of developing climate prediction and response capabilities could have substantial benefits, with a goal of reduced uncertainty and risk in investment in drought prone areas (Washington and Downing, 1999) such as in semi arid area of Tanzania.

With its high inter-annual rainfall variability and its largely agricultural based economy, Africa should be a prime beneficiary of seasonal weather forecasting (Washington and Downing, 1999). The loss of human life and economic disruption associated with extreme climate/weather fluctuations can be reduced with advanced warning of climatic variability (Zinyowera *et al.*, 1998). For agriculture and water resource management, the benefits could be quite extensive and far reaching in saving human, animal and plant lives. Washington and Downing (1999), for example, contended that the utility of reliable long range forecasts could be substantial for famine early warning systems, policy makers and farmers in planning. Downing *et al.* (1997) argued that enhancing present resource management and reducing climatic impacts is paramount and in particular improved seasonal climate forecasts and the use of climate information could have major benefits in much of

Africa. For instance, Glantz *et al.* (1997) argued that if Zimbabwe had a credible. accurate forecast in early 1991 and acted seriously upon it, it could have saved millions of dollars during 1991/92 drought. Lecler *et al.* (1996) argued that what is currently lacking, is the scientific application of these forecasts to operational decisions in water resources and agricultural management and an assessment of the cost-benefits of such decisions

Currently, there is limited study which link ENSO, rainfall and rainfed lowland rice production in semi arid areas of Tanzania. Therefore, given possible ENSO prediction lead times, the approach could provide an effective early warning system if used judiciously in rainfed lowland rice production in semi arid areas of Tanzania. This research is aimed, among other things, to fill this gap.

2.4 Measures to alleviate soil fertility constraints in rainfed lowland rice

Soil fertility is the status of the soil with respect to the amounts and availability of plants nutrient elements (ions) necessary for optimum growth of a specified crop (Pennamperuma, 1985). Fertilizers are required and added to soils to supply the most limiting plant nutrients in the soils. However, in order to determine the appropriate amount of fertilizers required, it is essential that the soil fertility status is assessed or evaluated. Soil fertility evaluation is the process by which nutritional problems are diagnosed and fertilizer recommendations are made where necessary (Sanchez, 1976).

Tisdale *et al.* (1993) reported several techniques that are commonly employed to assess the fertility status of soils and these included: i) nutrient-deficiency symptoms of the plants, ii) analysis of plant materials from plants growing on the soils, iii) biological tests in which the growth of either higher plants or certain micro organisms are used as a measure of soil fertility and iv) soil analysis.

i) Nutrient-deficiency symptoms of the plants

Growing plants act as integrators of all the growth factors such as light, temperature, rainfall, soils, varietal potential and management practices (Tisdale *et al.*, 1993). Therefore careful inspection of the growing rice plants can assist in the identification of specific nutrient stresses. Tisdale *et al.* (1993) categorized nutrient deficiency symptoms as follows; a) complete crop failure at seedling stage, b) severe stunting of plants, c) specific leaf symptoms appearing at varying time during the season, d) internal abnormalities such as clogged conductive tissues, e) delayed or abnormal maturity, f) obvious yield differences, with or without leaf symptoms, g) poor quality of the crop, including difference in protein, oil or starch content and storage quality and h) yield differences detected only by careful experimental work. Nutrient deficiency symptoms in rainfed lowland rice should be used to supplement the other diagnostic techniques such as soil and plant analysis. This is because nutrient deficiency symptoms can be caused by seasonal effects such as moisture stress and unusual environmental temperature.

ii) Analysis of the plant materials from plants growing on the soils

Plant analysis represents another type of approach in determining the nutrient availability or the fertility status of soils. Two types of plant analysis are commonly used, namely; i) plant tissue tests on fresh tissues in the field, and ii) total plant materials analysis performed in the laboratory (Tisdale *et al.*, 1993). Tisdale *et al.* (1993) further noted that plant analysis is based on the contention that the amount of a given nutrient in a plant is directly related to its availability in the soil. The fundamental limitation of plant analysis as a means of soil fertility evaluation is that by the time the analysis indicates nutrient deficiencies or toxicities, it is often too late to alleviate the problems without considerable yield loss (Sanchez, 1976; Sahrawat, 1983). However, the plant material analytical data gathered would be of great use and application in the next cropping seasons. Moreover, the concentration of a nutrient in plants has been found to be greatly affected by other factors such as kind of plant organs or tissues, growth stages, environmental conditions and the supply to the plants of other plant nutrients (Sahrawat, 1983; Mengel and Kirkby, 1987; Tisdale *et al.*, 1993). The dependence of plant analysis data on the aforementioned factors also creates another problem in interpreting nutrient availability based on plant analysis. However, it has been observed that when these techniques are used in combinations better results are expected compared to the use of a single technique.

iii) Biological tests

Tisdale *et al.* (1993) reported different biological tests where the growths of either higher plants or certain micro-organisms are used as a measure of soil fertility. These included; i) field tests, ii) strip test on farmers fields, iii) laboratory and greenhouse tests and iv) micro-biological methods.

The field-plot method is essential for measuring crop response to nutrients added/applied to soils. Specific nutrients are randomly assigned to an area of land which is the representative of the soil conditions in the area. For instance, when various levels of N are applied to lowland rice, the results are helpful in determining N recommendations. This technique is useful when large numbers of tests are conducted on a well characterized soil as the recommendation can be made and extrapolated to similar conditions. However, it is expensive in term of resource and time. Strip test on farmer's field uses narrow strip of farmer's field under selected fertilizer recommendation based on soil or plant tests. The results of this method need to be interpreted with caution if not replicated. Replication of strip test in several farmers' fields increases reliability of the results (Tisdale *et al.*, 1993).

Laboratory and greenhouse tests utilize small quantities of soils to quantify nutrient supplying power of the soils. Soils are collected to represent a wide range of soil chemical and physical properties that contribute to variation in availability of a specific nutrient (Tisdale *et al.*, 1993). Selected treatments are applied to the soils and the crop that is planted is sensitive to that specific nutrient to be evaluated. Crop response to the treatments can be determined by measuring total yields and nutrient contents. The total nutrients removed are quantified and tables are established to give the minimum values of macro and micro nutrients available for satisfactory yields (Tisdale *et al.*, 1993). This method is of short duration and less expensive compared to field tests. However, the results should be validated in the field (Tisdale *et al.*, 1993).

The microbiological method is used to assess the inherent fertility status of the soils. Certain microorganism exhibits behaviour similar to that of higher plants. For instance, *Azobacter* and *Aspergillus niger* reflect nutrient deficiency in the soils. The soil is rated from very deficient when the colony growth is very poor to not deficient when the colony growth is high for respective element. In comparison with methods that utilizes higher plants, the microbiological method is rapid, simple and requires little space (Tisdale *et al.*, 1993).

iv) Soil analysis

Soil testing is an important and indispensable tool essential for the assessment of the fertility status of soils (Sahrawat, 1983). Soil test values, however, are empirical numbers that become useful only when they are correlated with crop response to nutrients added to the soils (Tisdale *et al.*, 1993). It has been reported that soil test alone might not provide the best index for nutrient availability to plants hence can not be solely used in predicting fertilizer recommendations (Tisdale *et al.*, 1993). This is because the soil test or soil analytical data do not account for crop specific nutrient requirements, nutrient transport within the rhizosphere and interaction between nutrients (Beringer, 1985). Moreover, routine soil analysis is restricted to surface layer of soils and consequently the contribution of the subsoil to nutrient availability to the crop is neglected in most cropping systems (Tisdale *et al.*, 1993).

2.4.1 Response of rainfed lowland rice to inorganic fertilizers and manures

Nutrient status of soils in rainfed lowland rice is often low and response to applied nutrients is often modest due to limited availability of soil moisture (Lathovilayvong *et al.*, 1997; Mazid *et al.*, 1998). Thus, the magnitude of response may not be closely related to soil test values for critical elements (Angus *et al.*, 1990). Consequently limited amounts of fertilisers are applied in these systems because of inadequate soil moisture as there is no guarantee for crop growth success (Khunthasuvon *et al.*, 1998; Linquist *et al.*, 1998). Nutrient responses may be variable, especially on soils of high sand contents (Lathovilayvong *et al.*, 1997), or under the influence of insufficient or excess water. When water is in excess it leads to significant generation of surface run off, the fertilizers may be washed away while in period of drought, the nutrients applied to the soil as fertilizers may be unavailable in the root zone of the rice plant because there is no dissolution and ionization. Alternatively, farmers may simply decide not to apply fertilizers if they perceive little chance of the fertilizers being effective. Therefore, farmers adjust their fertilizer application rates based on their expectation of whether the season will be favourable or not (Wade *et al.*, 1998) and, this depends on whether there is standing water in the field or not. For instance, the time of disappearance of standing water relative to time of flowering has been related to yield reductions in late season dry periods (Jearakongman *et al.*, 1995), even when the soil remained moist. This response was attributed to a drop in soil pH when the free water disappeared, leading to a decline in availability of nutrients, especially of P and Fe (Khunthasuvon *et al.*, 1998; Fukai *et al.*, 1999). In simulation studies, Jongdee *et al.* (1997) reported mean yield losses of 33 % in North East Thailand due to drought. Most of the yield reduction was due to reduced nutrient availability as a result of limited translocation of nutrient from the soil mass to the root surfaces of the plants as water supply declined (Jongdee *et al.*, 1997). Better matching of nutrient supply with crop demand is often considered a basis for improving and stabilizing yield, in irrigated as well as rainfed lowland rice cultivation systems (Lafitte, 1998).

The main nutrients sources for lowland rice production are organic and inorganic fertilizers. The main inorganic fertilizers commonly used in rice production systems include nitrogen fertilizers like urea ($CO(NH_2)_2$) and phosphate fertilizers such triple super phosphate ($Ca(H_2PO_4)_2$) as N and P are the major nutrient elements deficient in most soils. On the other hand, organic manures'/amendments' include waste products of crops and animals which release the plant nutrients after mineralization.

a) Nitrogenous fertilizers

The responses to nitrogenous fertilizers vary among crops. Tanaka *et al.* (1985) observed a constant increase in rice yields with increased nitrogen levels from 0 to 100 kg N ha^{-1}. However, at N application rates beyond 100 kg N ha^{-1}, the yields started to decline due to nutrient imbalances. In Dakawa Rice Farm (Tanzania) Semoka and Shenkalwa (1985) obtained significant increase in rice yields with application of up to 200 kg N ha^{-1} on vertisols. However, De Datta (1981) reported that very high N levels frequently decrease rice yields due to plant lodging, severe diseases and pest infestations and high percentage of unfilled grains. The low rice grain yields due to unfilled grains are attributed to moisture stress. Kajiru, *et al.* (1998) observed that 30 kg N ha^{-1} as urea ($CO(NH_2)_2$) is economically profitable in

Maswa district for Planosols. A significant rice yield response by rice to N application as urea at a water depth of 5- 15 cm has been reported by Meertens *et al.* (2003). However, these studies were of short duration using limited rates of nitrogen hence the results were not conclusive.

Response of rice to applied N is known to depend on the time of planting, soil properties and variety grown (Mamaril *et al.*, 1985; De Datta, 1981). De Detta (1981) found that semi dwarf varieties have higher N response than tall varieties. This is due to higher harvested index in semi dwarf varieties than in tall varieties. Coarse textured soils usually have high percolation rate and high N losses by leaching and volatilization thus rice growing on such soils shows less response to applied N. The current N fertilizer recommendation for rainfed lowland rice is 40 kg N ha^{-1} and this rate is a blanket recommendation for the whole Lake zone of Tanzania (Mowo *et al.*, 1993). It has been recommended that the rate should be applied by broadcasting at active tillering stage of the rice plants. Different techniques have been used/ adopted and used to reduce losses of N applied to rainfed lowland rice soils in the Lake zone, Tanzania. These include proper time of N application and deep placement of N fertilizers as suggested by De Datta (1981).

b) Phosphorus fertilizers

The responses of rainfed lowland rice to P fertilizer applications are not as frequent as those of upland crops even in soils deficient in P (Diamond, 1985). This is due to the fact that rice is usually grown under flooding condition where availability of P is higher than in upland soils (Greenland and De Datta, 1985). Phosphorus is needed for tillering, but the total P requirement is small relative to nitrogen (Diamond, 1985). In addition, if sufficient P is absorbed at an early stages growth of the rice plants, it can be redistributed to the growing organs as growth progresses(Yoshida, 1981). Pheav *et al.* (2005) reported that application of 8 – 10 kg P ha^{-1} in acid soils in Cambodia maintained yields at 2.5 -3 t ha^{-1} and small positive balance in the soils. Further, the P balance was sensitive to the proportion of rice straw returned into the soils (Pheav *et al.*, 2005).

Critical P contents in the soils for rice which have been reported by various scientists show wide variations depending on the method of extraction, soil types and climatic conditions. The critical P value in the soils of warmer regions for rice has been reported to be 26 mg P kg^{-1} soil as determined by Bray-2-P extractant (Jones *et al.*, 1982). The Philippine Council for Agriculture Resource Research and Development, (PCARRD) (1978) established the critical Olsen P level for rice at 10 mg P kg^{-1} soil. Tissue P concentration of 0.1 % is reported as critical P concentration in rice leaves at tillering, while 0.1 – 0.18 % as the adequate range of P concentration for normal growth and yields (De Datta, 1989; Westfall *et al.*, 1990).

The major P-fertilizers for lowland rice cultivation include ordinary super phosphate, triple super phosphate and ammonium phosphates. De Datta (1981) obtained no significant difference in rice yield among these phosphorus sources. Due to its high solubility in water, (about 98 % water soluble), triple super phosphate is a preferred phosphate fertilizer for rice in Tanzania. Phosphorus fertilizers can be applied to the rice soils as surface broadcasting, drilling at seedling, or by dipping the rice seedling roots in super phosphate slurry. However, it has been reported that there is no significant difference in terms of yields among the application methods due to release of P (native P) in water logged soils (De Datta, 1981; Diamond, 1985). In Tanzania, surface broadcasting is the most common method of phosphate fertilizer application because it is less labour demanding as compared to other placement methods.

c) Organic soil amendments in rainfed lowland rice

A wide variety of organic plant nutrient resources are available for use as soil amendments in rice production. However, the current trends of organic resource management practices in Tanzania indicate that only animal dungs and, to a lesser extent, compost manure (animal excreta mixed with animal bedding materials) are used in crop production (Kyomo and Chagula, 1983). The use of animal manure in semi arid areas of Tanzania, Maswa and Meatu districts inclusive is justified by the fact that more than 50 % of the households in these areas keep livestock (Meertens *et al.*, 1999). Other sources of organic soil amendments include green manure such as *Sesbania sesban*, *Sesbania rostrata* and *Crotalaria ochroleuca* which are used as fallow crop prior to rice transplanting (Meertens, 2003).

Dogget (1965) reported that research on the use of locally available plant nutrient resources started in 1940s at Mwabagole Rice station, Mwanza, Tanzania. The control yield under research conditions were compared with puddling in green shoots of cassava plant (*Manihot glaziovii*) and Cassia (*Cassia sp.*) about a month before transplanting and with application of farmyard manure. Results over two seasons showed that the puddling in 10 t cassava tree shoots ha^{-1} increased rice yield by 1419 kg ha^{-1} relative (actual yield 6265 kg ha^{-1}) to control of 4846 kg ha^{-1} in a vertisol. Further the application of 10 t farmyard manure ha^{-1} gave an increase of 881 kg ha^{-1} compared to the control for the application of cassava shoots and farmyard manure.. The deference in yields might be due to difference in initial nutrient contents and release patterns of the cassava green manure and farmyard manure.

In 1960s to 1980s there was no further research on the use of manures for soil improvement in the Northwest Tanzania due to the availability of relative inexpensive mineral fertilizers as a result of government subsidies of fertilizer prices. The complete withdrawal of subsidies on mineral fertilizers in Tanzania during 1990s gave new impulses to such type of investigations. For instances, Otsyina *et al.* (1994) reported the cultivation of *Sesbania sesban, Sesbania rostrata* and *Crotalaria ochroleuca* as a fallow crop for incorporation to the soil prior to rice transplanting as the way as the way of enhancing the fertility status of the soils.

Otsyina *et al.* (1995) investigated the use of dried leaves from *Leucaena leucocephala* as green manure for incorporation in rice fields as a source of plant nutrient for rice. The dried leaves were incorporated prior to rice transplanting and also 4 and 8 weeks after transplanting. Total applications of 3 and 6 t dried leaves ha^{-1} were established and compared to control plot (no fertilizers). Average results from three seasons showed that the application of 3 t dried leaves ha^{-1} increased rice yields to 3018 kg ha^{-1} compared to the control yield of 2438 kg ha^{-1} while 6 t dried leaves ha^{-1} gave an average yield of 3198 kg ha^{-1}. The small defference might be attributed to inadequate soil moisture during the growing season. Upon consideration of the labour involved in transporting significant amounts of green matter to the farm, it was suggested to grow the green manure plant on the farm boundaries or on the bunds between the rice fields. However, Nair (1988) reported that biomass production by green manure plants in semi arid environments is seriously restricted by climatic conditions. It was further noted that growing trees on bunds can be unattractive to farmers as these bunds are usually used as footpaths. In addition, growing trees on bunds might further aggravate the problem of birds because such trees offer landing, nesting and hiding places for birds and rodents.

Makoye and Winge (1996) compared the application of 30 kg N ha^{-1} in the form of urea ($CO(NH_2)_2$) to rice plant at tillering with an incorporation of 10 t ha^{-1} of both farmyard manure and rice husk prior to rice transplanting in shinyanga region Tanzania. Two seasons' results gave rice yields of 3480 to 3580 compared to the control yield of 2580 kg ha^{-1}. However, sufficient amounts of rice husks are only available near milling machines and can thus be applied only very locally. The increase in rice yields with the application of rice husks was attributed to the increased moisture retention and storage by the husks hence extending the period of water availability to the rice plants (particularly during the dry spell of January/February).

In spite of the above investigations on the use of inorganic and organic soil amendments in lowland rice production there has not been a parallel and systematic investigation on the response of rainfed lowland rice to the combined effects (interactions) of farmyard manure and inorganic fertilizers so as to produce rice economically. This study therefore, among other things, is aimed at filling that gap as well.

2.4.2 Soil moisture nutrient interaction on rainfed lowland rice

The performance of rainfed lowland rice is variable due to differing seasonal conditions and spatial heterogeneity over soil types and topographic positions, consequently, agro- hydrology may vary from field to field (Wade *et al.*, 1999). Drought stress is commonly considered the most severe limitation to soil productivity in semi arid areas even if ponding or even complete submergence may occur some days during the cropping season and this may reduce crop performance. Low soil fertility is also complex, because a large number of nutrients may be in limited supply, or toxic and nutrient imbalance conditions may exist where soils are acid or saline (Wade *et al.*, 1998; Fukai *et al.*, 1999). The fluctuations in soil conditions from anaerobic to aerobic also have profound consequences on nutrient availability (Burford *et al.*, 1989). Bell and Seng (2004) reported that the more common effect of soil-moisture stress may be due to limited nutrient availability and uptake than the drought per se. Variation in soil-water saturation interact with nutrient availability (Bell *et al.*, 2001), phosphorus (Seng *et al.*. 1999) and Fe^{2+} and Al^{3+} toxicities in acid soils (Willet and Intrawech, 1988). In rainfed lowlands rice, significant period of loss of soil water saturation occur intermittently throughout the growing season (Fukai *et al.*, 2000; Homma *et al.*, 2003) by modifying the nutrient dynamics and equilibria in the soils. Growth may be depressed as the nutrient availability fluctuates (Fukai *et al.*, 1999). For example, intermittent flooding of soils results in significant loss of N through volatilization and leaching and reduced P availability due to fixation (Seng *et al.*, 1999). However, standing water in rice paddies increased availability of N, P and Si compared with non submerged conditions due to limited translocation of these nutrients from the soil mass to the root surface in soil moisture deficit soils (Regland and Boonpuckdee, 1987).

In acid soils, low productivity of lowland rainfed rice is linked to a general paucity of nutrients in the coarse-textured soils. The problems associated with coarse-textured soils (sandy soils) are low water holding capacity, low CEC, and micronutrient deficiencies including Zn, Mn, Cu and Fe (Dundal, 1980). Sanchez and Uehara (1980) reported that P deficiency is likely to occur when the soil pH is less than 6.0 for most crops. In soils with pH less than 6.0, P is bound in insoluble compounds such as Fe and Al phosphates which are essentially insoluble under aerobic conditions. However, rainfed lowland rice is grown under both aerobic and anaerobic conditions. In anaerobic soils, the Fe^{3+} phosphate is reduced to Fe^{2+} phosphates and subsequently converted into a soluble form and is normally more than adequate to supply sufficient P to rice (Shahandel *et al.*, 1994).

In alkaline soils, Ca phosphates are the predominant pool of soil P and their solubility is not directly influenced by redox reactions (Sanyal and De Datta, 1991). Instead, their solubility may increase after flooding when the soil pH decreases due to CO_2 accumulation and Ca^{2+} complexed by organic acids.

In spite of the above effort to improve soil fertility through both inorganic and organic soil amendments, there is limited work which has been done systematically to evaluate the response of rainfed lowland rice to farmyard manure, nitrogen and phosphorus in semi arid areas of Tanzania. This work therefore, among other things, is aimed to fill this gap.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 General description of the study area

3.1.1 Location

A study to evaluate the fertility status of soils for rice production and response of rice to nitrogen (N), phosphorus (P) and farmyard manure (F) was conducted on the Ndala River catchment in Maswa district, Shinyanga region, Tanzania. The Ndala River catchment is comprised of three villages, namely, Isulilo, Njiapanda and Bukangilija representing upper, middle and lower parts of the catchment, respectively (Fig. 6). The catchment lies between 2° 45’ and 3° 15’South and 33° 0’ and 34° 7’ East at 1200 to 1300 meters above sea level. Evaluation of the soils fertility status for rice production was done at catchment level (Isulilo, Njiapanda and Bukangilija villages) while the detailed field experiment on the response of rice to N, P, F and combinations was conducted at Bukangilija village.

3.1.2 Climate

Maswa district is moderately hot with an average annual temperature of 24 ° C with minimum daily temperatures ranging from 16 – 18 °C while the maximum daily temperatures range from 28 – 31 °C. Cool days are experienced towards the end of the rainy season that is in May and June and hot periods from July to September. The district is considered to have a bimodal rainfall distribution pattern of short and long rainy seasons although most of the hinterland of mainland of Tanzania has a monomodal rainfall pattern. . The short rainy season starts in September/October and reaches its peak in November and ends in early January with a long term average rainfall of 385 mm. The onset of the long rainy season is in early March with its peak in April and ends in late May with a long term average rainfall of 365 mm. The annual rainfall ranges between 600 and 900 mm being highly variable in terms of distribution and amounts. Based on rainfall amounts, Maswa district is categorized as a semi arid area as the rainfall lies between 400 and 800 mm per annum (Hatibu, 2000).

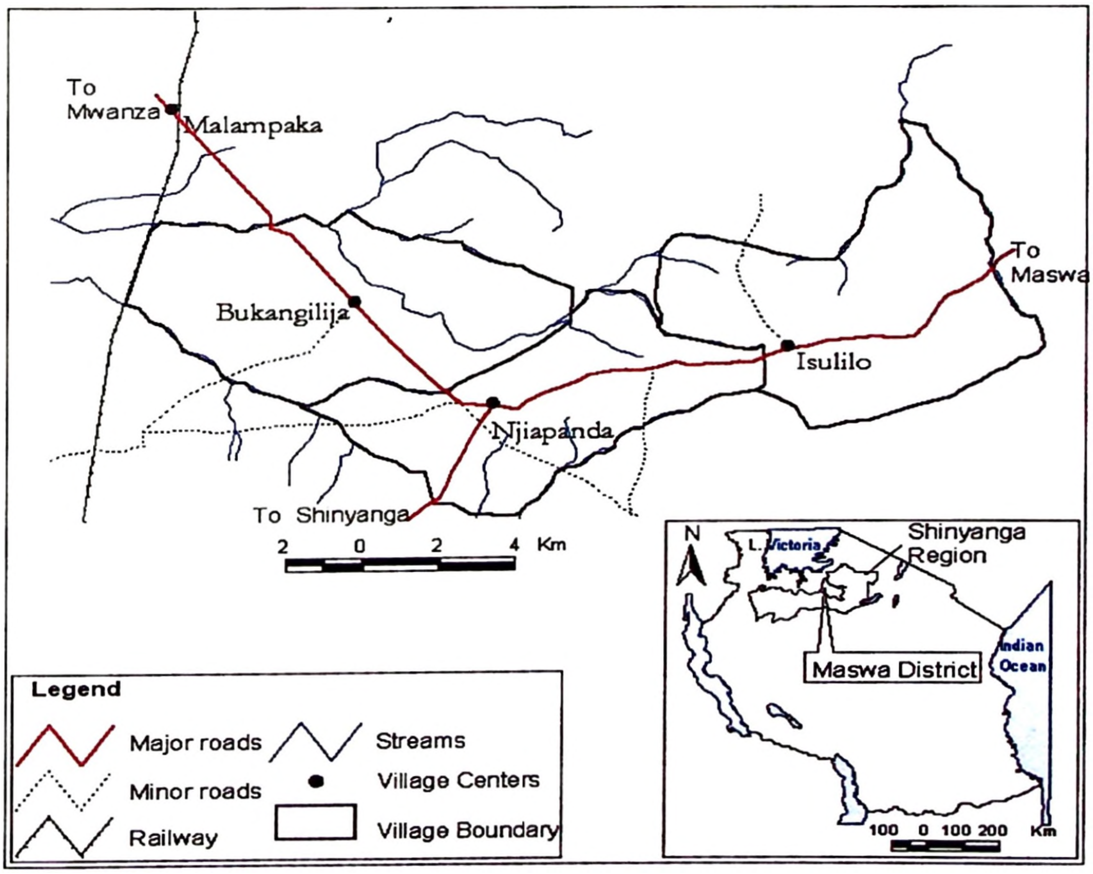


Figure 6: Ndala River Catchment Showing the Location of Isulilo, Njiapanda and Bukangilija Villages in Maswa District, Tanzania.

