# ASSESSMENT OF THE FERTILITY STATUS OF SOILS OF RICE GROWING AREAS OF SAME DISTRICT, KILIMANJARO REGION, TANZANIA.



BY

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## ABSTRACT

This study was conducted to assess the fertility status of the soils of rice growing areas of Same district. Thirty soil samples were collected from ten different sites where rice is grown. Following laboratory analysis, three bulk soil samples were collected from Kisiwani, Ndungu and Kihurio for pot experiments. The laboratory analysis included determination of total N, organic carbon, P by Bray 1 and Olsen methods, and exchangeable bases by ammonium acetate saturation. The micronutrients were determined by extracting with 0.005M DTPA at pH 7.3. The response of rice (*Oryza sativa* L) variety super SSD5 to N, P and K, as well as to different levels of Zn were assessed in a glasshouse experiment where plants were grown for 56 days. The harvested plant samples were analysed for N, P, K, Ca, Mg, Zn and Fe using the $HNO_3$-$H_2O_2$ wet digestion procedure. The results showed that all the soils in this study were deficient in N. About 53% of the soils had low available P. All the soils had adequate levels of K, Ca, Mg and Na, with the exception of soils from Ndungu, which had a low K, supply. Also, most of the soils had low Zn levels, and only two sites had adequate Zn levels. Soils from Mbugani had low Fe while the rest had adequate Fe and Cu. The glasshouse experiments showed that application of N, P and K increased rice dry matter yields in all the soils used. It was further revealed that Zn supplementation in addition to NPK also increased rice dry matter yields further. The results also indicated that the uptake of each nutrient applied was consistent with the dry matter yields increases. It was concluded that most of the soils under rice cropping in the district were deficient in N, P and Zn and required fertilisation using these nutrients. Iron was also required in Mbugani soils, which

were deficient of this element. Field experiments are recommended to confirm these initial findings.

## DECLARATION

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

Signature............NAmur................

Date ...............14th/04/2003...............

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## DEDICATION

To the Almighty God, for from Him comes knowledge, understanding and wisdom to those who worship Him. Give me your guidance and let my soul worship You.

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## LIST OF SYMBOLS AND ABBREVIATIONS

| | |
|---|---|
| % | Percent |
| $^0C$ | Degree Celsius |
| $Ca^{2+}$ | Calcium ion |
| $CaCl_2$ | Calcium chloride |
| CEC | Cation Exchange Capacity |
| Cmol (+)/kg | Centimole (+) per kilogram |
| $CO_2$ | Carbondioxide |
| $CO_3^{2-}$ | Carbonate ion |
| Cu | Copper |
| dS/m | Decisiemen per meter |
| EC | Electrical Conductivity |
| FAO | Food and Agriculture Organisation |
| Fe | Iron |
| $H_2SO_4$ | Sulphuric acid |
| ha | hectare |
| $HCO_3^-$ | Bicarbonate ion |
| IRRI | International Rice Research Institute |
| $K^+$ | Potassium ion |
| $K_2Cr_2O_7$ | Potassium dichromate |
| Kg | Kilogram |
| $La_2O_3$ | Lanthanum oxide |
| mg/kg | milligram per kilogram |

| | |
|---|---|
| mg/l | milligram per litre |
| $Mg^{2+}$ | Magnesium ion |
| Mn | Manganese |
| N | Nitrogen |
| $Na^{+}$ | Sodium ion |
| $Na_2CO_3$ | Sodium carbonate |
| $Na_2SO_4$ | Sodium sulphate |
| NaCl | Sodium chloride |
| $NH_4^{+}$ | Ammonium ion |
| nm | nanometer |
| $NO_3^{-}$ | Nitrate ion |
| OC | Organic Carbon |
| $SO_4^{2-}$ | Sulphate ion |
| SUA | Sokoine University of Agriculture |
| Zn | Zinc |

# CHAPTER ONE

## 1.0 INTRODUCTION

Rice is the most important food crop of the world if the area under rice cultivation and the number of people depending on it are taken into account (De Datta, 1981). In Tanzania rice rivals maize as one of the most popular and widely consumed cereals. Since the 1960s, the acreage under flooded or paddy rice has been steadily expanding, both under large and small-scale production. Although it is produced almost all over the country, the main production areas are in Mwanza, Shinyanga, Mbeya, Morogoro Kilimanjaro, and Tanga regions.