3.1.3 Soils

Detailed information on the soils of Maswa district has been given by Ngailo *et al.* (1994). A soil map was developed based on correlation between physiography and soils. The legend was built hierarchically with major physiographic units, parent materials and came up with three levels, namely, land form at level one, parent material at level two and soil characteristics level three. The idealised catenary sequence in the Northwest Tanzania was given by Payton (2000). At the local scale, the soil types found at Bukangilija village (FSR, 1989) apart from those identified by Ngailo *et al.* (1994) and Payton (2000) are as given in Appendix 1.

3.2 Soil fertility evaluation for rice production

The soil fertility evaluation study was conducted along the Ndala River Catchment to determine the nutrient status of the soil with respect to rice production using local indicators of soil fertility (LISF) and soil analytical data (soil testing). Activities were done in the following sequences namely, preliminary soil fertility evaluation using LISF, soil sampling, soil preparation and analysis and soil fertility status mapping and soil suitability rating for rice cultivation.

3.2.1 Preliminary soil fertility evaluation through LISF

The preliminary soil fertility evaluation using LISF was done as described by Barrios *et al.* (2000) at each village on the Ndala River catchment by visiting and assessing the soils and rice performance in the fields and gathering information from farmers. The identification of LISF was conducted through interviews and discussions with farmers in each village in the catchment. Ground truthing was done to verify some information and data gathered from interviews and discussions. The gathered information was used to assess fertility status of the soils. The soils were categorized based on the extent and magnitude of rice productivity as M1, M2 and M3 for high, medium and low rice producing soils (suitability levels), respectively. These categories were used as the basis for soil sampling and mapping.

3.2.2 Soil sampling

In each rice productivity level, that is M1, M2 and M3, 14 farmers' rice fields (for each productivity level) were selected and soil sampled at 0-30 cm depth (optimum rooting depth for rice plants) using an auger (screw type). Most of the rice plant roots concentrate in the 0-20 cm deep but significant number of roots extend to 30 cm hence the choice of 0-30 cm. The spot samples (20 from each farm/field) were thoroughly mixed to constitute the composite sample of that particular category which was used for analysis.

3.2.3 Soil preparation and laboratory analysis

Prior to laboratory soil analysis, the composite soil samples were air dried, ground and sieved through 2 mm sieve. The laboratory soil analyses were conducted at the Department of Soil Science, Sokoine University of Agriculture (SUA), Morogoro, Tanzania. The parameters determined included; soil pH, electrical conductivity (EC), organic carbon (OC), cation exchangeable capacity (CEC), total nitrogen (TN), available phosphorous, exchangeable bases and plant available zinc and copper and particle size distribution.

The soil pH was measured electrometrically in 1:2.5 (weight/volume) soil:water suspensions in accordance with the procedure described by McLean (1982). Organic carbon was determined by the wet digestion (oxidation) method of Walkley-Black (Nelson and Sommers, 1982). CEC was determined by the ammonium acetate (CH_3COONH_4) saturation method as described by Rhoades (1982). Total nitrogen was determined by the Kjeldah method as described by Okalebo *et al.* (1993). Available phosphorus was determined by the Olsen method in accordance with procedure described by Juo (1978). Particle size distribution was determined by the Bouyoucos hydrometer method as described by Gee and Bauder (1986) and textural classes of the soils by the United State Department of Agriculture procedure (USDA, 1975). Plant available Zn and Cu were extracted by DTPA and determined by atomic absorption spectrophotometry as described by Lindsay and Norvel (1978).

3.2.4 Soil fertility mapping

The soil sampling points, soil boundaries which were established by augering and relevant features based on LISF were geo-referenced using Global Positioning System (GPS) receiver. Based on soil properties and GPS coordinates the soil fertility spatial pattern map was generated using Arc View software. The soil fertility map so developed was compared to the preliminary suitability maps for rice production.

3.3 Field experiment

A field experiment was conducted at three sites located along the micro-toposequence (upper, middle and lower) at Bukangilija village to determine the response of rice to farmyard manure, phosphorus and nitrogen applications. The experiment was done for three consecutive seasons starting from 2002/03.

Activities conducted included soil sampling, soil samples preparation and laboratory analysis, farmyard manure gathering, mixing and analysis, experimental layout and design, application of N, P and F treatments, management of rice plots, data collection and plant analysis.

3.3.1 Soil sampling

Soil sampling was done at the start of the experiment and for specific F-P-N treatments at the end of each season. Soil sampling at the start of experiment was done to characterize the experimental sites. At each site, a composite soil sample constituted of 25 sub samples was collected at a depth of 0-30 cm using soil auger (screw type).

The soil sampling at the end of the season from specific F-P-N treatment plots was done to determine nutrient movement (N, P and K). Composite soil samples constituted of 6 sub samples at 0-15 and 15-30 cm were taken after harvest from treatment plots without any fertilizers application, with combination of 3.5 t of farmyard manure, 30 kg of P and 50 kg of N ha^{-1} and with combination of 7 t farmyard manure, 60 kg of P and 100 kg of N ha^{-1}. These treatment plots were designated as F1P1N1, F2P2N2 and F3P3N3, respectively, criteria used in the selection of the above treatment combinations was to study the interactions of farmyard manure, phosphorus and nitrogen on N, P and K mobility in the soils.

3.3.2 Soil preparation and laboratory analysis

The procedures used for of soil preparation and laboratory analysis were as described in section 3.2.3. For nutrient movement parameters determined for F1P1N1, F2P2N2 and F3P3N3 treatment plots included, nitrogen, available P and exchangeable K. Nitrogen was determined by the Kjeldah method as described by Okalebo *et al.* (1993). Available phosphorus was determined by the Olsen method according to procedure described by Juo (1978) and exchangeable K^+ by the ammonium acetate (CH_3COONH_4) saturation method (replacement of K^+ by NH_4^+) as described by Rhoades (1982).

3.3.3 Selection of farmyard manure, collection, mixing and analysis

a) Selection of farmyard manure

Farmyard manure is the most common organic material used in crop production in Maswa district. More than 50 % of farmers in the district own livestock which can produce farmyard manure. Farmyard manure was selected due to its potential importance in improving soil fertility in Maswa district and its availability.

b) Collection and mixing of farmyard manure

Kraal farmyard manure was collected from different farmer kraals at Bukangilija village. The manure was thoroughly mixed and five composite samples were taken from the mixed heap of farmyard manure for analysis of their plant nutrient contents.

d) Farmyard manure preparation and analysis

Two hundred grammes of the composite farmyard manure was oven dried at 70^0 C to constant weight and grounded to pass 0.5 mm sieve. The composite sample was analysed for pH in water at manure:solution of 1:2.5, total nitrogen (Bremner and Mulvaney, 1982) and P, K, and total C (Anderson and Ingram, 1993).

3.3.4 Experimental layout and design

On the upper, middle and lower sites along the micro-toposequence (Bukangilija village), a one hectare piece of land was selected and blocked into three equal portions that were used in each season. The field layout within a site is depicted in Appendix 2. In each season, the F, P and N experiment was conducted on a new block where treatments were applied. This was done in order to eliminate the residual effects of phosphorus and farmyard manure. The field experiment was a 3^3 factorial in a Randomized Complete Block Design (RCBD) with the upper, middle and lower experimental sites as replicate due to similarity in soil management, cultural practices, rainfall and the sites were within the same micro-catchment (less than 2 km apart). Treatments included nitrogen (N), phosphorus (P) and farmyard manure (F) applied randomly at three levels each. Nitrogen as $CO\ (NH_2)_2$ was applied at the rates of 0, 50 and 100 kg N ha^{-1}, phosphorus as $Ca\ (H_2PO_4)_2)$ at 0, 30 and 60 kg P ha^{-1} and farmyard manure (F) at 0, 3.5 and 7 t ha^{-1}. These rates were designated as N0, N1, N2, and P0, P1, P2 and F0, F1, F2, respectively. Gross plot size was 6 m by 8 m while the net plot size was 3 m by 4 m. These rates were based on the cost of fertilizers, price of rice grain in the local markets and purchasing power of the farmers (small scale farmers) and the availability of farmyard manure.

3.3.5 Application of the N-P-F treatments

The N-P-F treatments combinations were applied to the prepared 27 treatment plots at each experimental site randomly. The weighed amounts of farmyard manure and triple super phosphate (TSP) according to the F and P levels were evenly spread onto the treatment plots and then thoroughly incorporated into the 0-15 cm surface soils, two weeks before the sowing of the rice seeds. The dates of application of manure and TSP took into account the start of the rains based on the available meteorological data, use of indigenous records, farmers experiences and weather forecast. Two weeks after the application of the farmyard manure and TSP, rice seeds (Cultivar Supa India, which mature at 145 days) were row drilled at a depth of 5 cm at a spacing of 20 cm between rows and subsequently covered with soils, in the third week of December. Three weeks after germination, thinning of the rice plants was undertaken to ensure spacing of 20 x 20 cm in all treatment plots. Nitrogen as $CO(NH_2)_2$ was broadcasted according to the treatment combinations at two equal splits, the first split at tillering and the second at panicle initiation stage of the rice plants.

3.3.6 Management of the experimental plots

Management of the experimental plots involved weeding, in situ RWH and spate irrigation (diversion of water from Ndala River), bird scaring and harvesting. Weeding was done as the weeds appeared; four weeding frequencies were done in the field located in the upper part of the mico-toposequence due to shallow water depth. However, in the middle and lower fields three weeding were done per season.

The high moisture status suppresses weeds due to anaerobic condition created by water availability in middle and lower fields.

Water management was accomplished by ensuring that inter-treatment plot bunds were not broken hence the fertilizer treatment effects were not transferred to adjacent treatment plots. This was achieved by ponding runoff water adjacent to the experimental block and water was channelled to the different treatment plots to ensure enough water in the treatment plots during the dry spell of February. Further, each treatment plot was surrounded by a bund of 0.5 m width to protect the movement of applied fertilizers to the adjacent plots (treatment plots).

Bird scaring was done for the last 30 days before harvesting in replicate two and three located at the middle and lower part of the micro-toposequence due to presence of trees and bushes along the Ndala River. Harvesting was done by cutting the above ground plant portion then threshed by pounding with a stick after recording all required data, namely number of tillers per hill, plant height, dry matter and plant population.

3.3.7 Data collection

Data collection in the experimental sites included;

i). Plant samples: Above ground portion of twenty plants were randomly collected at maximum tillering stage in each treatment plots for determination of nutrient uptake/contents, namely percent N, P and K.

ii). Number of tillers per hill: The number of tillers per hill was obtained from an average of ten hills in each experimental plot at harvesting time

iii). Plant population was obtained from a $2m^2$ area in each plot at harvesting time and converted into plants ha^{-1}.

iv). The average plant height in cm per ten plants was measured in each treatment plot at maturity.

v). Twenty above ground rice plants portions were taken at maturity and dried to constant weights in a furnance at 70 °C for biomass yield determination in kg ha^{-1}.

vi). Grain yields were measured from 12 m^2 area in each treatment. Thereafter, the yields were converted into kg ha^{-1} at 14 percent moisture content using rice moisture metre.

vii). Rainfall data. Rainfall data were collected at the experimental site (Bukangilija Primary School) for the three seasons. Long term rainfall data were collected at the Maswa Meteorological station which is about 20 km from the trial site (Bukangilija village).

viii). Multvariate ENSO indices time series data from 1962/63 season were derived from Wolter (2005).

3.3.8 Plant preparation and analysis

Plant material preparation and analysis was undertake to determine nutrient uptake for elemental N, P, and K. Prior to analysis, the fresh plant samples were washed using distilled water. Thereafter, the samples were dried at 70 °C to constant weights and ground to a fine powder (0.5 mm sieve) for plant tissue analysis. Total plant analysis was done based on the procedures as described by Okalebo *et al.* (1993).

3.4 Data analysis

3.4.1 Statistical analysis

Where applicable, data were subjected to analysis of variance (ANOVA) to test the effects of farmyard manure, phosphorus and nitrogen applications based on the statistical model;

$$Y_{ijkl} = \mu + a_i + b_j + c_k + ab_{ij} + ac_{ik} + bc_{jk} + abc_{ijk} + \varepsilon_l \quad \text{..........................} (1)$$

Whereas;

Y_{ijkl} = response,

μ = general mean,

a_i = main effect of farmyard manure,

b_j = main effect of phosphorus,

c_k = main effect of nitrogen,

ab_{ij} = interaction of farmyard manure and phosphorus,

ac_{ik} = interaction of farmyard manure and nitrogen,

bc_{jk} = interaction of phosphorus and nitrogen,

abc_{ijk} = interaction of farmyard manure, phosphorus and nitrogen and

ε_l = error term effect in accordance with the procedure described by Gomez and Gomez (1984) and Montgomentry (1991).

Prior to analysis of variance (ANOVA), Anderson-Darling (AD) test was employed to test the significance of residues. Descriptive statistics was done for pre experimental soil analysis data. The mean separation was performed using Tukey test at 0.05 alpha levels. Results were presented in figures and tables.

3.4.2 Calculation of partial nutrient balances

Partial nutrient balances were calculated for elemental nitrogen, phosphorus and potassium after harvesting. The partial balances were obtained after subtracting nutrient taken up by both grain and straw from nutrient applied from different sources of soil amendments (i.e farmyard manure, triple super phosphate and urea applications) as described by Whitbread *et al.*, (1999) where a positive balance means that more of a nutrient remains in the soil at the end of the season after crops have been removed than was present at the beginning of the experiment (Whitbread *et al.*, 1999).

3.4.3 Grain yield variations

Grain yield vatiations for the three seasons (2002/03, 2003/04 and 2004/05) for different treatment combinations were obtained using the following formulae

CVyi = (Ymaxi – Ymini)/ Yxi *100 .... (2)

Where;

CVyi = yield variation for three seasons on treatment combination, i,

Ymaxi = maximun grain yield obtained within three seasons for treatment combination, i;

Ymini = minimun grain yield obtained within three seasons for treatment combination, i and

Yxi = mean grain yield obtained within three seasons for treatment combination, i.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Nutrient status of rainfed lowland rice soils on the Ndala River catchment Maswa, district

The Ndala river catchment has 3177 ha which are under rainfed lowland rice production (Fig. 7). Based on preliminary soil fertility evaluation using local indicators of soil fertility as specified in Section 3.2.1, 2945 ha were categorized as high rice producing areas/soils (M1), 883 ha as medium rice producing areas/soils (M2) and 349 ha as low rice producing areas/soils (M3). Isulilo village had only two categories (M1 and M2) while Bukangilija and Njiapanda villages had all the three categories. The local soil indicators used in categorization of soils into three soil fertility status classes included soil colour, textural class, vegetation, moisture content and soil depth. The soil test values (the technical indicators of soil fertility) of the composite soil samples from the three villages at the various levels/categories of rainfed lowland rice production (M1, M2 and M3) are as presented in Table 3. Based on in-depth information sharing with farmers it was evident that soil moisture status and water availability were considered most important in soil categorization in Ndala River catchment.

4.1.1 Soils' textural classes

The soil textural classes of the soils ranged from loamy sand to sandy clay loam. It has been reported that soils with high clay contents are suitable for rice production

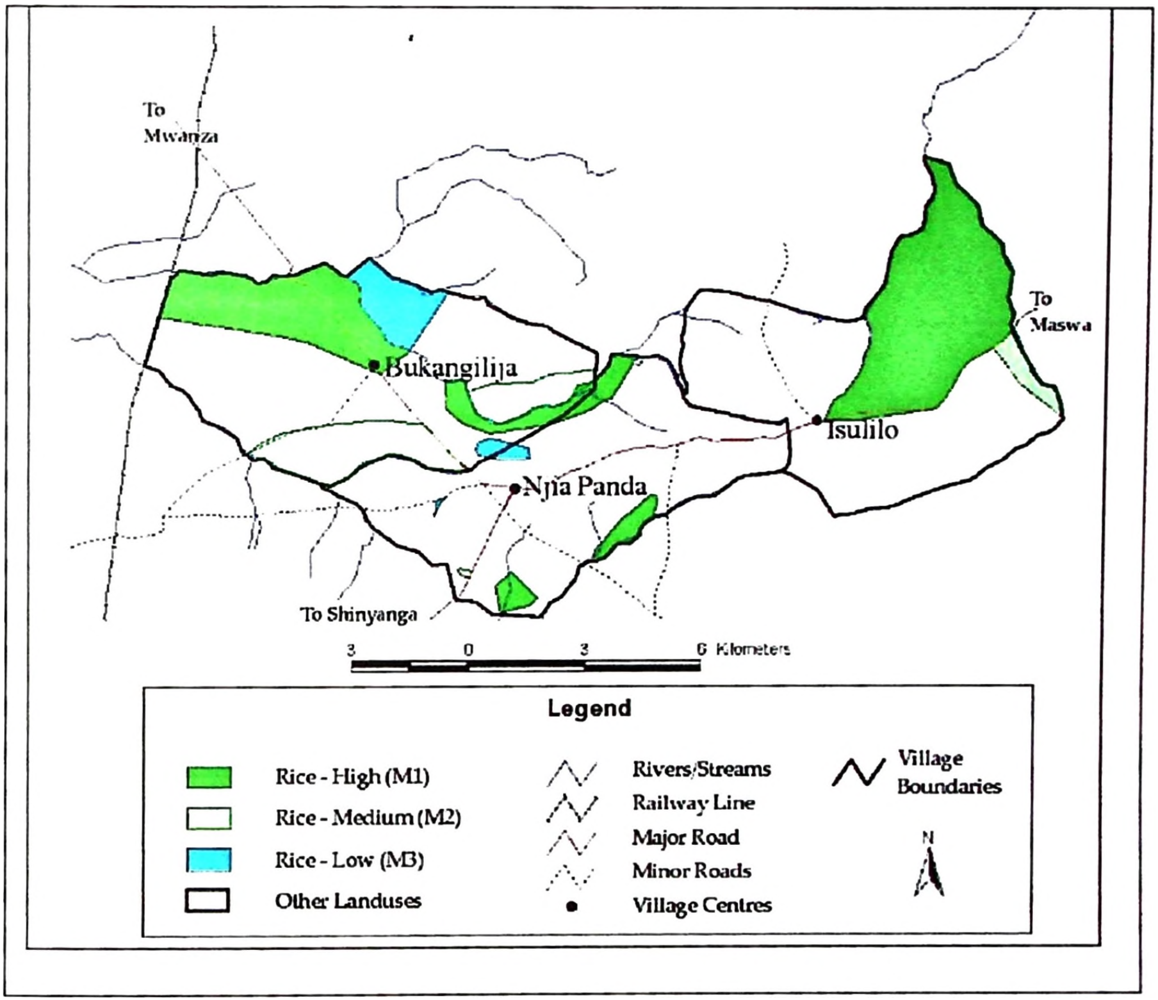


Figure 7: **Preliminary soil fertility categories of rainfed lowland rice producing areas/soils on the Ndala River Catchment**

because of their high capacities to retain plant nutrients and soil water (De Datta, 1981). The high clay contents in such soils further restrict the percolation of water through the soils, hence encouraging water ponding of the bunded fields.

High clay content extends and improves the water use efficiency of the harvested rainwater by the rice plants. It has also been reported that rice performs well in fine to medium textured soils (Landon, 1991). Based on the textural classes of the soils on the Ndala River catchment, most of the soils are suitable for rice production, if the other rice plant growth factors are optimal. However, at Bukangilija M2 and Njiapanda M2 the soils are marginally suitable for rice production contrary to the preliminary soil fertility evaluation based on LISF due to the low clay contents, hence poor soil moisture retention. For such soils, organic soil amendments should be applied so as to improve their water retention capacities. There is no clear cut pattern of textural classes (Appendix 3a) for the three soil classes (M1, M2 and M3) and this might be due to the fact that the preliminary categorizations were based on crop performance which might be influenced by water availability and other local indicators of soil fertility which are mostly qualitative.

4.1.2 Soil pH

The soils' pH values ranged from 6.68 (very slightly acid soil reaction) to 8.92 (strongly alkaline) with a mean pH of 7.82, 7.32 and 7.48 for M1, M2 and M3, respectively (Appendix 3c). The optimum soil pH for rice production is 5.5 to 6.5 under dry conditions (non irrigated rice production system) and 5.5 to 7.2 under flooded conditions (Landon, 1991; De Datta, 1981) However, it has been reported that cultivation of rice is even possible in soils with pH up to 9.0 although yield levels will negatively be affected. Based on soil pH, the soils along the Ndala River catchment are suitable for rice cultivation. The high pH values of the soils on the catchment could negatively influence the availability of most of the micronutrients such as zinc and copper as well as phosphorus. The high pH values may also affect some of physical, chemical and biological properties of the soils that contribute to soil fertility and consequently soil productivity.

4.1.3 Total nitrogen

The percentage total nitrogen in the soils ranged from 0.03 to 0.06. Mean percentage total nitrogen for M1, M2 and M3 were 0.05, 0.04 and 0.05, respectively (Appendix 3b). These values are rated as very low (Landon, 1991). The soils along the study area are therefore deficient in nitrogen. Pillai (2005) reported that N requirement is categorized as high, medium and low when the percentage total nitrogen values are less than 0.1, 0.1 – 0.2 and greater than 0.2, respectively. The low total nitrogen might be caused by limited use of organic soil amendments, uptake by plants, leaching, denitrification, sparse vegetation and burning of the crop residues and use of the crop residues as an animal feed. For high rice production on the Ndala River Catchment nitrogen in the form of fertilizers, manures or crop residues have to be applied to the soils to supplement the deficient levels of N in the soils. The rates of N to be added to the soils should be determined by field N-fertilizer/manure trials.

4.1.4 Organic carbon

The organic carbon contents in the soils ranged from 0.38% to 0.82 % (Table 3). Mean organic carbon based on rice producing areas were 0.69, 0.48 and 0.58 % for M1, M2 and M3, respectively (Appendix 3b). These values are rated as very low (Landon, 1991) as they less than 2 %. The low percent organic carbon contents translate to low organic matter contents in the soils. Organic matter in soils influence both the physical, chemical and biological properties of soils, such as soil structure, water retention, nutrient contents and retention and micro-biological activities in soils. To improve and sustain rice productivity of the soils on the Ndala River Catchment, organic soil amendments like manures or crop residues have to be applied/incorporated into the soils.

4.1.5 Available phosphorus

The plant available phosphorus in the soils ranged from 14.24 to 17.16 mg P kg^{-1} soil (Table 3). The mean available phosphorus based on the rice producing areas (soils) along the Ndala River catchment were 15.56, 14.61 and 16.88 mg P kg^{-1} for M1, M2 and M3, respectively (Appendix 3c). The soils available phosphorus values are rated as medium to high (Landon, 1991). Pillai (2005) reported that the P requirement for rice is high, medium and low when the available P (Olsen) values are less than 5, 5-10 and grater than 10 mg P kg^{-1}, respectively. In addition, the availability of phosphorus in ponded rice fields is a function of the soil pH (Ponnamperuma *et al.*, 1966; Wilson *et al.*, 1999) hence the available soil P, may be fixed or precipitated as calcium phosphate as results of high pH values of the soils. Rice being a low P demanding crop, the observed soil available phosphorus values would satisfy the phosphate demand or requirement by the rice crop, hence no dramatic response by rice to phosphate application to these soils as inorganic or organic fertilizers, would be expected. However, with continuous rice production under rainwater harvesting systems, the phosphorus that would be lost from the soils through crop uptake must be replenished.