The position or importance of rice as a food crop calls for more efforts to increase the yields of the crop so as to ensure food security in the country. However, recent data indicates that rice yields in many areas in the country are low and decreasing with time (Mnguu, 1997). A number of factors such as little or no use of fertilisers, poor crop husbandry, and inadequate water supply contribute to the low levels of rice yields (Msolla, 1991). Of these factors that affect rice production trends, adequate soil fertility and proper nutrient management have a major influence on both yields and productivity (Cassman *et al.*, 1997). Since Tanzania needs higher production levels to feed its growing population, soil fertility and nutrient monitoring are important to be able to design fertiliser packages which will raise productivity and ensure sustainability of farming systems.

Kihurio, Ndungu, Gonja and Kisiwani are important rice producing areas of Same district in Kilimanjaro region. Flooded rice has been grown in these areas for the last 100 years or so. While no production figures were recorded over time, estimates placed levels of yields at over 45 bags of paddy, equivalent to some 18, 100 kg bags of milled rice per acre (4.5 tons/ha) during the early periods of cultivation. However, one striking feature of rice production in these areas is that over time yields have been declining, to as low as 12 or less bags of paddy per acre (1.2 tons/ha) at present (Asenga, 2001, personal communication).

This trend of declining yields may be rationalised largely in terms of declining soil fertility because fertilisers have not been used at all. Therefore, the soil-derived nutrients must have been exhausted to the point of limiting yields, as there was no replenishment in the form of fertilisers. Lack of fertiliser use implies continual nutrient mining, which ultimately leads to decline in yields (Vlaming *et al.*, 2000). In contrast, in areas where fertilizers have been used a good response in rice yields has been realised, indicating that the nutrients added through fertilizers were the ones limiting higher yields (Mnguu, 1997).

A modern rice irrigation scheme has been commissioned at Ndungu, which has revolutionised rice production by, among other things, introducing high-yielding cultivars like the IRRI series, and some fertiliser use. The fertilisers recommended for rice have, so far, been those supplying N, P and K. Yet, dramatic increases in rice yields have not always been realised as a result of NPK use. In addition to NPK use, it is possible that the limiting factors to improved rice growth and high yields may be deficiency of nutrients other than N, P and K. Thus, there is a need to obtain the total picture of nutrient levels of these soils to be able to determine which could possibly be limiting increased production in these areas. Similarly, soil fertility levels need to be established in the other rice producing areas, namely Kihurio, Gonja and Kisiwani.

There are possibilities that the micronutrients such as Zn and Cu could be low in soil to the extent of limiting high rice yields in these areas. This is because the micronutrients are being continually removed by harvested produce without being replaced. An international study on micronutrients in different countries by Sillanpaa (1990) showed that micronutrient deficiencies probably were common problems leading to reduction in crop yields. In Tanzania several studies have shown that micronutrient deficiencies are associated with low rice yields. Studies by Msolla (1991) and by Bashiru (1992) showed that zinc deficiencies were an important constraint in paddy production in Tabora and Morogoro regions, respectively. Iron has also been reported to be associated with zinc deficiencies in limiting rice yields in some areas of Morogoro rural district. Also Semoka *et al.* (1996) reported iron and zinc deficiencies as being important factors limiting high rice yields in some rice growing soils of Morogoro district. Other studies on micronutrients in the country using some maize growing soils of Iringa rural district and wheat growing soils of Mbeya showed that there were zinc deficiencies, which limited the yields of respective crops (Mkangwa, 1992; Kamasho, 1980).

Micronutrient application as fertilisers to the soils that are deficient showed that there was substantial increase in yields (Sillanpaa, 1990). Msolla (1991) reported a significant increase in rice yields due to Zn application in soil at a rate of 10 kg Zn/ha in Igunga and Nzega districts in Tabora region. Semoka *et al.* (1996) reported a positive response to zinc application in rice yields. In Thailand, application of zinc fertiliser in addition to NPK was found to increase rice yields (Osotsapar, 2000).

No such work has been done in respect of these important rice-growing areas of Same district. Thus, data on these aspects is not available. Therefore, this study was undertaken to fill this gap and to generate information, which may be useful in attempts to raise rice yields and production in these areas.