4.1.6 Cation exchangeable capacity

The cation exchange capacities (CEC) and exchangeable bases of the soils on the Ndala River catchment ranged from 7.0 to 24.0 $Cmol_{(+)}$ kg^{-1} soil (Table 3) where as the mean CEC based on rice producing areas were 19.53, 13.4 and 18.3 $Cmol_{(+)}$ kg^{-1}, for M1, M2 and M3, respectively (Appendix 3c). These values range from low to medium (Landon, 1991) where 5-12.0 $Cmol_{(+)}$ kg^{-1}as low, 12.1-25 $Cmol_{(+)}$ kg^{-1} as medium and 25-40 $Cmol_{(+)}$ kg^{-1} as high. The low to medium CEC of the soils could be attributed to the low organic matter contents 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. The low to medium CEC of the soils is an indication of the low capacity of the soils to retain nutrients added to the soils in the form of fertilizers and manures.

4.1.7 Exchangeable bases

Exchangeable bases determined by NH_4^+ displacement included calcium (Ca^{2+}), Magnesium (Mg^{2+}), sodium (Na^+) and potassium (K^+).

a) Calcium (Ca)

The exchangeable Ca levels in the soils ranged from 2.29 to 13.97 $cmol_{(+)}\,kg^{-1}$ soil and the mean values based on rice productivity were 11.58, 6.27 and 13.1 $cmol_{(-)}\,kg^{-1}$ for M1, M2 and M3, respectively (Appendix 3c). These values are categorized as medium to very high (>2 cmol Ca kg^{-1} soil (Landon, 1991). However, indices of plant available Ca is of little value, since Ca availability varies greatly from soil to soil. Soils are considered to be deficient in Ca when the exchangeable Ca is less than 0.2 cmol Ca kg^{-1} soil. The medium to very high levels of exchangeable Ca in the soils could be attributed to high contents of Ca in the parent materials of the soils, the pH of the soils and concentration of Ca^{++} in the surface horizons of the soils as a result of insignificant leaching due to inadequate rainfall.

b) Magnesium (Mg)

The exchangeable Mg in the soils (Table 3) ranged from 0.64 to 3.8 cmol(+) kg^{-1} soil and the mean values based on rice productivity were 2.85, 1.86 and 2.05 $cmol_{(+)}\,kg^{-1}$ for M1, M2 and M3, respectively (Appendix 3d). These values are rated as high (>0.5 $cmol_{(+)}\,kg^{-1}$ soil) according to Landon (1991). However, the availability of Mg for the Bukangilija M2 and Njiapanda M3 soils may be reduced by the high Ca: Mg ratios which are greater than 5:1 (Landon, 1991). The soils in the study area, therefore, have adequate amounts of exchangeable Mg for rice production. The high exchangeable Mg in the soils could be attributed to high contents of Mg in the parent materials of the soils and limited uptake by plants because of the limited plant /vegetation growth due to inadequate soil moisture and predominance of the 2:1:1 layer silicate clay minerals (chlorites) in the soils.

c) Sodium (Na)

The exchangeable Na in the soils ranged from 2.09 to 7.79 cmol Na kg^{-1} soil and the mean values for rice productivity levels were 6.16, 4.36 and 5.68 cmol kg^{-1} for M1, M2 and M3, respectively (Appendix 3d). These values are rated as very high (Landon, 1991). The exchangeable Na percentages (ESP) of the soils range from 19% to 46% indicating that the soils are sodic as the boundary between sodic and non-sodic soils is 15 ESP. It has been reported that soils with exchangeable Na greater than one cmol Na kg^{-1} soil are regarded as potentially sodic. Rice is moderately tolerant to sodic soil conditions (ESP = 20 – 40) hence the rice crop along the Ndala River catchment will not be adversely affected by the high exchangeable Na values of the soils. The high ESP values of the soils conform to the high $pH_{(water)}$ values of the soils. Based on the pH of the soils and the exchangeable Na, the soils in the study area could be categorized as saline-sodic (ESP>15 and pH<8.5). The high exchangeable Na contents in the soils could be attributed to high contents of Na in the parent materials of the soils and minimum leaching of the Na because of inadequate soil solution percolating down the soil profiles. The high ESP of the soils would enhance the dispersion of the soils during when the fields are flooded, hence restrict percolation of water this increase concentration of exchangeable Na at the surface horizon

d) Potassium (K)

The exchangeable K in the soils ranged from 0.11 to 0.36 $cmol_{(+)} kg^{-1}$ soil (Table 3) and the mean values for rice productivity levels were 0.48, 0.17 and 0.21 cmol kg^{-1}

for M1,M2 and M3, respectively (Appendix 3d). These values are rated as low to medium (0.03 – 0.4 cmol K kg^{-1} soil) according to Landon (1991). However, exchangeable K levels in soils are of limited value in predicting crop response to K as there is no direct relationship between soil K values and its availability. It has been reported that soil samples with large amounts of available K lose some of the K through fixation and those with low amounts have their exchangeable K increased through transformation of the non-available K to available/exchangeable forms under field conditions. It has further been reported that the minimum absolute levels of exchangeable K in soils ranges between 0.07 and 0.2 cmol K kg^{-1} soil (Pillai, 2005). Thus the soil K values (0.11 to 0.36 $cmol_{(+)}$ kg^{-1} soil) of the Ndala River catchment soils are within and above the minimum levels of 0.07 and 0.2 cmol K kg^{-1} soil, respectively. The availability K uptake is thus controlled by the physico-chemical equilibrium between the soil solution K, exchangeable K and fixed K in the soils.

4.1.8 Micro nutrient

The DTPA extractable Zn and Cu in the soils ranged from 0.18 to 0.28 and 0.45 to 1.11 mg kg-1 soil, respectively (Table 3). The mean values for the different rice producing areas were 0.23, 0.24 and 0.24 mg kg-1 for Zn for M1, M2 and M3, respectively (Appendix 3e). The DTPA extractable Zn values in the soils are rated as low (0.5 to 1.0 mg Zn kg-1 soil) according to Landon (1991) hence deficient in plant available Zn. De Datta, (1989) gave the critical levels for Zn (DTPA) at 7.3 pH to be between 0.5 to 0.8 ppm for most crops.

Mean DTPA extractable Cu values were 0.76, 0.56 and 0.97 mg kg^{-1}, for M1, M2 and M3, respectively (Appendix 3.5). The DTPA extractable Cu in the soils are rated as adequate (0.75 mg Cu kg^{-1} soil), according to Landon (1991) and Lindsay and Norvel (1978), hence the soils on the Ndala River catchment have adequate amounts of available Cu for rice production. De Datta, (1989) gave the critical level of DTPA extractable Cu at 0.2 ppm for Cu.

Based on the preliminary soil fertility status categorization as M1, M2 and M3, the soil test values did not exactly conform to the preliminary soil fertility categorization based on LISF. This might be due to the fact that the preliminary soil fertility categorization was based on LISF and rice crop performance which was influenced by availability of water through RWH.

Table 3: Some of the physical and chemical properties of the soils on the Ndala River Catchment

Village	Particles Size Distribution									Exchangeable Bases Cmol$_{(+)}$kg^{-1}				Micro nutrient	
	Sand (%)	Silt (%)	Clay (%)	Textural Class	pH (Water)	% TN	% OC	Olsen P mg kg^{-1}	CEC Cmolkg^{-1} l	Ca	Mg	K	Na	Cu mg/kg	Zn mg/kg
Isulilo M1	62	7	31	SCL	8.75	0.04	0.63	14.46	24.0	13.97	3.89	0.78	7.27	0.70	0.24
Isulilo M2	54	14	32	SCL	7.73	0.05	0.61	14.46	17.2	10.47	2.52	0.26	3.63	0.64	0.28
Njiapanda M1	71	4	24	SCL	6.68	0.04	0.63	16.52	16.6	8.11	1.73	0.36	7.79	1.03	0.28
Njiapanda M2	74	7	19	SL	7.92	0.03	0.46	15.14	16.0	6.09	2.41	0.14	7.36	0.67	0.24
Njiapanda M3	62	6	32	SCL	8.03	0.05	0.63	17.16	20.6	14.19	2.41	0.23	4.57	1.11	0.25
Bakangilija M1	59	7	34	SCL	7.55	0.06	0.82	15.69	18.0	12.65	2.94	0.30	3.41	0.56	0.18
Bakangilija M2	86	5	9	LS	7.03	0.03	0.38	14.24	7.0	2.26	0.64	0.11	2.09	0.45	0.21
Bakangilija M3	66	4	30	SCL	8.92	0.04	0.52	16.60	16.0	12.0	1.68	0.18	6.78	0.83	0.22

Note: SCL Sand clay loam; SL Sand loam; LS Loam sand. M1 = high, M2 = medium and M3 = low rice producing areas

Moisture stress affects nutrient availability by limiting the translocation of nutrient from the soil mass to the root surfaces and the metabolic processes in the plants. Thus soil fertility status' rating for rice should be based on both LISF and technical indicator of soil fertility (TISF) that is quantitative and soil analytical data (Table 3) values/factors and soil and water management practices and technologies.

4.1.9 Soils suitability for rainfed lowland rice

From the soil analytical data generated in the current study (Table 3), the soils along the Ndala River catchment are moderately suitable (S2) for rainfed lowland rice production. The major limitations to rainfed lowland rice production include low total nitrogen, low organic matter, low available Zn, high exchangeable Na, and high soil pH values. For optimal rice production, the above limitations have to be rectified by adoption of the appropriate soil fertility management strategies and options and application of the proper soil amendments such as nitrogen fertilizers and farmyard manure. With the adoption of rainwater harvesting, the consequent development and enhancement of soil salinity, sodicity and salinity – sodicity conditions should be carefully monitored and corrected timely and appropriately so as to avoid decline in rice production and quality.

4.2 Rainfall characteristics in relation to rice growth/performance in Maswa

4.2.1 Long term annual rainfall amounts

Analysis of records from 1962 to 2002 at the Maswa Meteorological Station shows that seasonal rainfall ranged from 429 mm in 1974/75 to 1497 mm in 1997/98 (Table 4). The 1997/98 rainy seasons was affected by the El-Niño phenomenon with about

2.8 standardized departure from the mean (Table 4). Other El-Niño seasons (episodes) were in 1972/73, 1982/83, 1987/88 and 1993/94 (Wolter and Timlin, 1998). The rainfall amounts for the El-Niño seasons in Maswa were 1144, 1125, 1107 and 898 mm for 1972/73, 1982/83, 1987/88 and 1993/94, respectively. With an exception of 1985/86 to 1988/89 seasons (Table 4), the categorization of annual rainfall amounts alternate between wet (Q 4) and drier, dry, or normal season that is Q 1, 2 and 3, respectively. From 1985/86 to 1988/89 seasons, annual rainfall amounts were consistently in the drier category (Q 1), with consequent reduction of the amount of rainwater harvested for rice production, which in turn reduce rice yields. Based on the above long term rainfall data, Maswa district would therefore be categorized as semi-arid, hence conforming previous observations and conclusions from previous studies (Ngailo *et al.*, 1994; Payton, 2000).

4.2.2 Annual rainfall during the experimental (trial) seasons (2002/03 – 2004/05)

The annual rainfall amounts during the experimental seasons (Fig. 8) were lower than the long term average by 7.8, 13.4 and 1.8 % in 2002/03, 2003/04 and 2004/2005, respectively. Annual rainfall amount in 2002/2003 was a representative of the long term average as it conformed to the inter quartile range (Q1-Q4) of long term average. When annual rainfall amounts were classified from driest to wettest season (Table 4) the 2002/03 season is the 16th driest in 43 seasons while the 2003/04 is the 10th driest season in 43 seasons and the 2004/05 was 23rd average seasons in 43 seasons implicating inadequate rainfall in Maswa district hence its categorization as

Table 4: Long term annual rainfall (mm) in Maswa, Tanzania**

S/no	Season	Total rainfall (mm)	Rainfall Class	Quartile	ENSO INDEX
36	1997/98	1497	Wet	4	2.8
16	1977/78	1172	Wet	4	1.0
11	1972/73	1144	Wet	4	0.5
23	1984/85	1138	Wet	4	-0.3
1	1962/63	1127	Wet	4	-0.3
21	1982/83	1125	Wet	4	0.8
5	1966/67	1109	Wet	4	1.5
27	1987/88	1108	Wet	4	1.6
22	1983/84	1104	Wet	4	1.5
2	1963/64	1086	Wet	4	0.9
20	1981/82	1063	Average	3	0.8
39	2000/01	1019	Average	3	-0.5
7	1968/69	1015	Average	3	0.6
17	1978/79	962	Average	3	0.6
19	1980/81	962	Average	3	0.6
6	1967/68	937	Average	3	0.5
15	1976/77	901	Average	3	1.0
32	1993/94	898	Average	3	0.5
43*	2004/05	891	Average	3	0.5
10	1971/72	888	Average	3	-1.0
34	1995/96	878	Average	3	0.8
3	1964/65	869	Dry	2	-1.0
9	1970/71	861	Dry	2	0.3
18	1979/80	859	Dry	2	0.6
8	1969/70	850	Dry	2	0.5
38	1999/2000	847	Dry	2	-1.0
41*	2002/03	836	Dry	2	1.0
29	1990/91	821	Dry	2	0.5
33	1994/95	810	Dry	2	1.0
30	1991/92	807	Dry	2	0.5
40	2001/02	806	Dry	2	-0.5
4	1965/66	801	Dry	2	1.5
12	1973/74	800	Driest	1	-1.0
42*	2003/04	786	Driest	1	-0.3
31	1992/93	780	Driest	1	0.3
37	1998/99	770	Driest	1	-1.0
25	1986/87	751	Driest	1	0.7
24	1985/86	693	Driest	1	-0.6
35	1996/97	676	Driest	1	-0.5
26	1988/89	673	Driest	1	-1.5
28	1989/90	652	Driest	1	-1.0
14	1975/76	631	Driest	1	-1.8
13	1974/75	429	Driest	1	-2.0

Note: * Indicate rainfall during the experimental seasons: ** in a descending order semi arid. Annual rainfall amounts in 2002/2003 and 2003/04 fall in quartile 2 and 1, respectively. Therefore, in relation to long term averages the 2002/2003, 2003/04 and 2004/2005 are representative of dry, driest and average seasons, respectively. The dry and driest seasons have less amount of run off water ponded in the excavated bunded basin *(majaluba)* hence reduced the rice production due to moisture stress.

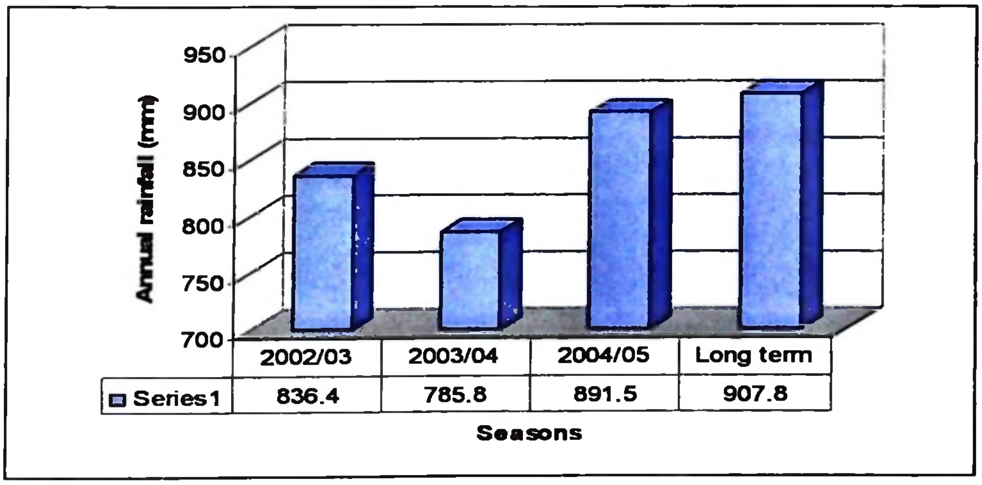


Figure 8: Comparison of the Annual Rainfall During the trial period (2002/03 – 2004/05) and Long Term Average.

4.2.3 Long term monthly rainfall distribution

The rainfall analysis of long term monthly rainfall distribution (Table 5) shows that the onset of rains occur in October (46.8 mm) and cease in May (63.7 mm). Therefore, the main rainy season hence the growing season occurs between November (116.4 mm) and April (162.6 mm) with a transitional period of low rainfall in February (91.4 mm). However, there is a considerable variation on the onset of rainfall (Appendix 4). The rains may start as early as October (1978/79) or as late as January (1990/91) while cessation occurs in May. Therefore, there is a wide (4 months) variation on the onset of rainfall while the cessation occurs within one month. This seems to be a common characteristic of rainfall in semi-arid areas of Tanzania (Hatibu et al., 1995). The wide variation on the start of the rainy season has an implication on rice establishment. Meertens *et al.* (1999) reported that rice planting in Maswa can extend up to March depending on rainfall, if the ceasation of rainfall goes beyond May.

The amount of rainfall received each month varies a great deal from year to year due to the semi aridity nature of the area. The rains may either concentrate in the early months (Appendix 4) of the season (1980/81, 1993/94) or in the late months (1963/64, 1977/78, and 1982/83). When the rains concentrate in the early months of the season, the late growing season moisture stress is experienced by the rice plants hence reduced growth. Whereas, when it concentrates in the late season, early moisture stress would lead to problems with rice plant establishment, hence poor crop establishment. Doorenbos (1976) defined monthly rainfall with coefficient of variation of 20 % or above to be highly variable. Therefore, the rains during the growing season (October – May) in Maswa district are highly variable. The variability of monthly rainfall ranges from 27 % for February to as high as 102.7 % for October (Table 5) and thus, the dry-spell that occurs in February is predictable due to its low variability compared to the other months during the growing season. Most of the farmers are aware of this situation and they collect large amount of water in their excavated bunded fields as a strategy to overcome the moisture stress in February. When enough water is collected during years of good rains, the February dry-spell has less effect on rice plants during the vegetative growth stage hence minimum reduction in yields.

4.2.4 Monthly rainfall distribution for the 2002 to 2005 rice cropping seasons

In 2002/03 seasons, monthly rainfall amounts were below the long term amount in all months except in November (Table 5). The rainfall amounts in October (7 mm) and November (175 mm) were not representative of the long term average as they do not fall within the IQR of the long term range. The rainfall in October was low while the November rainfall was high when compared to the long term IQR. January had slightly lower rainfall by 13 % when compared to the long term average (121.4 mm). February and March had about the same amount of rainfall (i.e 90.0 and 141.2 mm) when compared to the long term averages. The rainfall in April and May were lower than the long term averages by 24.4 and 27 %, respectively (Table 5). The possible reason might be due to semi aridity nature of the area. This affects the rice yields as the crop is in a reproductive stage.

Table 5: **Monthly rainfall distribution during the experimental seasons at Bukangilija village**

Season	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Total
2002/03	0.0	7.0	175.0	148.2	105.6	90.0	141.2	122.9	46.5	836.4
2003/04	0.0	34.0	50.0	120.0	181.8	63.0	166.0	156.0	15.0	785.8
2004/05	35.0	58.5	57.5	216.0	80.0	73.0	33.5	158.0	180.0	891.0
Long term	15.3	46.8	116.4	151.3	121.4	91.4	141.8	162.6	63.7	907.8
CV %	106.9	102.7	61.4	52.8	43.7	27.7	43.8	46.2	77.3	21.51
Q1	0.0	11.4	65.6	90.5	85.9	76.0	91.1	111.6	16.5	800.1
Median	11.6	29.0	98.1	152.3	123.8	92.6	141.4	153.0	64.0	873.5
Q3	27.3	66.3	153.1	197.5	157.5	108.0	184.0	215.4	85.5	1079.9

NOTE: CV = Coefficient of variation; Q1 = First quartile; Q3 = Third quartile

In 2003/04 season, monthly rainfall amounts were below the long term amount in all months except January and March (Table 5). The three months rainfall amounts (November, January and February) were not representative of the long term average. November and February had small amounts while January had excess amount of rainfall when compared to IQR of the long term averages. Other months during the season had representative amounts as they are within the IQR of long term average. March had higher amount of rainfall by 17 % while April was lower by 4 % than the long term averages. Rainfall in May was extremely low and 76.4 % below the long term average (63.7 mm). Similarly, the possible reason for the above fluctuations might be due to semi aridity nature of the area coupled with erratic rainfall distribution.

In 2004/05 season, monthly rainfall amounts were below the long term average in all months except in December and May (Table 5). The rainfall amount in December (120 mm) was higher than the long term average by 42.7 % indicating that more run off was generated for the rainfed lowland rice. The rainfall in May was exceptionally high (180 mm) when compared to the long term average (63.7 mm). The rainfall deficit was serious in March at 23.6% of the long term average (141.8mm). April had about the same rainfall amount (158 mm) when compared to the long term average (162.6 mm). Rainfall deficit between November to February had an effect on vegetative stage of rice while rainfall deficit after February affect the reproductive stage of the rice plants in semi arid areas of Maswa district hence reduced rice grain yields.The erratic and unreliable rainfall distribution compounds the problems by farmers and extension staff, an appropriate dates to sow or plant rice for high yields (positive results).

4.2.5 Rainfall amount in relation to ENSO indices

The seasonal long term rainfall in the study area has a linear positive correlation ($r = 0.670$, $P < 0.001$) with ENSO indices (Fig. 9). This indicates that ENSO indices can be used to predict seasonal rainfall. The highest seasonal rainfall was recorded in 1997/98 with ENSO index of 2.8 while the lowest rainfall was recorded in 1974/75 season with ENSO index of -2.0 which reflect El-Niño and La-Niño respectively. Other seasons had intermediate seasonal rainfall amounts and ENSO indices (Table 4). Thus, the high ENSO indices are associated with high rainfall amounts. The highest rainfall amount means more run off can be generated which is in turn harvested or diverted to rice fields hence more water can be ponded which can lead to high rice yields when other growth factors for rice production are optimal.

When the seasonal rainfall amounts were divided into early (October to December) and late rainfall amounts (March to May) it was observed that early season cumulative rainfall amounts (Fig. 10) were very highly significant and positive correlated with annual ENSO index ($r = 0.467$, $P<0.001$). The highest early season cumulative rainfall amounts (803 mm) was recorded in 1997/98 season with an ENSO index 2.8 while the lowest early season cumulative rainfall amount was recorded in 1974/75 (172 mm) with an ENSO index -2.0 (Appendix 5). Other seasons were having intermediate early season cumulative rainfall amounts. Rice crop establishment occurs between October and December, thus early season rainfall can be predicted well in advance using ENSO indices. This reduces the risk of poor rice establishment. A similar trend was observed when the early rainfall was correlated with bimonthly ENSO indices (Appendix 7).

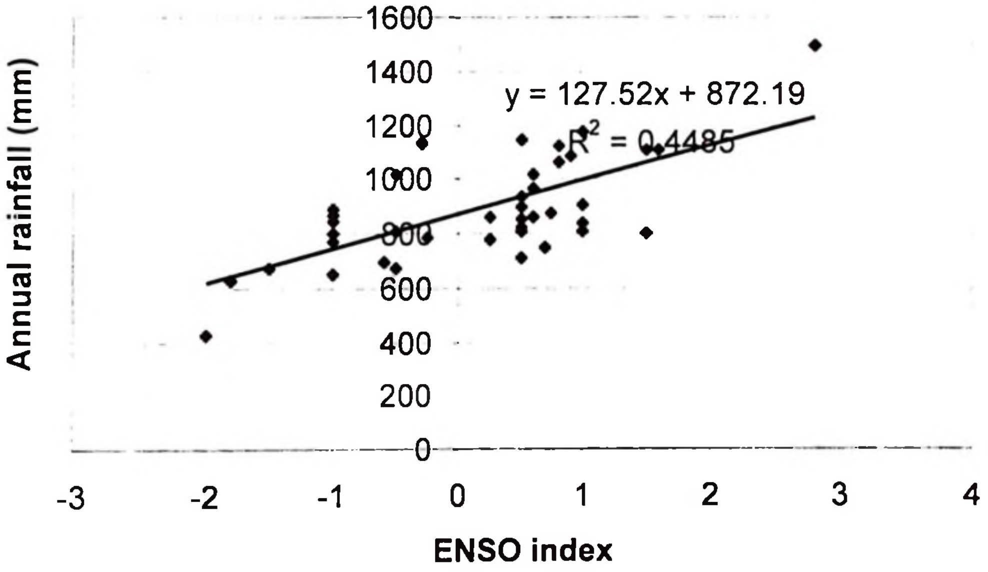


Figure 9: Relationship between annual rainfall (mm) and ENSO index in Maswa

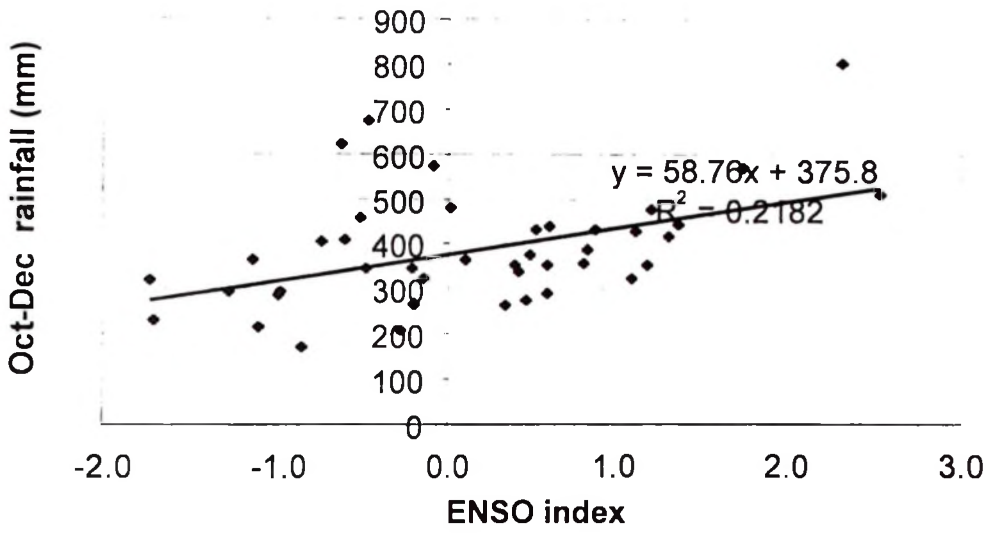


Figure 10: Relationship between early (Oct – Nov) cumulative rainfall (mm) in Maswa and ENSO indices

De Detta, (1981) reported that minimum rainfall amount of 100 mm per month is required for rice plant to thrive well hence good grain yields. This means that early rainfall amount of not less than 300 mm between November and April is required for rice plant to thrive well. Nicholson and Kim (1997) found a strong correlation between ENSO and short rains (October to December) over much of the African continent and suggested the linkage through ENSO-induced SST anomalities in the Indian Ocean which in turn modulate inter annual variability of rainfall over Africa.

Late seasonal (March – May) cumulative rainfall amounts in Maswa (Fig. 11) were not significantly correlated with annual ENSO index (r = 0.0842). The highest late season cumulative rainfall amounts (721 mm) was recorded in 1966/67 season with an ENSO index of -0.84 while the lowest early season cumulative rainfall amount was recorded in 2001/02 (164 mm) with an ENSO index of 0.41. Other seasons had intermediate early season cumulative rainfall amounts. This indicates that ENSO indices can not be used to predict the late season rainfall amounts in Maswa thus improved RWH systems particularly, the construction of medium to large water reserves is required.

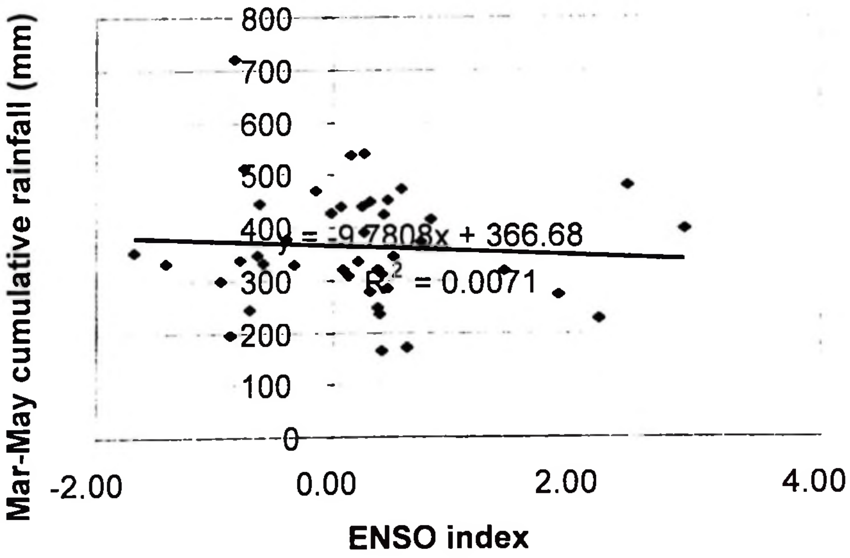


Figure 11: Relationship between late (March-May) cumulative rainfall (mm) in Maswa and ENSO indices

Table 6: Correlations between bimonthly long term ENSO indices (n=43) for Maswa

	Aug/Sept	Sept/Oct	Oct/Nov	Nov/Dec	Dec/Jan	Jan/Feb	Feb/Mar	Mar/Apr	Apr/May	May/June	Jun/Jul
Sept/Oct	0.98^{***}										
Oct/Nov	0.95^{***}	0.98^{***}									
Nov/Dec	0.94^{***}	0.97^{***}	0.98^{***}								
Dec/Jan	0.88^{***}	0.92^{***}	0.94^{***}	0.97^{***}							
Jan/Feb	0.86^{***}	0.89^{***}	0.92^{***}	0.95^{***}	0.98^{***}						
Feb/Mar	0.81^{***}	0.82^{***}	0.85^{***}	0.89^{***}	0.91^{***}	0.95^{***}					
Mar/Apr	0.74^{***}	0.74^{***}	0.76^{***}	0.81^{***}	0.83^{***}	0.88^{***}	0.95^{***}				
Apr/May	0.51^{**}	0.52^{***}	0.54^{***}	0.60^{***}	0.64^{***}	0.71^{***}	0.82^{***}	0.90^{***}			
May/Jun	0.25	0.27	0.31^{*}	0.35^{*}	0.40^{**}	0.47^{**}	0.60^{***}	0.72^{***}	0.91^{***}		
Jun/Jul	0.06	0.08	0.12	0.15	0.20	0.26	0.40^{**}	0.53^{***}	0.75^{***}	0.94^{***}	
Jul/Aug	.05	-0.03	0.01	0.05	0.09	0.14	0.28	0.41^{**}	0.64^{***}	0.86^{***}	0.97^{***}

NOTE: * = $P \leq 0.05$; ** = $P \leq 0.01$ and *** = $P \leq 0.001$

The correlation analysis of the long term bimonthly ENSO indices have shown very strong and positive significant correlations ($P < 0.001$) for bimonthly indices from August/September up to March/April (Table 6). The correlation coefficients decreased from August/September toward July/August. When early cumulative rainfall (October to February) were correlated to August/September and September/October ENSO indices, there were very strong and positive correlations ($r = 0.52^{***}$ and 0.48^{***}, respectively). This indicates that it is possible to predict early rainfall using ENSO indices from September up to February in Maswa. However, there was no significant correlation between bimonthly ENSO indices (December/January and January/February) and late season cumulative rainfall (March to May). This indicates that bimonthly ENSO indices for December/January and January/February can not be used to predict late seasonal rainfall. (March to May) Similar evidence was reported by Clark *et al.* (2003) who found strong correlation between ENSO indices and early rainfall (October to December) along the coastal areas of Kenya and Tanzania. In view of the agricultural production and economic implications of rainfall variability in rainfed lowland rice production in Tanzania and in particular Maswa, the above results can be used in forecasting the rainfall trends in the period of October to March. The bimonthly ENSO indices as from September can be used to forecast seasonal rainfall up to February (Table 6). This can reduces uncertainty in rainfed lowland rice establishment in Maswa.

As the early bimonthly ENSO indices (August/September and September/October) were strongly and positively correlated with early season cumulative rainfall

(October to February), it is possible to forecast moisture availability of the rice fields along the toposequence.

Dividing ENSO index in quartiles and grouping into three groups with their respective rainfall amounts (Q1 values , value between Q3 and Q1 and values above Q3) revealed that mean early rainfall amounts were statistically different ($P<0.01$). Thus this grouping could be used as criteria for advising farmers on when and where to grow rice along the toposequence as shown in Table 7. Using the above criteria, it was revealed that in 43 rainfall seasons' data, rice can be grown in the lower and middle parts for 33 seasons (Fig. 12) and all fields along the toposequence can be used for rice cultivation for only 10 seasons.

The above results demonstrated that ENSO index can be used to assist planners, extension staff on when and where rainfed lowland rice can be grown and where and when to be left fallow or used for other crops more efficiently along the toposequence and thus advice farmers correctly and appropriately so as to reduce the frustrations of rice farmers in semi-arid areas due to low rice grain yields..

Table 7: ENSO index criteria for growing rainfed lowland rice along the toposequence

Criterion	Recommendation
Less than -0.6 ENSO index	Grow rice at fields located at lower part of the toposequence
Between -0.6 and 0.85 ENSO index	Grow rice at fields located at middle and lower parts of the toposequence
Greater than 0.85 ENSO index	Grow rice at fields located at lower, middle and upper parts of the toposequence

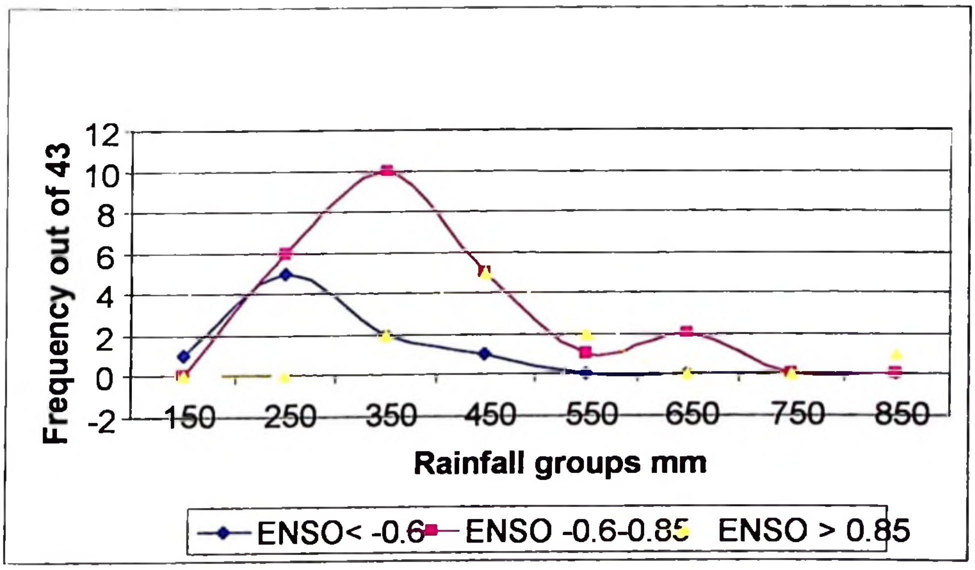


Figure 12: Relationships between rice growing frequencies and rainfall groups based on ENSO indices in Maswa

4.2.6 Rice crop performance during the trial period (2002-2005)

a) Crop establishment

Seeding dates for rice is the function of cumulative rainfall during the months of October, November and December. Seeding can be done when monthly cumulative rainfall amount is at least 100 mm (De Datta, 1981). Based on this criterion, the long term cumulative rainfalls of 43 seasons, seeding should be done either during the first week of December or January in 37 seasons (Fig. 13) on the assumption that the rains season would extend beyond May.

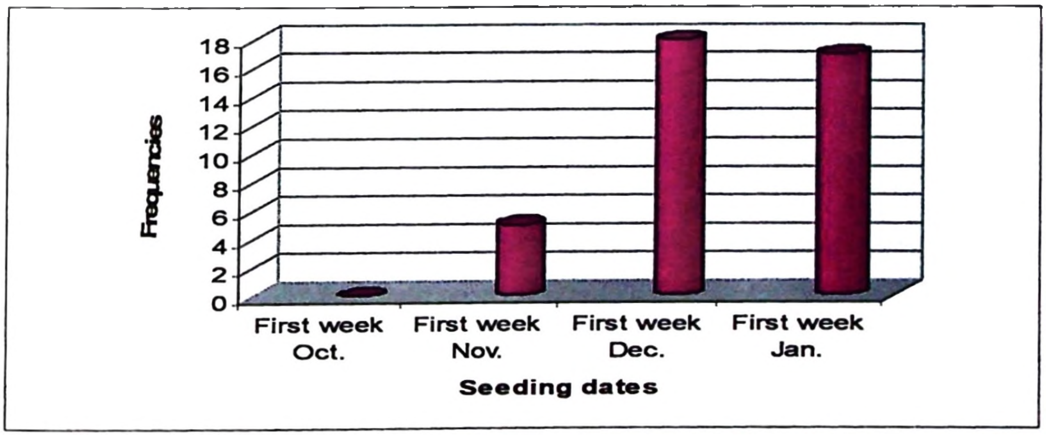
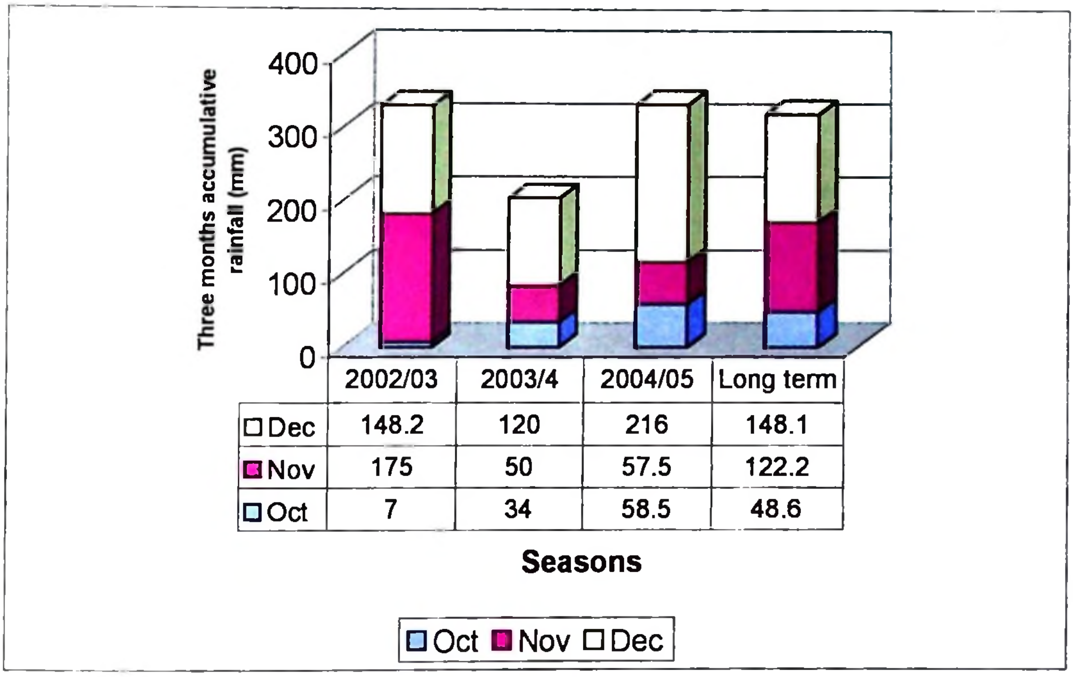


Figure 13: Seeding dates based on monthly long term rainfall amounts in Maswa

During the trial period, the cumulative rainfall amount in relation to long term average for the months of October, November and December were slightly higher than the long term average in 2002/03 and 2004/05 (Fig. 13). However, the rainfall distribution during the two seasons differed. In 2002/03 season, high amounts of rainfall were received in November (175 mm) and December (148.2 mm). In contrast, the 2004/05 season, high rainfall (216 mm) was received in December. In 2003/04 season, the cumulative rainfall amount was 36 % lower than the long term average. Substantial amounts of rainfall were received in December (120 mm). However, the amounts (120 mm) were 18.9 % lower than the long term average (148.1 mm). As a result of the above, the seeding was done on the third week of December in 2002/2003, first week of January in 2003/4 and 2004/2005 seasons (Table 5) respectively. Meertens *et al.* (1999) reported that crop establishment can extend to end of January to take advantage of available rainfall. However, the effects of February dry spell were not completely eliminated, hence rice grain yields/growth was not optimal.

b) Rice growth developmental phases

Monthly rainfall amounts in relation to rice growth developmental phases showed that in all three seasons the vegetative phase was affected by the February dry spell (Table 8). This is due to the fact that seeding was done at the end of December, and early January for 2002/03, 2003/04 and 2004/05 seasons (Fig. 14), respectively which led to the vegetative phase coinciding with the February dry spell. Ponding of run off water in the excavated bunded fields was used as a strategy to escape the effect of the dry spell which was however, not escaped in totality due inadequate rains a common phenomenon in semi arid areas.



	2002/03	2003/4	2004/05	Long term
☐ Dec	148.2	120	216	148.1
🟥 Nov	175	50	57.5	122.2
🟦 Oct	7	34	58.5	48.6

Figure 14: October to December cumulative rainfall (mm) at trial sites, Bukangilija village, Maswa.

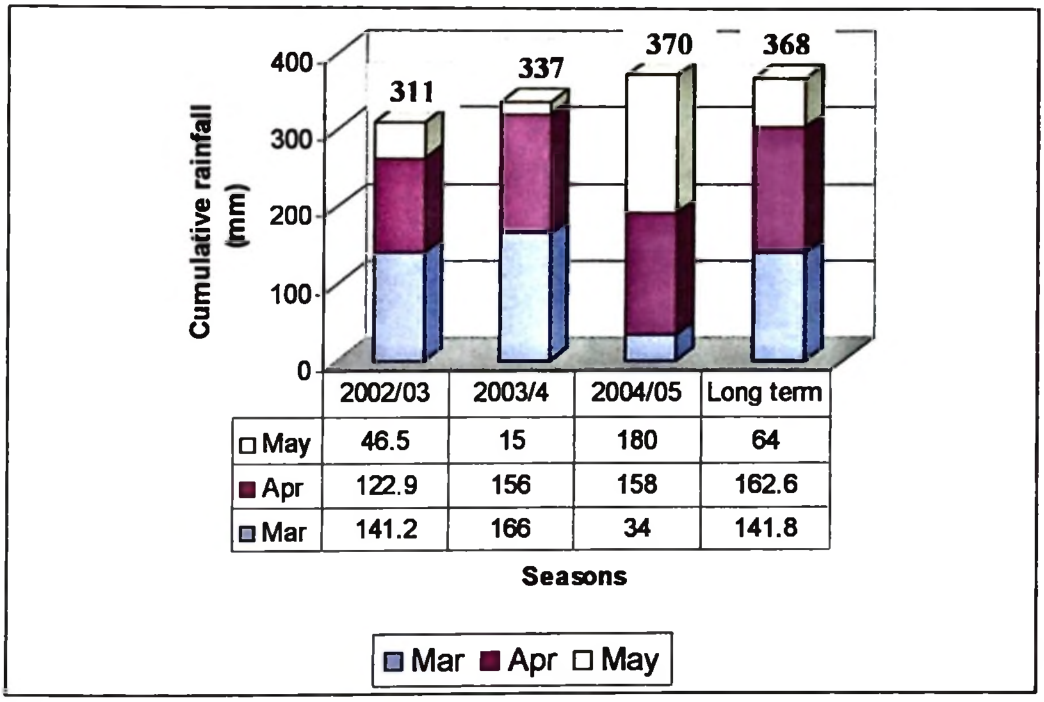
Variation in the rice root systems is considered to be a source for improving drought tolerance of rainfed lowland rice through superior water extraction (Fukai, and Cooper, 1995). A deep and thick root system is presumed to contribute to resistance to intermittent drought in lowland rice, based on evidence from upland rice (Lilley and Fukai, 1994; Yadav *et al.*, 1997), from capacity of roots to penetrate artificially formed compacted layers (Yu, *et al.*, 1995) and the assumption that resources are available after deep and thick roots penetrate hardpans in lowland paddy (Wade, 1999). The plant root growth, which is root extension and ramification within the soil volume/mass, is enhanced by adequate moisture/water availability during the early stage of rice plant establishment.

Table 8: Dates of different rice growth developmental phases at Bukangilija, Maswa

Seasons	Start of vegetative (seeding)	Start of reproductive phase	Start of ripening phase
2002/03	21.12.2002	01.03.2003	15.04.2003
2003/04	07.01.2004	21.03.2004	04.05.2004
2004/05	05.01.2005	15.03.2005	21.5.2005

The reproductive phase started early and late March in 2002/03 and 2003/04 seasons, respectively while in 2004/05 it started in mid March (Table 8). Post February monthly cumulative rainfall during the trial period had an effect on both reproductive and ripening phases. In 2002/03 season, the rainfall in March (141 mm) was about the same as the mean long term rainfall (142 mm). However, the April rainfall (122.9 mm) was lower by 19.7 mm when compared to the long term average rainfall (162.6 mm). A similar trend was observed in 2003/2004 season with rainfall amounts greater than 150 mm in both March and April. During the reproductive phase, both seasons (2002/03 and 2003/04) had about the same rainfall amounts except in April where rainfall amounts were lower than the long term mean by 24 % and 4 % in 2002/03 and 2003/04 seasons, respectively. Consequently, during the 2002/03 season, the upper and lower trial fields had no standing water for 20 and 15 days, respectively before maturity due to inadequate rainfall. The lower fields had ponded run off water during the reproductive phase for all trial seasons due to the large amounts of run off that accumulated at the lower part of the toposequence. The 2004/05 season had extremely low amounts of rainfall in March (35 mm) which led to delayed flowering and the drying of the standing water in all the fields for 20, 16 and 10 days for upper, middle and lower sites, respectively. The rainfall in April (156 mm) was about the same as the long term average (163 mm) and was sufficient to generate run off water in rice paddies which was essential during the reproductive stage/phases.

In general, the reproductive phase in 2002/03 and 2003/04 seasons had rainfall greater than 120 and 150 mm, respectively when compared to 2004/05 season, which resulted into ponding of the run off water in all the excavated bunded rice fields. In 2004/05 season, there was moisture stress during the initial period (March) of the reproductive phase caused by the drying of standing water in the excavated bunded fields. The ripening phase started in Mid April and early May for the 2002/03, 2003/04 and 2004/05 seasons, respectively. The amount of run off water ponded in May was a function of rainfall in April. In all seasons, rainfall amounts in April were greater than 150 mm, except in 2002/03, which had greater than 120 mm rainfall (Fig. 15). However, these amounts of rainfall in April were lower than the long term means which affected the reproductive stage especially the grain filling phase. Rainfall amounts in May were lower by 27 mm and 76 mm for 2002/03 and 2003/04 seasons, respectively when compared to long term mean of 163 mm. In 2004/05 season, May had exceptionally high rainfall (180 mm) when compared to the long term average (64 mm) which necessitated the need of draining water from the bunded fields during reproductive stage to enhance maturity.



	2002/03	2003/4	2004/05	Long term
□ May	46.5	15	180	64
■ Apr	122.9	156	158	162.6
▨ Mar	141.2	166	34	141.8

Figure 15: March to May cumulative rainfall (mm) at the Bukangilija trial sites

4.3 Field experiments

4.3.1 Soil and farmyard manure characterization

Some of the chemical and physical characteristics of the composite soil samples from the trial fields at 0-30 cm depth are depicted in Table 9. Based on classification by Landon (1991), the soil reactions for the three sites were mild alkaline, had very low organic carbon (OC) and medium to high available P and were very low total nitrogen. The exchangeable K was low for the upper and middle fields while the lower field had medium level of exchangeable K. Exchangeable Ca was high in all fields while exchangeable Mg ranged from low (upper field) to very high (middle and lower fields). Cation exchangeable capacity ranged from low (upper field) to medium (middle and lower fields).

Some of the chemical characteristics of the farmyard manure used in the field experiments are given in Table 9. According to Palm *et al.* (1997) high quality organic materials have N > 2.5%, P>0. 24%, lignin < 0.15% and polyphenol < 4%. Based on these critical values the farmyard manure had low N and high P contents. The threshold C:N ratio and soluble carbon to total P ratio for fast mineralization and net P mineralization are 20:1 and 30:1, respectively (Palm *et al.*, 1997; Nzinguheba *et al.*, 2000). Based on these critical ratios the farmyard manure used would undergo fast mineralization and further based on the analytical data is of medium quality.