The specific objectives were:

i. To determine the fertility of soils cropped to rice over long periods of time,

ii. To determine the nutrients which are low and which could be limiting increased rice yields,

iii. To evaluate yield responses to supplementation of the limiting nutrients (using pot trials).

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

### 2.1 Diversity of rice growing soils

Rice is grown in diverse soil conditions. Rice growing soils vary in terms of texture, drainage, fertility status and other edaphic characteristics (Ponnamperuma and Deturck, 1993). These soils can be found in various topographical and hydrological conditions, and in different landforms.

### 2.1.1 Soil properties

#### 2.1.1.1 Texture

Soil texture is an important factor in rice cultivation as it influences transmission and storage of water, flow of air in soil and soil capacity of nutrient supply (De Datta, 1981). Soil texture for rice cultivation varies from fine sand to clayey (Ponnamperuma and Deturck, 1993). For lowland rice cultivation, soils of fine to medium texture are commonly used while for upland rice cultivation fine to sandy textures are often considered best (De Datta, 1981). A study by Shekifu (1999) in some rice growing areas of Coast and Morogoro regions in Tanzania revealed that the texture of the soil ranged from sandy loam to clay. Texture of soils from Coast region ranged from sandy loam to clay while in some areas of Morogoro texture ranged from sand clay loam to clay. A similar study by Mnguu (1997) reported clay loam to clayey textured soils of some lowland rice growing areas of Mbeya region. Another study by Msolla (1991) in rice growing soils of Igunga and Nzega indicated that the texture ranged from sandy to silt clay loam, with the majority of soils being sandy loam. Soil textures of other important rice growing areas of the world are also variable. The lowland rice growing soils of Sri Lanka are predominantly sandy and contain little silt; where as soils of Bangladesh are generally silty (De Datta, 1981). Most inland valley swamps soils in West Africa are course-textured while the soils of wetland rice of Zimbabwe are sandy to clay textured. In Malawi and Zambia wetland rice soils texture ranged from sandy to heavy clay (Trans *et al.*, 1995).

In general, optimum rice production requires soils of medium to heavy texture, although in practice rice production is carried out in soils ranging from sandy loam to heavy clays (Landon, 1991).

**2.1.1.2 pH**

Soil pH before and after flooding of lowland fields is an important determinant in evaluating fertility and management of rice soils (De Datta, 1981). Rice can be grown in all types of soils with pH ranging from 3 to 10 (Ponnamperuma and Deturck, 1993). The study by Mzee (2001) in Morogoro, Coastal and Mbeya regions revealed that pH of soils in which rice is grown ranged from 4.9 to 5.9 while a similar study by Mnguu (1997) reported pH ranges of 4.9 to 6.7, which is rated as being low to medium pH. In Igunga and Nzega soils in Tabora region, pH ranged from 5.6 to 8.2, with the majority of soils being in the medium and high pH categories (Msolla, 1991). Shekifu (1999) reported pH range of 4.9 to 7.5 in some rice growing soils of Coast and Morogoro regions, where nine soils out of ten were of medium pH (<7), with only one soil from Dakawa having a high pH of 7.5. The soil pH of three ecosystems of rice growing areas of Ifakara (Morogoro region) was found to range between 5.2 to 6.9 with an average of 5.7. In the rice growing areas of India in Assam, west Bengal and Orissa areas, pH ranged from 4.9 to 7.5, and that of soils in Uttar Pradesh and Bihar from 7.0 to 8.5 (Singh, 1982). Like any other soil property, pH influences the availability of different nutrients to plants. Generally, nutrient availability decreases when pH is either too low or too high. Thus a medium pH range of 4.5 to 6.5 is satisfactory for rice production (Van Breemen, 1980).