Table 9: Some of the chemical and physical characteristics of the composite soil samples from the trial sites and the farmyard manure

a) Soil Parameters	Fields position along the micro-toposequence				
	Upper	Middle	Lower	Mean	Rating[1]
pH (water)	7.57	7.56	7.41	7.51	Mild alkaline
EC (mS/cm)	0.19	0.22	0.15	0.19	Normal
Organic carbon (%)	0.34	0.44	0.35	0.38	Very low
Total nitrogen (%)	0.03	0.03	0.04	0.03	Low
Extractable P (Olsen, mg kg^{-1})	11.62	10.94	18.61	13.72	Medium
Exchangeable Na (cmol kg^{-1})	0.59	0.68	0.92	0.73	Normal
Exchangeable K (cmol kg^{-1})	0.11	0.26	0.36	0.24	Medium
Exchangeable Ca (cmol kg^{-1})	6.42	13.43	15.05	11.63	High
Exchangeable Mg (cmol kg^{-1})	0.93	2.81	2.66	2.13	High
CEC (cmol kg^{-1})	11.00	19.40	20.40	16.93	Medium
Particle size distribution					
Sand (%)	80.23	56.19	46.54	60.99	
Silt (%)	7.5	10.77	16.64	11.64	
Clay (%)	12.27	33.04	36.82	27.38	
Textural class	SL	SCL	SC		

b) Farmyard manure		Rating[2]
pH	8.08	Moderately alkaline
Organic carbon (%)	7.43	Low
Total nitrogen (%)	0.83	Low
Phosphorus (%)	0.33	High
Potassium (%)	1.79	Low
C:N ratio	8.34	Good
C:P ratio	22.27	Good

SL =Sandy loam; SCL=Sandy clay loam; SC= Sandy clay

1 Soil rating was done according to Landon, (1991)

2 Farmyard manure rating was done according to Palm *et al.* (1997)

4.3.2 Number of ponding days

Analysis of variance revealed that number of ponding days (days with standing water in the fields) varied significantly ($P < 0.05$) between different field positions along the toposequence (Fig. 16). The upper field had significantly ($P<0.05$) less number of ponding days when compared with middle and lower fields. The mean numbers of days with standing water were 48, 64 and 75 for upper, middle and lower fields, respectively in 2002/03 season while in 2003/04 the numbers of days with standing water were 39, 53 and 62 for upper, middle and lower fields, respectively. In 2004/05 season, the mean numbers of days with standing water were 56, 77 and 90 for upper, middle and lower fields, respectively. Consistently, there was no significant difference in the number of ponding days between different nutrient treatments for all seasons (Appendix 8). The above numbers of ponding days were very small compared to 180 to 250 days reported in irrigated rice in Usangu river basin, Tanzania (Mdemu *et al.*, 2003). This is due to limited amount of water in rainfed rice and in particular in semi arid areas compared to irrigated rice.

The short duration of the standing water on upper field compared to middle and lower was due to the fact that upper field lost water through percolation and seepage (mostly by lateral movement) due to its coarse texture of the surface horizons of the soil. The particle size distribution at 0-30 soil depth, determined before the start of experiment, for the three fields along the toposequence showed that (Table 9) the upper field has high percent of sand (80 %) compared to middle (56 %) and lower fields (47 %). Consequently, water was lost easily in the upper field through percolation and seepage. This made the upper field more prone to drought. Similar evidence was reported by Ngailo *et al.* (1994) who worked in the same area. Other authors working in Asia (Homma *et al.*, 2003; 2004; Samson *et al.*, 2004) have reported differential movement of water along the toposequence in rainfed lowland rice hence the observed yield difference.

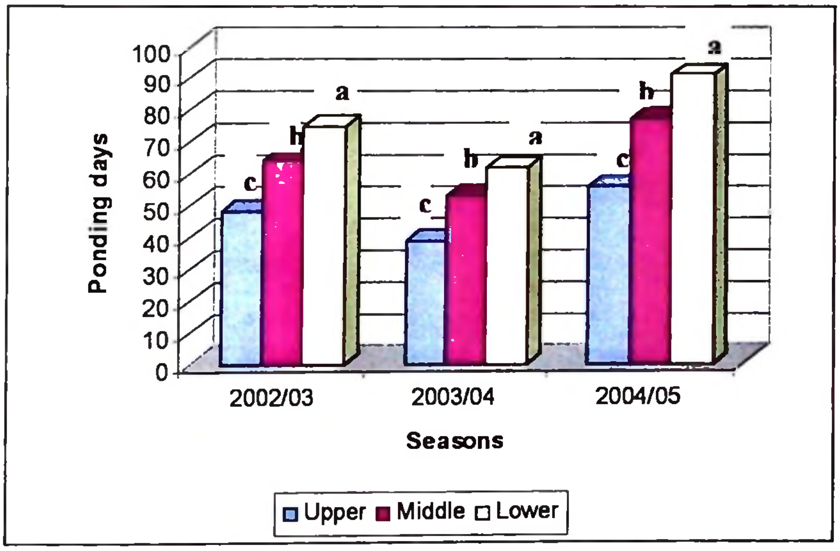


Figure 16: Relationship between field position and ponding days along the toposequence

4.3.3 Effect of farmyard manure (F), phosphorus (P) and nitrogen (N) applications on the extent of tillering of rice plants

The response of rice plants to F, P and N application in terms of number of tillers per hill is as presented in Table 10. The number of tillers per hill increased with increasing rates of F, P and N applications for the three cropping seasons. The trend in the increase in the number of tillers per hill was in the order N>F>P. The increase in number of tillers per hill with increasing rates of N (main effect of N) ranged from 9.3 to 14.1 for F1P1N1 (0 kg N ha^{-1}) to F1P1N3 (100 kg N ha^{-1}) (Table 10). Further the increase in number of tillers per hill with increasing rates of F (main effect of F) ranged from 9.3 to 11.1 for F1P1N1 (0 t F ha^{-1}) to F3P1N1 (7 t F ha^{-1}) and the increase was statistically significant ($P<0.05$). Furthermore, the increase in number of tillers per hill with increasing rates of P (main effect of P) ranged from 9.3 to 10.7 for F1P1N1 (0 kg P ha^{-1}) to F1P3N1 (60 kg P ha^{-1}) and the increase was also statistically significant ($P<0.05$). The response of rice plant in term of number of tillers per hill to the F, P and N combinations were statistically significant. The field positions (replicates) on a micro catchment showed a significant effect ($P<0.05$) on number of tillers per hill (Fig. 17). The upper field had lower mean number of tillers per hill (11.9) than the middle (14.6) and lower fields (15.3).

The increase in number of tillers per hill with the application of N was attributed to the increase in soil N as the soils at the trial sites (locations) were deficient in N (Table 9). Furthermore, from the applied soil amendments, N is, among other things, responsible for promotion of rapid plant growth which in turn increased the number of tillers per plants (De Datta, 1981; Tisdale *et al.*, 1993). The increase in number of tillers with the application of F, was attributed to the increased N and availability of other nutrients to the plants like P, K, Ca, Mg, S and the micro-nutrients, consequent to the decomposition and mineralization of the F which contained substantial amounts of the essential plant nutrient (Table 9). Further, F has ability to retain water during the moisture stress condition. Similar observation has been reported by Chakraborty *et al.,* (2003) in West Bangel, India. Phosphorus applications had lowest responses in term of number of tillers per hills due to the high initial available P levels in the soils determined at the start of the trial (Table 9) hence dramatic response to P was not expected as P requirement by rice for growth is low to medium.

The F, P and N treatments combinations increased the number of tillers per hill due improvement of nutrient balances in the soils and their interactions. For instance, F is assumed to have gradually released the nutrients ocuring in complex compound in the F through decomposition and mineralization hence extending the availability of the nutrient within the season. In contrast, the inorganic fertilizer that is urea, being highly soluble, was capable of releasing the nitrogen (as NH_4^+ and probably as NO_3^-) at a rate that conformed to the rice plant N uptake and had invigorating effect on soil microbes that were responsible for enhancing the decomposition of the farmyard manure. Thus the combined application of F, P and N commensurately released the nutrients steadily for the rice crop. A similar observation has been reported by Kumar *et al.*, (1999) and Chakraborty *et al.*, (2003) in West Bangel, India who where combined application of inorganic and organic soil amendments improved tillering in rice resulting into increased rice yields as a consequent to the increased number of panicles in reponse to the adequate supply of nutrients from the amended soils.

The low mean number of tillers per hill in the field on the upper position on the landscape as compared to the middle and lower fields might be due to short duration of ponding days on the upper field compared to middle and lower fields (Fig.17) attributable to the difference in the textural classes of the soils. The upper field had higher percentage of sand than the middle and lower fields hence water percolation was faster consequently the reduced number of ponding days. Further, the low number of tillers in the upper fields was attributed to low level of availabe P and organic matter which is reflected in low organic cabon (Table 9). Similar evidence has been reported by Ngailo *et al.* (1994) and Payton (2000) who worked in the same area. Other studies in Northeast Thailand and Bangladesh (Homma *et al.*, 2003; Samson *et al.*, 2004) reported similar results where adequate water and nutrients positively influenced the number of tillers per plant or per hill.

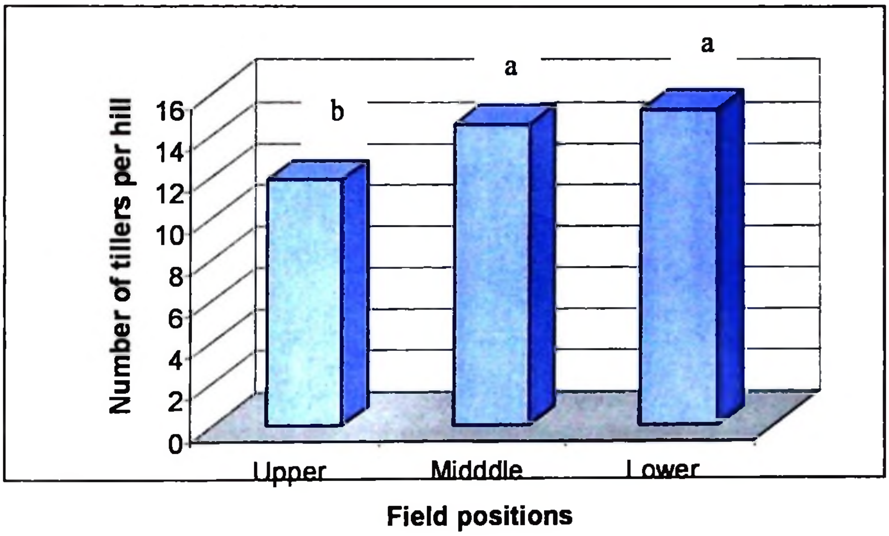


Figure 17: Effect of field positions along the toposequence on the tillering in rice plants.

Table 10: Effect of farmyard manure, phosphorus and nitrogen applications on number of tillers per hill

	N1			N2			N3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
F1	**9.3** j	**9.8** ij	**10.7** hij	**12.3** efghij	12.4 defghij	14.2 bcdefghij	**14.1** bcdefghij	15.6 abcdefgh	16.6 abcdef
F2	**10.0** ij	10.7 hij	11.4 ghij	12.6 dcefghij	13.6 cdefghij	15.2 abcdefgh	15.7 abcdefg	16.7 abcde	17.5 abc
F3	**11.1** ghij	11.7 fghij	12.1efgij	14.5 bcdefghi	15.4 abcdefgh	17.3 abcd	17.5 abc	18.7ab	19.9 a
Mean	14.5								
CV (%)	10.5								

Means followed by the same letter(s) in the entire table are not significantly different ($P<0.05$) according to Tukey Test
N1, N2 and N3 = 0, 50 and 100 kg N ha^{-1}, respectively. P1.P2 and P3 = 0, 30 and 60 kg P ha^{-1} respectively. F1, F2 and F3 = 0, 3.5 and 7 t manure ha^{-1}

4.3.4 Response of rice in terms of straw yields to farmyard manure (F), phosphorus (P) and nitrogen (N) applications

The response of rice plants to F, P and N applications in terms of straw (dry matter) yields is as presented in Table 11. The straw dry matter yields increased with increasing rates of F, P and N for the three cropping seasons. The trend in the increase in the straw dry matter yields was in the order N>F>P and the increases were statistically significant ($P<0.05$) for N. The increases in straw dry matter yields for main effects of N, F and P ranged from 2688 to 4993, 2688 to 3923 and 2688 to 3786 kg ha^{-1}, respectively (Table 11). The response of rice plant in term of straw dry matter yields to the F, P and N combinations were statistically significant ($P<0.05$). The effect of P and N interaction was significant during the 2003/04 cropping season (Table 13) but was insignificant in the 2002/03 and 2004/05 seasons. The field positions on the landscape had significant effect ($P<0.05$) on straw dry matter yields (Fig. 18). The upper field had lower mean straw dry matter yield (2599 kg ha^{-1}) than the middle (3602 kg ha^{-1}) and lower fields (7756 kg ha^{-1}).

From the data in Table 11, nitrogen application had the greatest increase on straw dry matter yields and the increase was attributed to the increase in soil N as the soils at the trial sites were deficient in N (Table 9). The increase in straw dry matter yields conform to the trend in the increase in tillering in the rice plants with increasing N application rates. The increase in straw dry matter yields with the application of F was attributed to the increased N and other nutrients availability to the plants, consequent to the decomposition and mineralization of the F which contained substantial amount of the essential plant nutrients (Table 9). Similar observation has been reported by Chakraborty *et al.*, (2003) in India where N increased straw dry matter yields. Increased vegetative growth in plants increases with availability and uptake of N-by plants (Tisdale *et al.*, 1993) as N is essential for synthesis of plant tissues.

Phosphorus applications gave the lowest responses in term of straw dry matter yields due to the high initial P in the soils (Table 9). Landon (1991) reported that rice response to applied P for soils with initial P (Olsen) between 12-20 mg kg^{-1} is highly questionable and if obtained it would not be that dramatic/high. The plant available P (Olsen)) in the trial sites was 13.72 mg kg^{-1} which is within the medium range of 12-20 mg kg^{-1} leading to low response of rice in terms of straw dry matter yields.

The interaction of N and P in 2003/04 season might be due to synergetic effect of N and P on the rice growth performance. This was boosted by the good rains received in January, March and April 2004 which increased N and P availability to and uptake by the rice plants by facilitating the movement of the nutrient from the soil mass to the root surface. Water availability promoted uptake of both N and P which promoted growth and root development, respectively. Similar evidence in Asia has been reported by De Datta (1981) and Tisdale *et al.* (1993). Complementary increase of dry matter yield on the use of both N and F has been reported by Chakraborty *et al.* (2003), however, in the current study there was no significant complementary effect on N and F which might be limited by small amount of nutrients in F in term of nitrogen (Table 9).

Treatment combinations F, P and N increased straw dry matter yields. This is due to the fact that when applied in conjunction increased availability of other soil nutrients and number of tillers per plant as discussed in Section 4.3.3. The Upper field had significantly lower mean straw dry matter yields than the middle and lower fields (Fig 18) due to short duration of ponding days on the upper field compared to middle and lower fields. Further low levels total N might have contributed to low straw yield on the upper fields. Furthermore, high pH might limit zinc availability to the rice crop (Table 9). Similar evidence of high pH has been reported by Ngailo *et al.* 1994 and Payton (2000) who worked in the same area. The number of ponding days affected the period of water stress to the plant hence the differential straw yields observed among the blocks (trial sites on the micro-toposequence)

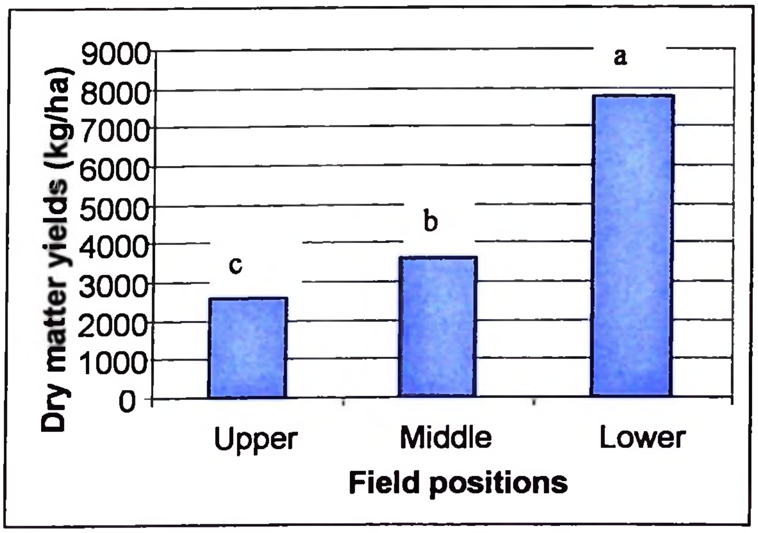


Figure 18: The effect of field positions on rice straw dry matter yields (kg ha^{-1})

Table 11: Effect of farmyard manure, phosphorus and nitrogen applications on straw dry matter yield (kg ha^{-1})

	N1			N2			N3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
F1	**2688** c	**3396** de	**3786** bcde	**3800** bcde	4201abcde	4482 abcde	**4993** abcd	5573 abc	5816 ab
F2	**3459** cde	3765 bcde	3901 bcde	4313 abcde	4670 abcde	4832 abcde	5249 abcd	5627 ab	5895 ab
F3	**3923** bcde	4081 abcde	4367 abcde	4757 abcde	5150 abcd	5472 abcd	5416 abcd	5796 ab	6210 a
Mean	4588.15								
CV (%)	8.29								

Means followed by the same letter(s) in the entire table are not significantly different ($P<0.05$) according to Tukey Test;
N1, N2 and N3 = 0, 50 and 100 kg N ha^{-1}, respectively. P1, P2 and P3 = 0, 30 and 60 kg P ha^{-1} respectively. F1, F2 and F3 = 0, 3.5 and 7 t manure ha^{-1}

Table 12: Effect of farmyard manure, phosphorus and nitrogen applications on grain yields (kg ha^{-1})

	N1			N2			N3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
F1	**1325** n	**1417**mn	**1708** lmn	**2083** ijklm	2167 hijkl	2458 fghijk	**2625** defghij	2833 bcdefgh	3042 abcdef
F2	**1792** klmn	1867 klmn	2042 jklm	2500 efghijk	2417 fghijkl	2625 defghij	2917 bcdefg	3200 abcde	3400 abc
F3	**2167** hijkl	2167 hijkl	2275 ghijkl	2833 bcdefgh	2783 cdefghi	3083 abcdef	3292 abcd	3500 ab	3667 a
Mean	2639.94								
CV (%)	14.3								

Means followed by the same letter(s) in the entire table are not significantly different ($P<0.05$) according to Tukey Test
N1, N2 and N3 = 0, 50 and 100 kg N ha^{-1}, respectively. P1, P2 and P3 = 0, 30 and 60 kg P ha^{-1} respectively. F1, F2 and F3 = 0, 3.5 and 7 t manure ha^{-1}

Table 13: Effect of phosphorus (P) and nitrogen (N) on interactions on dry matter yield (kg ha^{-1}) in 2003/04 season

	N1 (0 kg N ha^{-1})	N2 (50 kg N ha^{-1})	N2 (100 kg N ha^{-1})
P1 (0 kg P ha^{-1})	3 840 e	4 151 cd	4 405 b
P2 (30 kg P ha^{-1})	4 060 de	4 340 bc	4 344 bc
P3 (60 kg P ha^{-1})	4 135 cd	4 440 b	4 728 a
Mean	4 271		
CV (%)	3.7		

Means followed by the same letter(s) in the entire table are not significantly different ($P<0.05$) according to Tukey Test.

4.3.5 Effect of farmyard manure (F), phosphorus (P) and nitrogen (N) applications on rice grain yields (kg ha^{-1})

The response of rice to F, P and N applications in terms of grain yields is as presented in Table 12. The grain yields increased with increasing rates of F, P and N applications for the three seasons. The trend in the increase in rice grain yields was in the order N>F>P (Table 12) and increases were statistically significant ($P<0.05$) except for P. The trend conforms to number of tillers and straw dry matter yields. The increase in grain yields for the main effect of N, F and P ranged from 1325 to 2625, 1325 to 2167 and 1325 to 1708 kg ha^{-1} respectively (Table 12). The field positions on the micro catchment showed a significant effect ($P<0.05$) on grain yields (Fig. 19). The upper field had significant lower mean grain yields (1844 kg ha^{-1}) than the middle (2532 kg ha^{-1}) and lower fields (3200 kg ha^{-1}).

The highest increase in grain yields as a result of N application was due to increased number of tillers and dry matter yields (Table 10 and 11) cosequent to the increased

N-uptake by the plant. Furthermore, N is, responsible for increased size of the leaves and grains, number of tillers, spikelets per panicle and filled spikelets per panicle (De Datta, 1981) hence the observed positive significant response. These results agree with those of Meertens *et al.* 2003 who found that N applications consistently increased grain yields of lowland rice in the semi arid areas of Tanzania. The availability of N, further influenced the uptake of other essential plants the result of which was manifested in the increased rice grain yields. The increase in grain yields as a result of F application was due to increased N and other nutrients in the soils.

The lowest responses to P compared to N and F applications in term of grain yields due to high initial P content in the trial sites as described in Section 4.3.3. The upper field had significant lower mean grain yields (1844 kg ha^{-1}) than the middle (2532 kg ha^{-1}) and lower fields (3200 kg ha^{-1}). This might be due to variation in soil fertility along the micro-toposequence (Table 9). Further, the short duration of ponding days on the upper field compared to middle and lower fields contributed to differences in yields as well as non uniformity of water in the plots during the ponding period because of the sloping nature of the trial site.

Grain yield variations for different treatment combinations (calculated as shown in Section 3.4.3) for three seasons are shown in Table 14. In spite of poor rainfall during the experimental period the percentage yield variations for different treatment combinations ranged from 5 to 16.4 (Table 14). This indicate that yield variation were very low during the trial period. In general, it can be observed that different soil amendments reduced yield variations among different treatment combinations due to nutrient interaction and improved nutrient balances.

In the absence of applied nutrient, mean yield for the three seasons was 1325 kg ha^{-1} which was lower than the mean yields reported by URT (2003) which 1.5 t ha^{-1}. The slightly high yield reported by URT, (2003) is associated with good rains hence more runoff was generated and collected in the excavated bunded basins. The low yield levels obtained in this study is attributed to moisture stress during the growing seasons, low soil fertility especially nitrogen and zinc and poor grain filling during reproductive stage due to inadequate rains. However, the yields obtained (1325 kg ha^{-1}) in the absence of applied soil amendments was comparable with the mean rainfed lowland rice yields in Asia which were reported to range from 1.2 to 3.5 t ha^{-1} (Wade *et al.*, 1999). The narrow percentage yield variation might be due to ponded water adjacent to the trial field which was used to supply water when there was no standing water in the fields. This reduced the impact of drought on yield among the different soil amendments. However, the supplied water was not optimum for rice plant growth due to inadequate rainfall.

Table 14: Percentage means yield variations for different treatment combinations

	N1			N2			N3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
F1	13.7	12.6	10.4	8.7	8.4	7.4	6.9	6.4	6.0
F2	9.9	16.4	9.0	7.3	7.6	6.9	6.3	5.7	5.4
F3	8.4	8.5	8.0	6.4	6.6	6.0	5.6	5.3	5.0

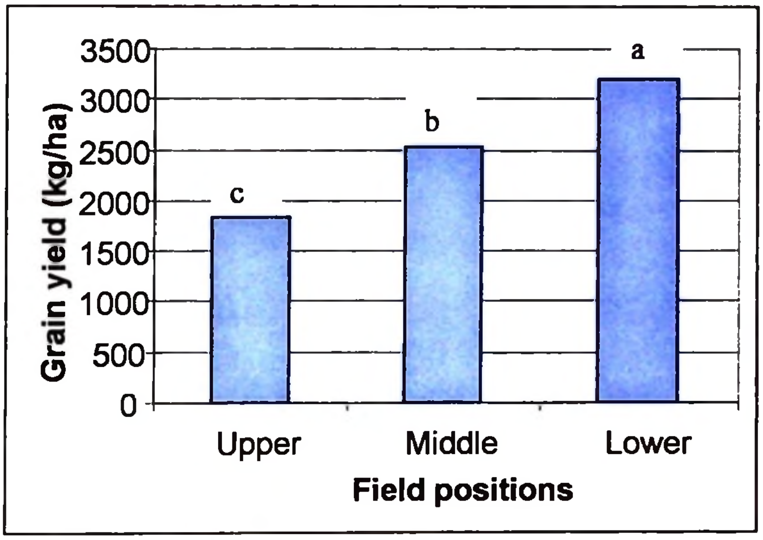


Figure 19: Effect of field positions on rice grain yields

4.3.6 Effect of farmyard manure, phosphorus and nitrogen on N, P and K contents in the rice plants

The concentrations of N, P and K in the rice plants at the tillering stage are as presented in Tables 15 to 21.

a) Nitrogen concentration

The nitrogen concentrations (Table 15) increased with increasing rates of F, P and N for the three seasons and the trend in the increase in nitrogen concentrations was in the order N>F>P (Table 15). The main effect of N, F and P on the N concentration in the rice plants ranged from 19.93 to 45.85 g kg^{-1}, 19.93 to 35.32 g kg^{-1} and 19.93 to 26.04g kg^{-1} (Table 15), respectively.

The response of the rice plants (above ground portions) in terms of N contents for the three seasons and the field positions on the landscape (micro catchment) to the NPF interactions (Table 16, 17) were significant ($P<0.05$). However, the lower fields had lower mean nitrogen concentrations (30.27 g kg^{-1}) than the upper (33.28 g kg^{-1}) and middle fields (33.77 g kg^{-1}) and this could be attributed to the dilution effect of nutrient content with increased growth. The N contents in the rice plants were above the critical N levels or range in rice plants (25 g kg $^{-1}$) indicating adequate supply of N from the soil.

The positive response of rice to N, F and P application in terms of N concentrations is attributed to the increase in available N from the N fertilizer used and N released from mineralization of F. Further, synergetic effect between N and P enhanced the uptake of N from the soils. Furthermore, the release of other essential plant nutrients from F through mineralization increased and maintained an appropriate nutrient balance in the soils. Mikkelsen (1971) rated nitrogen concentrations in the rice plants at tillering stage, < 2.4 % (24 g kg^{-1}) as deficient, 2.4-2.8% (24-28 g kg^{-1}) as low, 2.8-3.6 % (28-36 g kg^{-1}) as sufficient and > 3.6% (36 g kg^{-1}) as very high. Based on the results by Mikkelsen (1971), the N contents in the rice plants in this study ranged from deficient (19.93 g kg^{-1} control) to very high (45.85 g kg^{-1} for F3P3N3). From the categorization made by Pillai (2005), nitrogen concentration < 2.5% (25 g kg^{-1}) in rice plant at tillering stage was rated as deficient, then most of N content for various treatments in the current study were above the critical level of 25 g kg^{-1} (Pillai, 2005). A Similar observation has been reported by Bergmann (1992) where adequate nitrogen content range from 2.9 – 4.2 % (29 – 42 g kg^{-1}) in the upper fully developed leaves of rice plant before flowering under conditions of increased N applications hence availability. The increased in nitrogen concentrations with increasing levels of farmyard manure, phosphorus and nitrogen application rates was due to the fact that the soils were deficient in nitrogen as was evident in the initial soil analysis (Table 9). Similar responses of increased N uptake as a result of N application in N deficient soils were reported by Seleque *et al.* (2004). Nitrogen content was significantly higher in the upper and middle fields than the lower fields regardless of all fields being deficient in nitrogen (Table 9). This was attributed to the availability of water in the upper and middle fields in relation to the run off generating catchment. The upper field received water first although the water was lost more quickly than the lower field due to its high sand content of the soils and the sloping nature of the topograhy. Consequently N in the upper fields might have beeen lost through laeching. Similar observation was reported by Ngailo *et al.* (1994) and Payton (2000).

Table 15: Effect of farmyard manure, phosphorus and nitrogen applications on nitrogen concentrations (g kg^{-1})

	N1			N2			N3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
F1	19.93 j	24.70 ij	26.04 hj	22.80 ij	26.19 hi	27.68 ghi	24.89 ij	27.71 ghi	34.52 cdef
F2	24.19 ij	30.78 fgh	34.18 ghi	26.89 defg	31.98 bcde	36.57 efgh	31.21 cfgh	34.27 cdef	41.32 ab
F3	35.32 cdef	36.25 bcdef	37.17 bcd	37.02 bcd	37.69 bcd	39.42 bc	39.63 bc	41.87 ab	45.85 a
Mean	32.45								
CV (%)	5.4								

Means followed by the same letter(s) in the entire table are not significantly different ($P<0.05$) according to Tukey Test

Note: N1, N2 and N3 = 0, 50 and 100 kg N ha^{-1}, respectively. P1,P2 and P3 = 0, 30 and 60 kg P ha^{-1} respectively. F1,F2 and F3 = 0, 3.5 and 7 t manure ha^{-1}

Table 16: Effect of the N-P interaction on N concentration in rice plants (g kg^{-1})

	N1 (0 kg N ha^{-1})	N2 (50 kg N ha^{-1})	N3 (50 kg N ha^{-1})
P1 (0 kg P ha^{-1})	26.48 d	28.90 cd	31.91 bc
P2 (30 kg N ha^{-1})	30.58 bcd	31.95 bc	34.61 b
P3(60 kg N ha^{-1})	32.46 bc	34.56 b	40.56 a
Mean	32.45		
CV (%)	5.4		

Means followed by the same letter(s) in the entire table are not significantly different (P<0.05) according to Tukey Test

Table 17: Effect of the F-P interaction on N concentrations in rice plants (g kg^{-1})

	P1 (0 kg N ha^{-1})	P2 (30 kg N ha^{-1})	P3 (60 kg N ha^{-1})
F1 (0 kg P ha^{-1})	22.54 d	26.20 cd	29.41 bc
F2 (3.5 t N ha^{-1})	27.43 c	32.34 b	37.35 a
F3(7 t N ha^{-1})	37.32 a	38.60 a	40.81 a
Mean	32.45		
CV (%)	5.4		

Means followed by the same letter(s) in the entire table are not significantly different (P<0.05) according to Tukey Test

b) Phosphorus concentration

The effect of farmyard manure, phosphorus and nitrogen applications on mean phosphorus concentrations in the rice plants for the three seasons were as presented in Table 18. The phosphorus concentrations increased with increasing rates of F, P and N applications for the three seasons and the trend in the increase was in the order N>F>P (Table 18). The trend conforms to number of tillers, straw dry matter and grain yields. The main effects of N, F and P on P contents in the whole rice plant above the soil levels ranged from 0.82 to 1.2 g kg^{-1} 0.82 to 1.4 g kg^{-1} and 0.82 to 1.17 g kg^{-1}, respectively. The field positions on the landscape had significant effect ($P<0.05$) on the phosphorus concentration (Table 19) in the rice plants. The upper fields had lower mean phosphorus concentration (1.30 g kg^{-1}) than middle (1.41 g kg^{-1}) and lower fields (1.47 g kg^{-1}).

Pillai (2005) categorized P concentration of 0.1 % (1 g kg^{-1}) in the dry matter of rice plant at tillering stage as deficient. Based on P concentration obtained in the current study (Table 18) adequate concentration was attained when phosphorus was combined with farmyard manure and nitrogen at P2 (30 kg P ha^{-1}). Further, Fageria (2004) reported optimum phosphorus concentration in rice plant of 2.4 g kg^{-1} at active rice plant tillering stage. Based on this criterion, the obtained P concentrations in Table 18 are in the lower category hence the rice plants are deficient in P. The observation that the P concentrations in the rice plants at various F-P-N treatment combinations ranged from deficient to adequate based on the categorization by Pillai (2005) and deficient according to Fageria (2004), regardless of the adequate to high initial availability of P in the soils (Table 9) could be attributed to soil moisture content variations during the rice growing seasons. Further, the high pH of the soils and exchangeable Ca could have to some extent reduced the availability of P to the rice plant through the transformation of the native and applied P to non-available P forms. Such transformation includes the formation of insoluble Ca-phosphate in alkaline soils with high quantities of exchangeable Ca. Similar evidence was reported by Slaton *et al.* (2002). Phosphorus contents were significantly higher in lower fields than in upper and middle fields due to adequate water during the growing season and comparable high contents of other nutrients on the flat landscape as a result of seasonal deposition. High available P in the lower part of the toposequence has been reported by Maggogo, (1990) who worked along the toposequence of Ukiriguru, Mwanza Tanzania.

Table 18: Effect of farmyard manure, phosphorus and nitrogen applications on phosphorus concentrations in rice plants (g kg^{-1})

	N1			N2			N3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
F1	**0.82**g	**0.99** efg	1.17 **bcdefg**	**0.93** fg	1.08defg	1.30bcdefg	**1.20** bcdefg	1.24bcdefg	1.66abcd
F2	**0.98**efg	1.18bcdefg	1.41bcdefg	1.30bcdefg	1.37bcdefg	1.57abcdef	1.15cdefg	1.50bcdef	1.69abcd
F3	**1.40**bcdefg	1.58abcdef	1.66abcd	1.36bcdefg	1.63abcde	1.78abc	1.81ab	1.78abc	2.20a
Mean	1.40								
CV (%)	19.9								

Means followed by the same letter(s) in the entire table are not significantly different ($P<0.05$) according to Tukey Test

Note: N1, N2 and N3 = 0, 50 and 100 kg N ha^{-1}, respectively; P1, P2 and P3 = 0, 30 and 60 kg P ha^{-1}, respectively; F1, F2 and F3 = 0, 3.5 and 7 t manure ha^{-1}, respectively

Table 19: Effect of farmyard manure, phosphorus and nitrogen applications on rice plant N, P and K concentrations (g kg^{-1}) along the toposequence

	N	P	K
		g kg^{-1}	
Upper	33.28 a	1.31 b	8.22 a
Middle	33.77 a	1.41 ab	8.73 a
Lower	30.27 b	1.47 a	8.44 a
Mean	32.35	1.4	8.47
CV%	5.4	19.9	22.2

Means followed by the same letter(s) in the same column are not significantly different ($P<0.05$) according to Tukey Test

c) Potassium concentration

The effect of farmyard manure, potassium and nitrogen applications on the mean potassium concentrations in rice plants for the three seasons were as presented in Table 20. The total potassium concentrations increased with increasing rates of F, P and N applications and the trend in the increases was in the order N>F>P (Table 20). The main effect of N, F and P on K contents in the rice plants ranged from 4.15 to 16.27 g kg^{-1} , 4.15 to 6.34 g kg^{-1} and 4.15 to 5.6 g kg^{-1} respectively. The main effect of N, F and P on K contents in the rice plants were statistically significant as well as the N x P interactions (Table 21). The field position on the landscape had no significant effect ($P<0.05$) on the potassium concentrations in the rice plants at tillering (Table 19). All the same, the upper fields had lower mean potassium concentration (8.22 g kg^{-1}) than middle (8.73 g kg^{-1}) and lower fields (8.44 g kg^{-1}). Fageria (2004) reported optimum potassium concentration in rice plant of 32.2 g kg^{-1} at active tillering stage. Further, Bergmann, (1992) reported as adequate a range of

18 - 26 g K kg^{-1} for the upper fully developed leaf of the rice plant before flowering. Based on the above critical values given by Fageria (2004) and Bergmann (1992), the K concentrations in the rice plant for the current study (Table 20) are in the lower category. The observation that the K content in the rice plants at various F-P-N treatment combinations were deficient regardless of medium K levels obtained in the soils (Table 9) could be attributed to influence of Ca:Mg:K ratio in the soils which created nutrient imbalances hence affect uptake of K. Furher, soil moisture stress experienced along the growing season reduced the mobility of K in the soils and adsorption by the plant. Potassium content in the rice plants was statistically similar due to the fact that the soil amendment F had small amount of K (Table 9).

Table 20: Effect of farmyard manure, phosphorus and nitrogen applications on potassium concentrations in rice plants (g kg^{-1})

	N1			N2			N3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
F1	**4.15f**	**4.81**ef	**5.60**def	**4.47**ef	5.60def	8.72cdef	**7.20**def	7.17def	11.33abcd
F2	**4.81ef**	6.94def	5.59def	5.52def	7.76def	8.71cdef	7.00def	11.00abcd	14.48abc
F3	**6.34**def	9.34bcdef	7.74def	7.22def	10.58abcde	14.02abc	11.06abcd	15.28ab	16.27a
Mean	8.47								
CV (%)	22.2								

Means followed by the same letter(s) in the entire table are not significantly different ($P<0.05$) according to Tukey Test

Note: N1, N2 and N3 = 0, 50 and 100 kg N ha^{-1}, respectively. P1,P2 and P3 = 0, 30 and 60 kg P ha^{-1} respectively. F1,F2 and F3 = 0, 3.5 and 7 t manure ha^{-1}

Table 21: Effect of the P-N interactions on potassium concentrations in rice plants (g kg^{-1})

	N1 (0 kg N ha^{-1})	N2 (50 kg N ha^{-1})	N3 (100 kg N ha^{-1})
P1 (0 kg P ha^{-1})	5.09 d	5.73 cd	8.42 bcd
P2 (30 kg P ha^{-1})	7.02 bcd	7.98 bcd	11.15 ab
P3(60 kg P ha^{-1})	6.30 bcd	10.48 abc	14.02 a
Mean	8.47		
CV (%)	22.2		

Means followed by the same letter(s) in the entire table are not significantly different ($P<0.05$) according to Tukey Test

4.3.7 Nutrient dynamics

Nutrient dynamics were determined for F1P1N1, F2P2N2 and F3P3N3 treatment combinations at two soil layers, namely, surface layer (0-15 cm depth) and sub surface layer (15-30 cm depth) each season after harvesting. Some soil parameters investigated included percentage total nitrogen, available phosphorus, and exchangeable potassium. Procedures for the respective determinations were as described in Section 3.2.3. In each season, the results were subjected to ANOVA for each soil layer to determine the effect of F, P and N applications on the movement of N, P and K (dynamics) in the soils

a) Total nitrogen

The results of the percentage total nitrogen for the two soil layers during the study period are portrayed in Table 22. In the upper soil surface layer (0-15 cm depth) the percentage total nitrogen ranged from 0.04 to 0.05 while in the subsurface soil layer

(15-30 cm depth) the total ranged from 0.03 to 0.04. For three years consistently, there was no statistical evidence that application of the three treatment combinations (F1P1N1, F2P2N2 and F3P3N3) had significant effect on percentage total nitrogen in the soils during the experimental period. Mean percentage total nitrogen were higher in the upper surface soil layers than in subsurface soil layers in all treatment combinations. Lack of significant difference within the surface layers might be due to the fact that nitrogen is a very mobile nutrient. During the trial period, nitrogen loss in the soils might have taken place through uptake by plant, ammonia volatilization, leaching, denitrification and run off. Further, the amount of N added to the soils as $CO(NH_2)_2$ and F was not enough to change percentage total nitrogen. Similar evidence have been reported by Kundu and Ladha (1999).

Table 22: Effect of F, P and N applications on percentage N variations with depth

Treatment Combinations	Seasons 2002/03	2003/04	2004/05	Mean
0-15 cm depth (Upper soil surface layer)				
F1P1N1	0.05	0.05	0.04	0.04
F2P2N2	0.05	0.05	0.05	0.05
F3P3N3	0.06	0.04	0.05	0.05
F test (P = 0.05	NS	NS	NS	
CV (%)	15.6	21.2	17.7	
15- 30 cm depth (Sub soil surface layer)				
F1P1N1	0.03	0.04	0.03	0.03
F2P2N2	0.04	0.03	0.04	0.04
F3P3N3	0.03	0.04	0.04	0.04
F test (P = 0.05	NS	NS	NS	
CV (%)	19.2	10.4	8.6	

NS =not significant (P>0.05).

b) Available phosphorus

Table 23 shows the effect of three treatment combinations on available phosphorus (mg kg^{-1}) at two different soil surface layers during the trial period. Within the same layer, at upper soil surface layer, available phosphorus significantly ($P<0.05$) differed among the three treatment combinations while at the subsurface layer the treatment combinations had significant effect ($P<0.05$) on available P in 2002/03 and 2004/05 seasons.

Table 23: Effect of F, P and N applications on available P (mg kg^{-1}) variations with depth.

Treatment Combinations	Seasons 2002/03	2003/04	2004/05	Mean
0-15 cm depth (Upper soil surface layer)				
F1P1N1	11.83c	10.73c	9.77c	10.77
F2P2N2	24.21b	23.90b	22.25b	23.45
F3P3N3	31.23a	36.67a	28.71a	32.20
F test (P = 0.05	**	*	**	
CV (%)	8.8	14.4	9.2	
15-30 cm depth (Sub surface soil layer)				
F1P1N1	12.23b	11.36a	10.88b	11.49
F2P2N2	18.17ab	16.60a	16.54ab	17.10
F3P3N3	21.31a	24.21a	20.71a	22.07
F test (P = 0.05	*	NS	*	
CV (%)	11.6	21.6	20.3	

Means followed by the same letter(s) in the same column are not significantly different ($P<0.05$) according to Tukey Test; ** and * = significant at 0.01 and 0.05 probability levels, respectively; NS = not significant ($P>0.05$).

When treatment combinations were compared the available P increase was significantly different between N1P1F1 and F3P3N3 for the two seasons.

The treatment combinations F2P2N2 and F3P3N3 had higher mean available P at the upper soil surface layer than the sub surface soil layer. The F3P3N3 had highest available P in all soil layers than the other treatment combinations due high application of phosphorus as farmyard manure and triple supper phosphate.

Contrary to N movement, consistently, significant amount of available P was recorded in treatment F3P3N3 (7 t FYM, 60 kg P and 100 kg N ha^{-1}). This is due to the fact that P is not a mobile nutrient compared to N and K. Fukai *et al.* (1995) reported that the maximum of P leaching would be possible when the ground water drops below the root zone, a condition which does not favour productivity of rainfed lowland rice. Another possible P movement or loss would be through run off, however, in this experiment this form of P loss was prevented by bunds to contain water and P within the plots. Haefele *et al.* (2004) reported significant difference in P movement in the soils for treatments which had received P doses (26 and 52 kg P ha^{-1}) when compared with the control (0 kg P ha^{-1}) in rice.

c) Exchangeable potassium

Exchangeable potassium values (cmol$_{(+)}$ kg^{-1}) for the two soil layers during the trial period are shown in Table 24. In the upper soil surface layer (0-15 cm depth) the results of exchangeable potassium ranged from 0.20 to 0.33 (cmol$_{(+)}$ kg^{-1}) while the corresponding results in the subsurface soil layer (15-30 cm depth) ranged from 0.19

to 0.25 (cmol$_{(+)}$ kg^{-1}) organic carbon. The applications of three treatment combinations (F1P1N1, F2P2N2 and F3P3N3) had no significant effect on exchangeable potassium during the experimental period. Mean percentage exchangeable potassium levels were higher in the upper surface soil layers than in subsurface soil layers in all respective treatment combinations.

Table 24: Effect of F, P and N applications on K variations (cmol K kg^{-1}) with depth

Treatment Combinations	Seasons			
	2002/03	2003/04	2004/05	Mean
0-15 cm depth (Upper soil surface layer)				
F1P1N1	0.20	0.27	0.23	0.23
F2P2N2	0.28	0.21	0.23	0.24
F3P3N3	0.30	0.33	0.28	0.30
F test (P = 0.05)	NS	NS	NS	
CV (%)	22.3	19.6	15.4	
15-30 cm depth (Sub surface soil layer)				
F1P1N1	0.22	0.26	0.26	0.24
F2P2N2	0.23	0.19	0.20	0.20
F3P3N3	0.25	0.24	0.24	0.24
F test (P = 0.05)	NS	NS	NS	
CV (%)	12.8	15.2	13.4	

NOTE: NS =not significant (P>0.05).

The results of exchangeable K movement within the soils were not significantly different due to the fact that the sources of K used (FYM) was low in K content (1.79

%, Section 4.3.1) hence the input did not result into any significant effect on exchangeable K. Furthermore, some of the K might be leached beyond the root zone apart from rice plant uptake.

4.4 Partial nutrient balance

Partial nutrient balances were determined for elemental nitrogen, phoshorus and potassium as described in Section 3.4.2.

4.4.1 Nitrogen

Partial nitrogen balances in 2002/03 season ranged from -53.7 to 71.7 kg ha^{-1} for F1P3N1 and F3P1N3 treatment combinations respectively (Table 26). Similarly, in 2003/04 season the balances ranged from -57.4 to 75.5 kg ha^{-1} for F1P3N1 and F3P1N3 treatment combinations respectively (Table 27). In 2004/05 season, the nitrogen balance ranged from -58 to 67.4 kg ha^{-1} for F1P3N1 and F3P1N3 treatment combinations respectively (Table 28). Analysis of variance revealed that the main effect of farmyard manure, phosphorus and nitrogen applications had significant ($P<0.05$) effects (Table 25) on nitrogen balances in all seasons. There were no significant interactions among the main effects of different soil amendments on nitrogen balance. Separately N and F applications significantly ($P<0.05$) increased soil residual nitrogen in three seasons, the increase was highest in nitrogen application followed by farm yard manure.

In 2002/03 season, when farmyard manure and phosphorus were not applied, nitrogen application increased soil residual nitrogen by 63.4 kg ha^{-1} more at N3 than at N1. The increase was 77.6 kg N ha^{-1} more at N3 than N1 in 2003/04 season. In 2004/05 season, the increase was 63.69 kg ha^{-1} more at N3 than at N1. The increase of nitrogen as a result of farmyard manure application when nitrogen and phosphorus were not applied were 39.2 and 52.9 kg ha^{-1} more at F3 than F1 in 2002/03 and 2003/04 season, respectively (Table 27). In 2004/05 season, the increase was 39.3 kg ha^{-1} more at F3 than at F1. Nitrogen application in the form of urea resulted in higher increase in soil nitrogen than F due to the fact that F used had low nitrogen content compared to the N from urea and the microbial of the N released during decomposition into complex humic compounds.

Table 25: Effect of F, P and N applications on the partial N (kg ha^{-1}) in the soils

Soil amendments	Seasons		
	2002/03	2003/04	2004/05
N1 (0 kg N ha^{-1})	-39.78 c	-49.81 c	-44.19 c
N2 (50 kg N ha^{-1})	-9.30 b	-12.53 b	-13.60 b
N3 (100 kg N ha^{-1})	23.70 a	27.82 a	19.50 a
F1(0 t FYM ha^{-1})	-39.78 c	-49.81 c	-44.19 c
F2 (3.5 t FYM ha^{-1})	-21.99 b	-27.22 b	-26.29 b
F3 (7 t FYM ha^{-1})	-0.55 a	-3.15 a	-4.86 a
P1 (0 kg P ha^{-1})	-39.78 a	-49.81 a	-44.19 a
P2 (30 kg P ha^{-1})	-46.50 b	-52.15 a	-50.80 b
P3 (60 kg P ha^{-1})	-53.70 c	-57.43 b	-58.00 c

Means followed by the same letter(s) in the same column are not significantly different ($P<0.05$) according to Tukey Test

Phosphorus applications increased the removal of nitrogen in all seasons. In 2002/03 season, when nitrogen and farmyard manure were not applied, the depletion was 14 kg N ha^{-1} more at P3 than at P1. The applications of N2 and N3 had depletion of 10.7 and 12.3 kg N ha^{-1} more at P3 than at P1, respectively (Table 26). In 2003/04 season. the soil nitrogen depletion was about the same (7.6, 8.0 and 8.5 kg N ha^{-1}) at N1, N2 and N3, respectively (Table 27). In 2004/05 season, soil nitrogen depletion as a result of application of phosphorus while in treatment where nitrogen and farmyard manure were not applied per hectare depletion was 13.8 kg ha^{-1} more at P3 than at P1 (Table 28). Phosphorus is responsible for root development, hence application of P increased root growth which facilitated increased uptake of nutrient by the rice plants.

Over the three seasons, partial nutrient balances for nitrogen indicated net export of soil N except in N3 treatment combinations as a result of removal of N contained in both grains and straws. It was estimated that about 90 % of the straw is used as fodder for livestock feeding and thatching purposes (Meertens *et al.*, 1999). The N balances in N3 treatment combinations (~100 kg N ha^{-1}) remained consistently positive for the entire trial period.

In cases (treatment plots) where soil amendments were applied, the mean N balance over the experimental period was -56.4 kg N ha^{-1} which was smaller than -112 kg N ha^{-1} which was estimated by Smaling *et al.* (1993) at district scale in Southwest Kenya. The differences might be due attributed by the processes taking place in the soils such as leaching, nitrogen fixation and deposition (Smaling *et al.*, 1993) in the estimation of nutrient balances which in the current study were not considered.