#### 2.1.1.3 Cation exchange capacity

The cation exchange capacity (CEC) gives an idea of the potential fertility of a soil and the capacity of the soil to retain nutrients against leaching. This is usually influenced by organic matter content, clay content and type of clay minerals (Brady and Weil, 1996). The soils in which rice is grown varies in their CEC levels. The CEC of rice growing soils varies in different locations. In some parts of Morogoro, Coast regions and Mbeya regions the CEC of the soils ranged from 7.67 to 40.63 cmol(+)/kg, which is regarded as being low to high (Mnguu, 1997). In another study on rice growing areas Mzee (2001) reported the CEC values as ranging from 6.8 to 22.8 cmol(+)/kg, which were rated as being low to medium. In both studies the higher CEC was mainly influenced by the content and type of clay since the soils studied had low organic carbon content. In Igunga and Nzega, CEC ranged from 2.4 to 4.4 cmol(+)/kg with majority of soils being low in CEC (Msolla, 1991). The mean value for effective CEC of soils of flood plains of West Africa ranges from 7.03 to

12.34 cmol(+)/kg the high values of CEC are reported to be due to lower leaching, higher clay content and river deposits rich in cations from flooding (Buri *et al.*, 1999). Also the CEC of the two lowland rice growing soils of Brahmanputra valley in India ranges from 4.8 to 9.6 cmol(+)/kg in North Lakhimpur and 4.9 to 15.3 cmol(+)/kg in South bank Shillongani, the higher CEC value in south bank (Shillongani) was reported to be attributed by clay content because the CEC was found to be significantly positively correlated with clay (r = 0.93) (Baruah *et al.*, 1996).

**2.1.1.4 Exchangeable calcium, magnesium and sodium**

Studies have shown that rice can be grown in soils with different levels of exchangeable bases ranging from high to low. Shekifu (1999) showed that the levels of exchangeable bases were: $Ca^{2+}$ 1.37 to 7.89 cmol(+)/kg which is low to medium, $Mg^{2+}$ 0.61 to 7.55 cmol(+)/kg (high), $Na^{+}$ 0.41 to 0.98 cmol(+)/kg (low to high). Also a previous work by Mnguu (1997) in the rice growing soils of Morogoro, Coast and Mbeya regions reported levels of exchangeable bases as follows: $Ca^{2+}$ 1.55 to 12.25 cmol(+)/kg (Low to medium), $Mg^{2+}$ 0.53 to 9.55 cmol(+)/kg (low to very high), $Na^{+}$ 0.24 to 2.70 cmol(+)/kg (low to high). These results indicated that among the exchangeable bases calcium was the most abundant followed by magnesium and lastly sodium. The exchangeable bases for West Africa flood plains soils were: $Ca^{2+}$ 4.11 to 7.26 cmol(+)/kg, $Mg^{2+}$ 1.47 to 3.81 cmol(+)/kg, $Na^{+}$ 0.55 to 1.47 cmol(+)/kg (Buri *et al.*, 1999). Higher levels of exchangeable bases were found in Sudan and Sahel Savannah zone than those found in Guinea savannah and Equatorial forest zone (Buri *et al.*, 1999). The levels of exchangeable bases vary depending on type of parent materials, degree of weathering and sedimentation, extent of leaching and clay content (Buri *et al.*, 1999).

### 2.1.2 Clay mineralogy

An understanding of clay minerals is important for management of rice soils. Clay mineralogical characteristics also have great bearing on the productivity of soils (De Datta, 1981). There are four groups of clay minerals:

#### 2.1.2.1 The 1:1 type clay minerals (1silica: 1alumina). e.g. kaolinite

These are non expanding clay minerals because cations and water do not enter between layers. Therefore rice soils with 1:1 type clay have low CEC and low water holding capacity. An example of these is the rice growing soils in northeast Thailand (De Datta, 1981).

#### 2.1.2.2 The 2:1 expanding type clay minerals (2 silica: 1 alumina). e.g. montmorillonite

This can expand because the layers are loosely held together by O to O linkages. As a result swelling and shrinking capacity is high in a soils rich in montmorillonite (Troeh and Thompson, 1993). It has high CEC and water holding capacity. An example of such soils is the vertisols. Soils with montmorillonitic clays have higher fertility and higher yield potential than soils with kaolinite (De Datta, 1981). Vertisols and soils with vertic characteristics are amply found in Tanzania.

### 2.1.2.3 The 2:1 non-expanding type (2 silica: 1 alumina) clays

These are similar to montmorillonite but have much larger particles. An example is illite (hydrous mica group). It is intermediate between kaolinite and montmorillonite with regard to cation adsorption, hydration, swelling and shrinking capacity. Soils in the northern and central valley of Thailand are rich in these clays (De Datta, 1981). The exact extent of occurrence of such soils in Tanzania has not been established.