Table 26: Effect of F, P and N applications on the partial N balances (kg ha^{-1}) in the soils in 2002/03 season

	N1			N2			N3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
F1	**-39.8** opq	**-46.5** pq	**-53.7** q	**-9.3** klmn	-13.6 klmn	-20.0 lmno	**23.7** defghi	16.3 efghij	11.4 fgijk
F2	**-22.0** mnop	-25.4 mnop	-29.0 nopq	11.2 fghijk	9.7 ghijk	5.4 hijkl	48.0 abcd	41.0 bcde	36.0 cdef
F3	**-0.5** hijklm	-1.7 ijklm	-5.5 jklmn	33.4 defg	31.1 defg	24.3 defgh	71.7 a	65.8 ab	60.2 abc

Means followed by the same letter(s) in the entire table are not significantly different ($P<0.05$) according to Tukey Test
Note: N1, N2 and N3 = 0, 50 and 100 kg N ha^{-1}, respectively. P1,P2 and P3 = 0, 30 and 60 kg P ha^{-1} respectively. F1,F2 and F3 = 0, 3.5 and 7 t manure ha^{-1}

Table 27: Effect of F, P and N applications on the partial N balances (kg ha^{-1}) in the soils in 2003/04 season

	N1			N2			N3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
F1	**-49.8** n	**-52.2** n	**-57.4** n	**-12.5** ijk	-15.2 jk	-20.5 kl	**27.8** de	23.8 de	19.3 ef
F2	**-27.2** lm	-30.3 lm	-33.0 m	9.8 fg	9.5 fg	6.1 gh	52.0 b	49.0 b	42.6 bc
F3	**-3.2** hi	-5.0 ij	-7.0 ij	34.4 cd	33.9 cd	28.5 de	75.5 a	73.8 a	67.3 a

Means followed by the same letter(s) in the entire table are not significantly different ($P<0.05$) according to Tukey Test

Note: N1, N2 and N3 = 0, 50 and 100 kg N ha^{-1}, respectively. P1,P2 and P3 = 0, 30 and 60 kg P ha^{-1} respectively. F1,F2 and F3 = 0, 3.5 and 7 t manure ha^{-1}

Table 28: Effect of F, P and N applications on the partial N balances (kg ha^{-1}) in the soils in 2004/05 season

	N1			N2			N3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
F1	**-44.2** nop	**-50.8** op	**-58.0** p	**-13.6** jklm	-17.9 jklm	-24.2 klmn	**19.4** defgh	12.0 cfghi	7.1 fghij
F2	**-26.3** lmno	-29.7 lmno	-33.4 mnop	6.9 fghij	5.3 ghij	1.1 hijk	43.7 abcd	36.7 bcde	31.7 cdef
F3	**-4.9** hijkl	-6.1 ijkl	-9.8 ijklm	29.1 defg	26.8 defg	20.0 defgh	67.4 a	61.5 ab	55.9 abc

Means followed by the same letter(s) in the entire table are not significantly different ($P<0.05$) according to Tukey Test

Note: N1, N2 and N3 = 0, 50 and 100 kg N ha^{-1}, respectively. P1,P2 and P3 = 0, 30 and 60 kg P ha^{-1} respectively. F1,F2 and F3 = 0, 3.5 and 7 t manure ha^{-1}

4.4.2 Phosphorus

Partial phosphorus balances in 2002/03 season ranged from -35.7 to 43.6 kg ha^{-1} for F1P1N3 and F3P3N1 treatment combinations, respectively (Table 30). A similar trend was observed in 2003/04 where phosphorus balances ranged from -33.5 to 43.0 kg ha^{-1} in F1P1N3 and F3P3N1 treatment combinations, respectively (Table 31). During the 2004/05 season, phosphorus balance ranged from -37.7 to 32.3 kg ha^{-1} in F1P1N3 and F3P3N1 treatment combinations, respectively (Table 32). Analysis of variance revealed that, farmyard manure, phosphorus and nitrogen applications had significant ($P<0.05$) effects (Table 29) on phosphorus balances separately in all seasons. There were no significant interactions on different soil amendments on phosphorus balance. In all seasons, phosphorus applications significantly increased phosphorus balances, similar effect was observed in farmyard manure in both seasons.

The magnitude of phosphorus increase as a result of phosphorus applications when farmyard manure and nitrogen were not applied was 53.3 kg ha^{-1} more at P3 than at P1 in 2002/03 season. A similar trend was observed in 2003/04 season on P increase with a magnitude of 56.5 kg ha^{-1} more at P3 than at P1. In 2004/05 season the magnitude of phosphorus increase was 53.4 kg ha^{-1} more at P3 than at P1 when farmyard manure and nitrogen were not applied. Farmyard manure applications increased soil P levels by 4.6 kg ha^{-1} more at P3 than at P1 in 2002/03 season when phosphorus and nitrogen was not applied. Similar effect was observed in 2003/04 season by 8.5 kg P ha^{-1} more at P3 than at P1 (Table 31). In 2004/05 season the effect was 4.7 kg ha^{-1} more at P3 than at P1.

In all seasons, nitrogen applications increased the removal of N and increased the deficit of P in the soils. In 2002/03 season, when nitrogen was applied without farmyard manure and phosphorus, the magnitude of soil P depletion was 17 kg ha^{-1} more at N3 than at N1 (Table 30). A similar trend was observed in 2003/04 season (Table 31) but at a lower magnitude (9.9 kg P ha^{-1}). In 2004/05 season, the magnitude of depletion was 17 kg ha^{-1} more at N3 than N1 (Table 32).

Table 29: Main effect of F, P and N applications on the partial P balances (kg ha^{-1}) in the soils

Soil amendments	Seasons		
	2002/03	2003/04	2004/05
P1 (0 kg P ha^{-1})	-18.70 c	-23.65 c	-20.70 c
P2 (30 kg P ha^{-1})	8.00 b	5.26 b	6.00 b
P3 (60 kg P ha^{-1})	34.60 a	32.93 a	32.70 a
F1(0 t FYM ha^{-1})	-18.70 b	-23.65 c	-20.70 b
F2 (3.5 t FYM ha^{-1})	-17.25 b	-19.72 b	-19.21 b
F3 (7 t FYM ha^{-1})	-14.03 a	-15.18 a	-16.00 a
N1 (0 kg N ha^{-1})	-18.70 a	-23.65 a	-20.70 a
N2 (50 kg N ha^{-1})	-27.70 b	-29.20 b	-29.70 b
N3 (100 kg N ha^{-1})	-35.70 c	-33.45 c	-37.70 c

Means followed by the same letter(s) in the same column are not significantly different ($P<0.05$) according to Tukey Test

Table 30: Effect of F, P and N applications on the partial P balances (kg ha^{-1}) in the soils in 2002/03 season

	N1			N2			N3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
F1	**-18.7** lmn	**8.0** fgh	**34.6** abc	**-27.7** nop	0.2 hij	27.3 bcd	**-35.7** p	-9.3 jkl	18.8 def
F2	**-17.2** lmn	11.1 efgh	39.5 ab	-25.0 mnop	4.1 ghi	32.2 abc	-31.2 op	-4.4 ijk	23.3 cde
F3	**-14.0** klm	15.3 efg	43.6 a	-21.4 lmno	7.4 fghi	34.2 abc	-26.8 nop	0.4 hij	27.7 bcd

Means followed by the same letter(s) in the entire table are not significantly different ($P<0.05$) according to Tukey Test

Note: N1, N2 and N3 = 0, 50 and 100 kg N ha^{-1}, respectively. P1,P2 and P3 = 0, 30 and 60 kg P ha^{-1} respectively. F1,F2 and F3 = 0, 3.5 and 7 t manure ha^{-1}

Table 31: Effect of F, P and N applications on the partial P balances (kg ha^{-1}) in the soils (kg/ha) in 2003/04 season

	N1			N2			N3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
F1	**-23.6** mno	**5.3** h	**32.9** cd	**-29.2** pq	-0.4 j	27.2 ef	**-33.5** q	-5.2 k	22.7 f
F2	**-19.7** lm	8.8 h	37.6 b	-25.5 op	4.3 hi	32.8 cd	-28.9 pq	-0.1 ij	26.9 f
F3	**-15.2 l**	13.9 g	43.0 a	-20.7 mn	8.9 h	36.6 bc	-24.7 nop	4.7 h	31.6 de

Means followed by the same letter(s) in the entire table are not significantly different ($P<0.05$) according to Tukey Test

Note: N1, N2 and N3 = 0, 50 and 100 kg N ha^{-1}, respectively. P1,P2 and P3 = 0, 30 and 60 kg P ha^{-1} respectively. F1,F2 and F3 = 0, 3.5 and 7 t manure ha^{-1}

Table 32: Effect of F, P and N applications on the partial P balances (kg ha^{-1}) in the soils in 2004/05 season

	N1			N2			N3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
F1	**-20.7** lmn	**6.0** fgh	**32.7** abc	**-29.7** nop	-1.8 hij	25.3 cde	**-37.7** p	-11.3 jkl	16.5 def
F2	**-19.2** lmn	9.1 fgh	37.5 ab	-26.9 mnop	2.2 ghi	30.3 abc	-33.2 op	-6.4 ijk	21.3 cde
F3	**-16.0** klm	13.4 efg	41.6 a	-23.4 lmno	5.4 fghi	32.3 abc	-28.8 nop	-1.6 hij	25.8 bcd

Means followed by the same letter(s) in the entire table are not significantly different ($P<0.05$) according to Tukey Test

Note: N1, N2 and N3 = 0, 50 and 100 kg N ha^{-1}, respectively. P1,P2 and P3 = 0, 30 and 60 kg P ha^{-1} respectively. F1,F2 and F3 = 0, 3.5 and 7 t manure ha^{-1}

In the three seasons the applications of both farmyard manure and phosphorus reduced the soil P depletion, however, the effect was opposite when nitrogen was applied. The soil P depletion as a result of nitrogen applications was due to increased yields in terms of both gain and straw. When no any form of soil amendments was applied, the mean soil P balances over three seasons was -21 kg P ha^{-1} which is larger than -3 kg P ha^{-1} estimated by Smaling *et al.*, (1993) at district scale in southwest Kenya. The difference might be due to high rainfed rice yields obtained in Northwest Tanzania as a result of RWH.

4.4.3 Potassium

Potassium balances in all seasons were negative. The results ranged from -110.8 to -35.0 kg ha^{-1} for F1P3N3 and F3P1N1 treatment combinations, respectively in 2003/03 season (Table 34). A similar trend was observed in 2003/04 where the range was -87.2 to -36.3 kg K ha^{-1} for the above treatment combinations, respectively (Table 35). In 2004/05 season the potassium balance ranged from -114.7 to -39.0 kg ha^{-1} for the F1P3N3 and F3P1N1 treatment combinations, respectively (Table 36). Analysis of variance revealed that farmyard manure, phosphorus and nitrogen applications had significant ($P<0.05$) effects on potassium balances in the three seasons (Table 33). There were no significant interactions on different soil amendments on potassium balance. In both seasons, farmyard manure applications significantly increased potassium balances. This is due to the fact that application of farmyard manure contained potassium which was released into the soil upon decomposition of farmyard manure. Soil potassium depletion as a result of farmyard manure applications when nitrogen and phosphorus were not applied were 15.9 kg ha^{-1} more at F3 than in Fl in 2002/03 and 33.5 kg ha^{-1} more at F3 than at Fl in 2003/04 season (Table 34). In 2004/05 season, the depletion was 16 kg K ha^{-1} more at F3 than F1 an indication that soil amendment applied (F, P, and N) increased soil K depletion.

Nitrogen applications significantly increased potassium depletion in all seasons, a similar trend was observed with phosphorus applications. In 2002/03 season, nitrogen application without farmyard manure and phosphorus application, increased soil K depletion to the magnitude of 44.1 kg ha^{-1} more at N3 than N1 (Table 34). A similar trend was observed in 2003/04 season (Table 35) but at a low magnitude (10.5 kg ha^{-1}). In 2004/05 seasons the depletion was 44.1 kg K ha^{-1} more at N3 than N1.

Table 33: Effect of F, P and N applications on the partial K balances (kg ha^{-1}) in the soils

Soil amendments	Seasons		
	2002/03	2003/04	2004/05
F1(0 t FYM ha^{-1})	-51.00 b	-69.87 c	-55.03 b
F2 (3.5 t FYM ha^{-1})	-45.90 b	-52.85 b	-49.87 b
F3 (7 t FYM ha^{-1})	-35.05 a	-36.32 a	-39.03 a
N1 (0 kg N ha^{-1})	-51.00 a	-69.87 a	-55.00 a
N2 (50 kg N ha^{-1})	-72.60 ab	-75.34 b	-76.50 ab
N3 (100 kg N ha^{-1})	-95.10 b	-80.38 c	-99.10 b
P1 (0 kg P ha^{-1})	-51.00 a	-69.87 a	-55.00 a
P2 (30 kg P ha^{-1})	-64.00 b	-72.46 b	-67.90 b
P3 (60 kg P ha^{-1})	-71.60 b	-75.48 c	-75.50 b

Means followed by the same letter(s) in the same column are not significantly different ($P<0.05$) according to Tukey Test

Table 34: Effect of F, P and N applications on the partial K balances (kg ha^{-1}) in the soils in 2002/03 season

	N1			N2			N3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
F1	**-51.0** abcd	**-64.0** abcdef	**-71.6** abcdefgh	**-72.6** abcdefgh	-80.0 bcdefgh	-85.6 cdefgh	**-95.1** fgh	-106.0 gh	-110.8 h
F2	**-45.9** abc	-51.6 abcd	-54.4 abcde	-62.7 abcdef	-68.9 abcdefg	-72.3 abcdefgh	-80.4 bcdefgh	-87.7 defgh	-93.0 efgh
F3	**-35.0** a	-37.9 a	-43.2 ab	-51.4 abcd	-58.4 abcdef	-64.8 abcdef	-64.2 abcdef	-71.4 abcdefgh	-79.2bcdefgh

Means followed by the same letter(s) in the entire table are not significantly different ($P<0.05$) according to Tukey Test

Note: N1, N2 and N3 = 0, 50 and 100 kg N ha^{-1}, respectively. P1,P2 and P3 = 0, 30 and 60 kg P ha^{-1} respectively. F1,F2 and F3 = 0, 3.5 and 7 t manure ha^{-1}

Table 35: Effect of F, P and N applications on the partial K balances (kg ha^{-1}) in the soils in 2003/04 season.

	N1			N2			N3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
F1	**-69.9** hij	**-72.5** ijk	**-75.5** jkl	**-75.3** jkl	-78.8 jklm	-81.7 klm	**-80.4** klm	-83.2 lm	-87.2 m
F2	**-52.8** def	-57.9 efg	-58.9 efg	-60.6 fgh	-64.5 ghi	-65.7 ghi	-65.9 ghi	-63.9 ghi	-72.4 ijk
F3	**-36.3** a	-40.8 ab	-41.9 abc	-44.2 abcd	-46.8 bcd	-49.7 bcde	-50.3 cde	-47.6 bcd	-57.0 efg

Means followed by the same letter(s) in the entire table are not significantly different ($P<0.05$) according to Tukey Test

Note: N1, N2 and N3 = 0, 50 and 100 kg N ha^{-1}, respectively. P1,P2 and P3 = 0, 30 and 60 kg P ha^{-1} respectively. F1,F2 and F3 = 0, 3.5 and 7 t manure ha^{-1}

Table 36: Effect of F, P and N applications on the partial K balances (kg ha^{-1}) in the soils in 2004/05 season.

	N1			N2			N3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
F1	**-55.0** abcd	**-67.9** abcdef	**-75.5** abcdefgh	**-76.5**abcdefgh	-84.0 bcdefgh	-89.6 cdefgh	**-99.1** fgh	-110.0 gh	-114.7 h
F2	**-49.9** abc	-55.5 abcd	-58.3 abcde	-66.7 abcdef	-73.0 abcdefg	-76.3 abcdefgh	-84.4bcdefgh	-91.7 defgh	-97.0 efgh
F3	**-39.0** a	-41.9 a	-47.2 ab	-55.4 abcd	-62.4 abcdef	-68.8 abcdef	-68.2 abcdef	-75.4abcdefgh	-83.2 bcdefgh

Means followed by the same letter(s) in the entire table are not significantly different ($P<0.05$) according to Tukey Test

Note: N1, N2 and N3 = 0, 50 and 100 kg N ha^{-1}, respectively. P1,P2 and P3 = 0, 30 and 60 kg P ha^{-1} respectively. F1,F2 and F3 = 0, 3.5 and 7 t manure ha^{-1}

Phosphorus application significantly increased potassium depletion. In 2002/03 season when nitrogen and farmyard manure were not applied, K depletion was at 20.6 kg ha^{-1} more at P3 than at P1. In 2003/04 season, the depletion as a result of phosphorus application was at 5.6 kg ha^{-1} more at P3 than at P1. In 2004/05 season the potassium depletion was 20.5 kg ha^{-1} more at P3 than P1 this might be due to increased K uptake as a result of F, P and N applications. in the soils.

It is evident that K balances in all soil amendments were negatives. The severity of soil K depletion increased as the application rates of both N and P increased. This is due to the fact that applications of P and N increased both grain and straw yields as consequent of increased nutrient uptake. When no applications of F, P and N applied, mean soil K depletion for three seasons was 58.6 kg K ha^{-1} which was comparable with 70 kg K ha^{-1} estimated by Smaling *et al.*, (1993). Current system of not retaining crop residues in the field (Meertens *et al.*, 1999) has detrimental effect on soil K as approximate 80% K is in the straw but less important for N which is mostly contained and exported in the grains. Soil K balance of up to -362 kg ha^{-1} has been reported in Asia when straws was removed from the field and up to positive balance of 29 kg K ha^{-1} when straw was retained in the field (Whitbread *et al.*, 2003). Thus retaining crop residues in the field or better use of FYM has potential of improving the sustainability of rainfed rice productivity in terms of soil K balance. Even the use of farmyard manure did not increase the potassium balances to positive balance. This is due to low K nutrient content in farmyard manure.

4.4.4 Sustaining productivity of rainfed lowland rice

Maintenance of soil plant nutrient status is an important aspect of sustaining soil productivity for rainfed lowland rice, thus the management of different soil amendments to maintain soil fertility is necessary. The development of partial nutrient budgets which quantify soil nutrient balances is an important aspect in the understanding and development of nutrient management strategies in rainfed lowland rice for increasing productivity. Consistently, application of farmyard manure, phosphorus, and nitrogen reduced nutrient depletion for both N and P. A slight negative balance is reached for N and P at F3P1N1, F3P2N1 and F3N1P3 however the effect of farmyard manure interms of grain yields was low compared to N. Therefore, application of N is necessary for rice grain yield increase. Small positive balances were obtained for N and P (about 5 and 2 kg N and P ha^{-1}, respectively)at treatment combination F2P2N2 (3.5 t of FYM, 30 kg P and 50 kg N ha^{-1}) where N and P balances were greater than 5 and 2 kg ha^{-1}, respectively. Higher level greater than F2P2N2 result in excess balances for both P and N. Due to transportation problem of farmyard manure and high prices of inorganic fertilizers manure (Meertens, 2003), the F2P2N2 treatment combination is appropriate for sustaining soil N and P instead of the 40 kg N ha^{-1} (Mowo *et al.*, 1993)

Contrary to partial nutrient balances for N and P, balances for K were consistently negative in all seasons. This is due to the fact that the use of N and P mineral fertilizers increased both grain and straw biomass yields which aggravated the depletion of soil K for grain production, but more important for straw production as it contained about 80 % K. Furthermore, FYM obtained from farmers' kraals has low percentage of K due to its poor management in the kraal. This led to negative K balances even in the plot treated with a combination of 7 t FYM, 60 kg P and 100 kg N ha^{-1} (F3P3N3). However the severity of nutrient K depletion was less in unfertilized plot (F1P1N1) due to poor rice growth performance.

The results of this study have shown that the use of 3.5 t FYM, 30 kg P and 50 kg N ha^{-1} (F2P2N2) maintained a slightly positive balance of P and N. However, partial nutrient balances for K were negative for the entire experimental period. This necessitates evaluating soil K reserves and its capacity to supply the required amount of K. The total K pool consist of large K sources with between 300 and 100,000 kg ha^{-1} in the upper 20 cm of the soil profile depending on parent materials, soil type and mineralogy (Sparks, 1987). Traditionally, four forms of K have been recognised namely, structural or mineral K, non exchangeable K also referred as fixed K, exchangeable K and K in the soil solution (Sparks, 1987). Exchangeable and soil solution K are considered to be available to plant while fixed and structural K are slowly or potentially available (Pal *et al.*, 1999). Defoer *et al.* (2000) reported how to estimate soil K in the tropical soils. The soil analytical data portrayed that exchangeable K were 0.11, 0.26 and 0.36 cmol(+) kg^{-1} for upper, middle and lower fields, respectively. These values fall into average and high levels for upper and middle, lower fields, respectively. If the incorporation of rice straw to the soils can be up to 40 % of the produced straw, the depletion of K would have been lessened as the large amount of K is contained in the rice straw. In spite of above extrapolation, some nutrient including K might be brought by run off water and flush floods as a result of macro catchment rainwater harvesting practiced in the area. A similar trend was observed in K nutrient balance where there was a depletion of 171.3 kg K ha^{-1} in 1998 in Egypt but substantial amount of nutrient were brought by water from the Nile River (Sheldrick and Lingard, 2004). Similarly, the amounts of nutrient brought by run off were not considered in this analysis. However, in order to sustain the productivity of rainfed lowland soils some practical soil fertility management aspects need to be taken into account. These included conserving soil N, recycling of organic residues and use of organic manures and reduce losses of applied N.

a) Conserving soil N

In semi arid areas of Tanzania where rainfed lowland rice is grown, soils undergo intermittent anaerobic and aerobic conditions. They remained anaerobic (flooded) during the growing season but between the rice crops growth cycle, the soils usually dry and become aerobic, NH_4 formed from mineralization of organic N and N fertilizers is oxidized to NO_3 that may be used by the plant. Most of the NO_3 that is not used by the plant may be lost thorough leaching or denitrification when the soils are subsequently flooded for rice production. The negative impacts of NO_3 loss on long term N fertility of rainfed lowland rice have been neglected. Rice productivity and N fertility of such soils are not likely to be sustained unless practical measures are taken to limit NO_3 build up and conserve it through incorporation of crop residues.

b) Recycling crop residues and use of organic manure

The nitrogen supplying capacity of the rainfed lowland rice soils originates from organic matter, and thus addition of organic matter is important to sustain soil fertility of rainfed lowland rice. Organic matter supplied to the soils not only increases soil plant nutrient but its cation exchangeable capacity as well. It also improves the soil physical properties and increases the amount of CO_2 available to plant and soil micro organisms. The incorporation of organic materials through incorporation of straws, stubble, and animal manure adds nutrient to the soils. Among the farm organic substances, rice straw has been reported to be the best in lowland rice (Kundu and Ladha, (1999). Currently, rice straw is used for thatching and feeding livestock (Meertens, 2003) in Maswa district, Tanzania. The rice straw can be incorporated immediately after harvesting after removing straw for both thatching and livestock during the dry season. The uses of any K fertilizers material seem to be impossible as they are not available.

Farmyard manure can be used directly or indirectly in rainfed lowland rice. Meertens (2003) reported that there is limited possibility of using F in the semi arid areas of Tanzania due to its bulkiness and insufficient availability. However, opportunities still exist as 50 % of the households in semi arid area of Maswa own cattle and rice is produced at the middle and lower parts of the toposequence in relation to run off generating catchments. Thus farmyard manure can still be applied by the households who owned livestock and ox-carts. For those who do not have ox-carts can still be applied at the upper soils which are more depleted as they are near to the kraals and the nutrient will be moved by the run off water to the middle and lower parts of the toposequence where rice is grown. This will indirectly improve the soil fertility of rainfed lowland rice.

c) Reduce losses of the applied N

Inorganic fertilizers applied to the rice fields is partly assimilated by rice crop, partly immobilized in the soils and partly lost through ammonia volatilization, leaching, denitrification and runoff water. To minimize these risks, the applications of fertilizers N into two or three equal splits have been reported to increase fertilizer N recovery up to 40 % (Kundu and Ladha, 1999). When the N-fertilizers are used in combination with organic soil amendments such as farmyard manure and rice straw, they can reduce the amount of inorganic fertilizers required hence reduce costs and amounts required.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

This chapter highlights the general conclusions with respect to the objectives of this study as stated in Chapter One. It further, outlines the implications inferred from the conclusions and finally propose recommendations and future research needs which are aimed at improving and sustaining rainfed lowland rice productivity in macro-catchment RWH systems in semi arid areas in Maswa district which could be extrapolated to other semi arid areas with similar soil conditions and landscapes in Tanzania.

5.1 Conclusions

5.1.1 Fertility status of rainfed lowland rice soils on the Ndala River catchment, Maswa district

From the physico-chemical properties of the composite soil samples (Section 4.1) the following conclusion can be made;

i) The preliminary soil fertility evaluation and categorization into three classes, low, medium and high based on LISF did not exactly conform to the soil fertility status based on the technical indicators of soil fertility (soil properties). This might be due to the fact that the preliminary soil categorization was based on qualitative properties of the soils and rice crop performance which was influenced by the availability of water, while the TISF were based on quantitative analytical data, hence, more informative Both procedures/categorization be given due consideration in the assessment of soil fertility status of the soils.

ii) The fertility status of the soils on the Ndala River catchment were categorized as low to medium soil fertility status based on LISF and TISF. The main attributes to low to medium soil fertility status of the soils include low levels of total nitrogen, organic carbon and available zinc content and high exchangeable CA:Mg and Ca:K ratios and high exchangeable Na^+.

iii) With regard to land suitability for rainfed lowland rice production, the soils on the Ndala River Catchment are moderately suitable (S2) for rainfed lowland rice production under RWH practices/situations. The presence of hard pan in the sub soil layer which extend the period of ponding due to restricted vertical percolation of water contributes to suitability of the soils to rice production.

5.1.2 Rainfall characteristics in the semi arid areas of Maswa district

In accordance with the rainfall characteristics and rice crop biology in the study area (Section 4.2), the following conclusions were made;

i) Rainfall in the study area is highly variable in terms of amounts and distribution with a less variable and predictable transitional dry spell in February. Rainfall may start as early as October or as late as December while cessation occurs mostly in May.

ii) Based on the seasonal long term rainfall, early seasonal cumulative rainfall amounts and long term bimonthly ENSO indices for August/September, the ENSO indices can be used to predict the early rains (October-December) on the Ndala River Catchment and Maswa district and this can reduce the risk of rainfed lowland rice establishment.

iii) When divided into quartile based on early rainfall amounts (October - December), the ENSO indices can give indications as to when and where to sow rice in the semi arid areas of Maswa and elsewhere with similar landscape conditions and characteristics.

iv) Based on the long term seasonal rainfall and ENSO indices rice sowing on the Ndala River Catchment should be undertaken during the first week of December or early January.

5.1.3 Productivity of rainfed lowland rice in relation to soil amendments

i) Based on the results of the F-P-N trial for three consecutive seasons (Section 4.3) application of farmyard manure, phosphorus as triple super phosphate and nitrogen as urea increased rice grain yield and the response was in the order of N>F>P, suggesting that high and sustainable rice yields can be achieved through the use of appropriate soil amendments based on soil analytical data.

ii) Based on the N, P,K balances and their mobilities in the soils, P and F should be applied at sowing time while N should be applied in splits so as to limit the loss of N through leaching and volatilization when the rice fields are ponded.

5.1.4 Sustaining productivity of rainfed lowland rice soils

From the results of partial nutrient balances described in Section 4.4 the following conclusion can be made;

i) Based on the rice performance data for the three cropping seasons (2002/03 to 2004/05) the rainfed lowland rice production on the Ndala River Catchment under rainwater harvesting could be sustained through the use of both inorganic and organic plant nutrient sources so as to maintain the proper-equilibrium relationship between soils physical, chemical and biological properties appropriate for rice cultivation.

5.2 Recommendations

The following recommendations are made with respect to improving rainfed lowland rice productivity on the Ndala River Catchment and elsewhere with similar conditions under RWH in semi arid area of Tanzania.

i) Agro-climate extension service should be establishment through partnership among Meteorological Department, Research and Agricultural Extension. for farmers growing rice in Semi arid areas of Tanzania

ii) The ENSO indices should be used to assist planners, extension staff and farmers on the start of rainfed lowland rice cropping seasons and this should undergo frequent validation.

iii) Policy makers, extension staff and farmers should be involved in the validation of the use of ENSO indices for early rainfall predictions.

iv) Based on the rice responses to applied F, P and N, application of 3.5 t F, 30 kg P and 50 kg N ha^{-1} should be adopted for rainfed lowland rice along the Ndala River Catchment with frequent reviews so as to take care of nutrient depletion with time.

v) The economics of using the above fertilizers recommendation should be established so as to bring into light as to where rice production on the Ndala River Catchment is profitable and farmer be advised and encouraged to use farmyard manure in rainfed lowland rice production.

vi) Due to abundance of farmyard manure and the high prices of inorganic fertilizers farmers should be educated on using affordable ways to imrpove manure quality like proper storage and use of bedding materials.

vii) Due to the high pH of the soils on the Ndala River Catchment investigation on the availability of micro nutrients should be conducted.

viii) Split application of N sources should be adopted at least in three splits so as to limit losses of N through leaching and volatilization.

ix) Other studies be conducted to determine appropriate N sources for rice production in semi arid areas where RWH technologies and practices are in place and operational.

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7.0 APPENDICES

Appendix 1: Description of Soil types found at Bukangilija village, Maswa District (Ngailo *et al.,* 1994).

a) Haplic Arenosols (*Luseni* soils)

These are loamy sandy soils over ironstone mostly associated with granite boulders on the upper part of the landscape. These soils are light brownish-grey sandy soils. The subsoil is yellowish grey, parent materials are granitic wash and have low soil fertility because of the nature of the parent materials.. Major land uses are cultivation and grazing. Crop grown are cotton, bulrush millet, maize, cassava, and sweet potatoes. These soils are not suitable for rice production as water percolates very fast.

b) Eutric Regosols (*Itogoro* soils)

These are generally clayey soils with a characteristic hard pan present in the subsoils. These soils are dark brownish grey to black heavy clay loams to sandy clay and some are calcareous. These soils are imperfectly drained and are found at the middle of the toposequence after *Luseni* soils. These soils are suitable for rice cultivation due to presence of hard pan layer at 30 -50 cm depth which restricts percolation of water. Major land uses are cultivation of rice and grazing.

c) Calcic vertisols *(Mbuga* soils)

These are black soils with cracking clays and have slickensides. They are calcareous heavy clays found in the lowlands. They have $CaCO_3$ concretions at 15 -30 cm depth. These soils are suitable for rice production as water does not percolate very fast. Major land uses are grazing and some cultivation of rice, sugarcane and sweet potatoes.

d) *Haplic Acrisols* (*Lukungu/Ikungu* Soils)

These soils are well-drained, reddish brown to red clay loams with slight to moderate acidity: parent material in upper basement schist. The soils are not suitable for rice production due to its high drainage capability. Major land uses are cultivation and grazing. Crops grown are maize, pigeon peas and sorghum.

e) Haplic Arenosols (*Lusanga* Soils)

These are sandy-to-sandy loam soils and are well drained and less fertile compared to *Itogoro* soils. The soils are not suitable for rice production due to their high drainage capability. Major land use is cultivation of sweet potatoes.

Appendix 2: Field layout from one hectare partitioned into three blocks for three seasons trial

8	12	20	2	22	18	10	15	6	18	10	21	5	15	27	6	22	13	17	4	19	27	7	21	13	9	1
1	14	24	7	16	26	3	27	11	9	16	23	1	20	12	26	3	24	12	6	25	15	26	5	24	18	11
17	21	4	23	9	25	13	19	5	4	19	7	14	25	2	11	17	8	2	14	10	20	3	22	16	8	23

Season 1 **Season 2** **Season 3**

BOCK 1 **BLOCK 2** **BLOCK 3**

NOTE

1=F1P1N1; 2=F1P2N1; 3=F1P3N1; 4=F1P1N2; 5=F1P2N2; 6=F1P3N3; 7=F1P1N3; 8=F1P2N3; 9=F1P3N3; 10=F2P1N1

11= F2P2N1; 12=F2P3N1; 13=F2P1N2; 14=F2P2N2; 15=F2P3N2; 16=F2P1N3; 17=F2P2N3; 18=F2P3N3; 19=F3P1N1

20=F3P2N1; 21=F3P3N1; 22=F3P1N2; 23=F3P2N2; 24=F3P3N2; 25=F3P1N3; 26=F3P2N3; 27=F3P3N3

Appendix 3: Physiochemical characteristics of Ndala River catchment rice soils based on rice production levels

Appendix 3a Particle size distribution (percentage) on the Ndala River Catchment

Villages	Clay content (%)				Sand content (%)				Silt content (%)			
	M1	M2	M3	Mean	M1	M2	M3	Mean	M1	M2	M3	Mean
Isulilo	31.0	32.0	-	31.5	61.0	54.0	-	57.5	7.0	14.0	-	10.5
Njiapanda	24.0	19.0	32.0	25.0	71.0	74.0	62.0	69.0	4.0	7.0	6.0	5.7
Bukangilija	34.0	9.0	30.0	24.0	59.0	86.0	66.0	70.0	7.0	5.0	4.0	5.3
Mean	29.7	20.0	31.0		63.7	71.3	64.0		6.0	8.7	5.0	

Appendix 3b **Total nitrogen, organic carbon (%) and cation exchangeable capacities of the soils (cmol $_{(+)}$ kg^{-1}) on the Ndala River catchment**

Villages	Total nitrogen (%)				Organic carbon (%)				CEC (cmol $_{(+)}$ kg^{-1})			
	M1	M2	M3	Mean	M1	M2	M3	Mean	M1	M2	M3	Mean
Isulilo	0.04	0.05	-	0.05	0.63	0.61	-	0.62	24.00	17.20	-	20.60
Njiapanda	0.04	0.03	0.05	0.04	0.63	0.46	0.63	0.57	16.60	16.00	20.60	17.73
Bukangilija	0.06	0.03	0.04	0.04	0.82	0.38	0.52	0.57	18.00	7.00	16.00	13.67
Mean	0.05	0.04	0.05		0.69	0.48	0.58		19.53	13.40	18.30	

Appendix 3c Soil pH, Available P (mg kg^{-1}) and exchangeable Ca (cmol kg^{-1}) of the soils on the Ndala River catchment

Villages	pH				Aval. P (Olsen) (mg kg^{-1})				Exchangeable Ca (cmol kg^{-1})			
	M1	M2	M3	Mean	M1	M2	M3	Mean	M1	M2	M3	Mean
Isulilo	8.75	7.73	-	8.24	14.46	14.46	-	14.46	13.97	10.47	-	12.22
Njiapanda	6.68	6.68	7.92	7.09	16.52	15.14	17.16	16.27	8.11	6.09	14.19	9.46
Bukangilija	8.03	7.55	7.03	7.54	15.69	14.24	16.60	15.51	12.65	2.26	12.00	8.97
Mean	7.82	7.32	7.48		15.56	14.61	16.88		11.58	6.27	13.10	

Appendix 3d Exchangeable bases (Mg, Na and K) of the soils on the Ndala River catchment

Villages	Mg (cmol kg^{-1})				Na (cmol kg^{-1})				K (cmol kg^{-1})			
	M1	M2	M3	Mean	M1	M2	M3	Mean	M1	M2	M3	Mean
Isulilo	3.89	2.52	-	3.21	7.27	3.63	-	5.45	0.78	0.26	-	0.52
Njiapanda	1.73	2.41	2.41	2.18	7.79	7.36	4.57	6.57	0.36	0.14	0.23	0.24
Bukangilija	2.94	0.64	1.68	1.75	3.41	2.09	6.78	4.09	0.30	0.11	0.18	0.20
Mean	2.85	1.86	2.05		6.16	4.36	5.68		0.48	0.17	0.21	

Appendix 3e DTPA ectractable Zn and Cu of the soils on the Ndala River catchment

Villages	Zn (mg kg^{-1})				Cu (mg kg^{-1})			
	M1	M2	M3	Mean	M1	M2	M3	Mean
Isulilo	0.24	0.28	-	0.26	0.70	0.64	-	0.67
Njiapanda	0.28	0.24	0.25	0.26	1.03	0.67	1.11	0.94
Bukangilija	0.18	0.21	0.22	0.20	0.56	0.45	0.83	0.61
Mean	0.23	0.24	0.24		0.76	0.59	0.97	

M1= High rice producing area; M2= Medium rice producing area and M3= Low rice producing area

Appendix 4: Amount (mm) of monthly rainfall in the Maswa district

S/no	Season	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Total
1	1962/63	0.0	0.0	206.3	253.0	160.3	61.0	216.5	147.0	83.0	0.0	0.0	0.0	1127.0
2	1963/64	0.0	60.3	133.8	164.5	89.8	124.5	177.8	227.0	108.3	0.0	0.0	0.0	1085.8
3	1964/65	17.5	47.5	103.0	90.5	211.5	91.3	77.5	147.3	82.5	0.0	0.0	0.0	868.5
4	1965/66	37.0	21.3	197.8	123.3	95.8	47.0	78.8	123.5	76.3	0.0	0.0	0.0	800.5
5	1966/67	25.3	11.0	95.3	124.0	46.3	85.5	133.0	418.8	169.5	0.0	0.0	0.0	1108.5
6	1967/68	12.5	89.5	66.8	104.0	176.8	155.0	110.0	202.8	19.3	0.0	0.0	0.0	936.5
7	1968/69	0.0	36.5	62.5	202.5	165.5	76.0	156.0	181.0	135.0	0.0	0.0	0.0	1015.0
8	1969/70	55.5	12.8	62.0	164.8	50.3	76.3	81.0	273.3	74.5	0.0	0.0	0.0	850.3
9	1970/71	0.0	21.0	74.5	183.0	108.5	120.0	247.5	93.0	13.5	0.0	0.0	0.0	861.0
10	1971/72	28.0	27.3	72.5	N/A	221.8	99.0	172.5	258.0	8.5	0.0	0.0	0.0	887.5
11	1972/73	28.3	30.8	151.0	309.8	109.3	90.3	96.3	240.5	88.3	0.0	0.0	0.0	1144.3
12	1973/74	0.0	82.5	63.8	8.8	247.3	65.0	205.3	111.5	16.0	0.0	0.0	0.0	800.0
13	1974/75	0.0	0.0	81.8	45.3	44.8	62.3	43.8	124.8	26.3	0.0	0.0	0.0	428.8
14	1975/76	0.0	7.5	43.8	119.3	69.0	91.8	90.8	136.5	72.0	0.0	0.0	0.0	630.5
15	1976/77	20.5	80.0	76.0	153.5	146.5	104.0	187.5	97.3	37.3	0.0	0.0	0.0	902.5
16	1977/78	48.8	25.0	113.8	185.3	133.5	124.4	158.3	233.5	149.3	0.0	0.0	0.0	1171.7
17	1978/79	7.5	101.8	43.3	211.3	84.8	122.0	150.5	169.0	70.5	0.0	0.0	0.0	960.5
18	1979/80	0.0	20.0	29.0	146.8	182.0	66.0	311.8	43.8	59.5	0.0	0.0	0.0	858.8
19	1980/81	21.0	116.8	156.3	197.5	126.8	94.8	132.8	111.8	4.0	0.0	0.0	0.0	961.5
20	1981/82	57.5	22.5	153.8	64.3	106.5	120.0	253.3	199.3	85.5	0.0	0.0	0.0	1062.5
21	1982/83	20.0	99.6	160.5	185.0	165.0	98.0	135.8	170.0	91.1	0.0	0.0	0.0	1125.0
22	1983/84	0.0	194.3	85.5	124.0	138.1	120.0	57.6	182.8	200.7	0.0	0.0	0.0	1103.0
23	1984/85	0.0	0.0	380.0	216.2	77.0	116.0	118.7	224.3	5.4	0.0	0.0	0.0	1137.6
24	1985/86	10.7	7.7	65.9	177.0	23.7	87.4	98.3	195.1	26.7	0.0	0.0	0.0	692.5
25	1986/87	13.6	34.6	44.0	152.3	125.5	94.9	147.1	116.5	7.6	0.0	0.0	14.8	750.9
26	1987/88	0.0	67.0	144.3	232.8	99.8	115.0	159.7	242.7	46.2	0.0	0.0	0.0	1107.5
27	1988/89	9.4	20.0	75.9	68.9	149.4	104.0	74.9	120.1	50.5	0.0	0.0	0.0	673.1
28	1989/90	9.3	6.6	90.5	149.3	125.9	98.0	85.6	70.5	15.8	0.0	0.0	0.0	651.5
29	1990/91	1.8	1.3	66.0	50.0	148.2	102.0	215.9	219.6	16.5	0.0	0.0	0.0	821.3
30	1991/92	0.0	51.2	116.6	205.3	122.2	86.7	31.2	188.8	4.7	0.0	0.0	0.0	806.7
31	1992/93	0.0	64.3	150.3	80.5	57.7	109.0	147.0	106.1	65.2	0.0	0.0	0.0	780.1
32	1993/94	13.8	106.9	165.0	127.1	146.1	105.0	72.7	124.6	36.7	0.0	0.0	0.0	897.9
33	1994/95	25.0	8.0	149.8	114.5	89.3	79.6	114.1	163.6	66.2	0.0	0.0	0.0	810.1
34	1995/96	30.6	1.4	53.8	196.7	207.7	59.2	92.3	158.7	78.0	0.0	0.0	0.0	878.4
35	1996/97	34.9	52.4	31.7	82.2	95.7	93.5	202.0	28.6	54.8	0.0	0.0	0.0	675.8
36	1997/98	30.0	24.0	240.0	402.0	161.0	80.0	155.0	261.1	64.0	15.0	0.0	65.0	1497.1
37	1998/99	34.0	23.8	101.0	73.0	111.0	87.0	222.9	102.7	14.4	0.0	0.0	0.0	769.8
38	1999/00	13.7	200.4	173.9	N/A	41.1	41.1	155.6	107.5	114.1	0.0	0.0	0.0	847.4
39	2000/01	7.0	60.7	106.5	245.0	57.8	70.7	186.1	138.9	146.1	0.0	0.0	0.0	1018.8
40	2001/02	0.0	34.9	267.0	166.8	139.2	33.9	120.7	43.7	N/A	0.0	0.0	0.0	806.2

Note: N/A = Not available. Source: Maswa Metrological Station

Appendix 5: Classification of early cumulative rainfall amounts

S/no	Season	Early Cum.	Rainfall class	Quartile	ENSO index
1	1997/98	803	Wet	4	2.8
2	1984/85	673	Wet	4	-0.3
3	1962/63	620	Wet	4	-0.3
4	2001/02	573	Wet	4	-0.5
5	1972/73	570	Wet	4	0.5
6	1982/83	511	Wet	4	0.8
7	1980/81	481	Wet	4	0.6
8	1987/88	477	Wet	4	1.6
9	1995/96	458	Wet	4	0.8
10	1991/92	444	Wet	4	0.5
11	1993/94	438	Average	3	0.5
12	1977/78	433	Average	3	1.0
13	1968/69	431	Average	3	0.6
14*	2002/03	429	Average	3	1.0
15	1965/66	417	Average	3	1.5
16	2000/01	409	Average	3	-0.5
17	1964/65	405	Average	3	-1.0
18	1963/64	388	Average	3	0.9
19	1976/77	376	Average	3	1.0
20	1970/71	366	Average	3	0.3
21	1989/90	366	Average	3	-1.0
22	1979/80	358	Dry	2	0.6
23	1994/95	354	Dry	2	1.0
24*	2004/05	354	Dry	2	0.5
25*	2003/04	352	Dry	2	-0.3
26	1983/84	348	Dry	2	1.5
27	1967/68	348	Dry	2	0.5
28	1978/79	339	Dry	2	0.6
29	1981/82	325	Dry	2	0.8
30	1986/87	322	Dry	2	0.7
31	1973/74	320	Dry	2	-1.0
32	1971/72	294	Dry	2	-1.0
33	1988/89	294	Driest	1	-1.5
34	1992/93	289	Driest	1	0.3
35	1998/99	285	Driest	1	-1.0
36	1969/70	277	Driest	1	0.5
37	1985/86	267	Driest	1	-0.6
38	1966/67	266	Driest	1	1.5
39	1990/91	264	Driest	1	0.5
40	1975/76	232	Driest	1	-1.8
41	1999/2000	215	Driest	1	-1.0
42	1996/97	210	Driest	1	-0.5
43	1974/75	172	Driest	1	-2.0

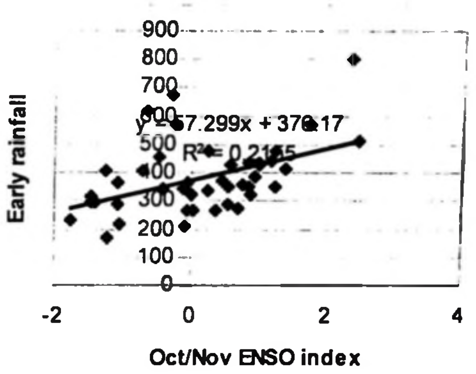
NOTE: * Early cumulative rainfall classification during the experimental seasons

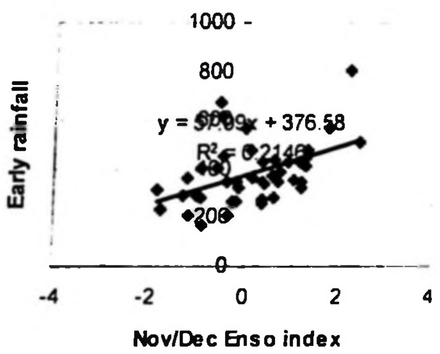
Appendix 6: Classification of late cumulative rainfall amounts

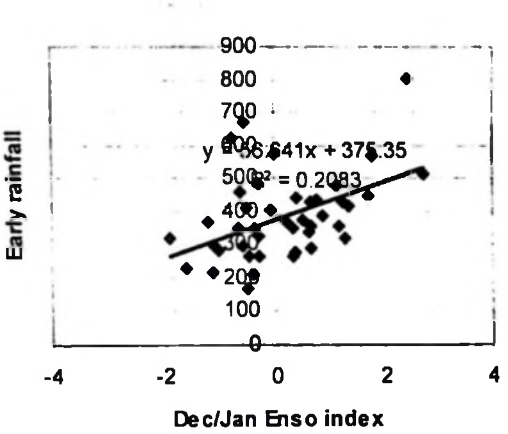
S/no	Season	Late	Rainfall class	Quartile	ENSO index
1	1966/67	721	Wet	4	1.5
2	1977/78	541	Wet	4	1.0
3	1981/82	538	Wet	4	0.8
4	1963/64	513	Wet	4	0.9
5	1997/98	480	Wet	4	2.8
6	1968/69	472	Wet	4	0.6
7	2000/01	471	Wet	4	-0.5
8	1990/91	452	Wet	4	0.5
9	1987/88	449	Wet	4	1.6
10	1962/63	447	Wet	4	-0.3
11	1983/84	441	Average	3	1.5
12	1971/72	439	Average	3	-1.0
13	1969/70	429	Average	3	0.5
14	1972/73	425	Average	3	0.5
15	1979/80	415	Average	3	0.6
16	1982/83	397	Average	3	0.8
17	1978/79	390	Average	3	0.6
18	1999/2000	377	Average	3	-1.0
19*	2004/05	372	Average	3	0.5
20	1970/71	354	Average	3	0.3
21	1984/85	348	Average	3	-0.3
22	1994/95	344	Average	3	1.0
23	1998/99	340	Dry	2	-1.0
24*	2003/04	337	Dry	2	-0.3
25	1973/74	333	Dry	2	-1.0
26	1967/68	332	Dry	2	0.5
27	1995/96	329	Dry	2	0.8
28	1976/77	322	Dry	2	1.0
29	1985/86	320	Dry	2	-0.6
30	1992/93	318	Dry	2	0.3
31*	2002/03	311	Dry	2	1.0
32	1964/65	307	Dry	2	-1.0
33	1975/76	299	Dry	2	-1.8
34	1996/97	285	Driest	1	-0.5
35	1965/66	279	Driest	1	1.5
36	1986/87	271	Driest	1	0.7
37	1980/81	249	Driest	1	0.6
38	1988/89	246	Driest	1	-1.5
39	1993/94	234	Driest	1	0.5
40	1991/92	225	Driest	1	0.5
41	1974/75	195	Driest	1	-2.0
42	1989/90	172	Driest	1	-1.0
43	2001/02	164	Driest	1	-0.5

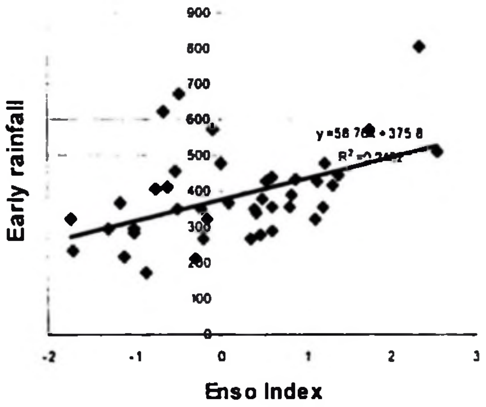
NOTE: * Late cumulative rainfall classification during experimental seasons

Appendix 7: Relationships between early rainfall (Oct-Dec) and bimonthly ENSO indices[1]









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[1] Bimonthly ENSO indices were obtained from Wolter, (2005).

Appendix 8: Mean number of ponding days during the trial period

Appdendix 8a: Mean number of ponding days during the trial period in 2002/03

	N1			N2			N3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
F1	62.7	64.0	64.0	62.0	63.0	63.3	60.3	62.3	63.0
F2	60.7	60.0	61.7	59.7	60.3	61.0	61.3	64.7	65.7
F3	64.3	64.3	62.7	61.3	62.7	61.3	63.7	61.67	61.3

Mean	62.3
CV (%)	4.5

Appdendix 8b: Mean number of ponding days during the trial period in 2003/04

	N1			N2			N3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
F1	52.0	50.7	50.7	53.3	50.7	52.0	51.0	50.7	52.0
F2	51.0	50.3	52.3	51.7	52.3	51.0	51.7	52.7	52.7
F3	51.3	51.7	51.3	52.0	49.7	52.0	49.7	49.7	50.0

Mean	51.3
CV (%)	3.4

Appdendix 8c: Mean number of ponding days during the trial period in 2004/04

	N1			N2			N3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
F1	76.0	77.0	76.0	77.0	66.7	74.0	73.7	75.7	74.7
F2	68.3	76.0	74.0	75.7	75.0	74.3	72.7	73.3	74.0
F3	73.7	76.7	73.7	74.7	75.3	74.3	77.0	73.7	75.0

Mean	74.7
CV (%)	4.7

Appendix 9: Effect of farmyard manure, phosphorus and nitrogen application on mean plant height (cm)[1]

	N1			N2			N3		
	P1	P2	P3	P1	P2	P3	P1	P2	P3
F1	80.0	86.1	89.4	84.7	86.3	91.9	86.1	89.4	92.7
F2	83.6	88.1	91.1	88.7	88.6	94.5	90.2	92.7	98.3
F3	88.7	94.3	93.8	92.6	92.2	97.3	94.7	97.3	101.4

Mean	93.1
CV (%)	3.19

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[1] Mean of three seasons