### 2.1.2.4 The 2:2 type clays (2 silica: magnesium) e.g. illite.

Their particle size and cation exchange capacities are about the same as kaolinite but these have little water adsorption between layers.

### 2.1.2.5 Allophanes

These are amorphous clay sized materials that have been derived from volcanic ash and pumice. Soils rich in these clays are generally referred to as Andosols or volcanic ash soils. The dominant clay mineral is allophane. Such soils are dark in colour and contain large quantities of organic matter. These soils are mostly acidic and effective CEC is highly dependent on pH. They also fix large amounts of P (De Datta, 1981). It has been estimated that 12% of paddy areas of Japan are typical volcanic soils (Andosols) (Hirata *et. al.*, 1999). In Tanzania such soils occur around mount Kilimanjaro, Meru, and in the Southern Highlands.

Clay minerals play a significant role in physical and chemical properties of rice soils. It has been found that clay mineralogical composition controls nitrogen fertility status by regulating the behaviour of inorganic nitrogen in soil and mineralization process of organic nitrogen. Also, clay mineralogy influences the level of CEC in the plough layer of paddy soils. The increase in rice yields and natural fertility of paddy soils in relation to clay mineralogy are in the order smectite>vermiculite>kaoline>low clay content group (Egashira *et al.*, 1992). The type of clay mineralogy also affects phosphorus and potassium availability to plant as it controls both the intensity factor of these nutrients in soil solution and their buffering capacity of soil. It has been found that less weathered smectite rich soils desorbeb more P at high P release rate than illite dominant soil and kaolinitic soil. Though the clay content decrease in the order smectite>illite>kaoilinite, thus there is positive correlation between P availability and clay content and smectite but negative correlation with kaolinite. However, in highly weathered soils with kaolinite as a major mineral negative correlation between available P and clay content exist (Tomar, 1997). Also Pal and Rao (1997) have reported a positive correlation between clay and amount and rate of potassium supply to the roots.

## 2.2 Nutrient contents of rice growing soils

### 2.2.1 Nitrogen

Nitrogen holds the key to productivity of all cereal crops. In rice up to two thirds of the N absorbed by the crop comes from the soil (Ponnamperuma and Deturck, 1993). Thus the fertility of wetland rice and fertiliser requirement is influenced by natural source of N, N transformation and N availability (Ponnamperuma and Deturck, 1993). Among other factors, availability of N in flooded soils increased with increases in nitrogen content of the soils (De Datta, 1981). The total N content of nearly 1000 wetland rice soils in south and southeast Asia ranged from 0.02% in a sandy soil to 1.34% in a Histosol (Ponnamperuma and Deturk, 1993). In some selected rice growing soils of Morogoro, Coast and Mbeya region in Tanzania the total N values ranged from 0.08% to 0.13% (Mnguu, 1997). The total N of rice soils of Igunga and Nzega in Tabora regions ranged from 0.11 to 0.32%, which falls under the medium category (Msolla, 1991). The mean values of total N of the topsoil of West Africa flood plains ranged from 0.071 to 0.13%. The total N in these areas is generally low throughout the sub-region with the Guinea savannah zone being only slightly higher (Buri *et al.*, 1999). Also Kawaguchi and Kyuma (1977) recorded topsoil total N levels of 0.13% and 0.29% for lowland paddy fields in tropical Asia and Japan, respectively. In most cases low levels of total N is due to inability of most farmers to supply N fertilizers. Nature of clay mineralogy, use or non-use of nitrogen fertilizers and low organic matter content of the soils reduce nitrogen content in rice soils (Egashira *et al.*, 1992; Mae, 1997).

### 2.2.2 Phosphorus

The only natural source of P for plants is soils. Phosphorus is present in soils as primary minerals and as phosphates of Al, Fe and Ca. It is also present adsorbed on clay and hydrous oxides, and also as organic phosphate. The total P content of more than 400 south and southeast Asia wetland rice soils ranged from 4 to 245 mg/kg (Ponnamperuma and Deturck, 1993). The mean topsoil level of available P in flood plains of West Africa ranges from 7.25 to 9.84 mg/kg. This shows that there is deficiency of P throughout this West Africa sub-region (Buri *et. al.*, 1999). The extractable P in rice growing soils of Morogoro, Coast and Mbeya regions ranged from 1.26 to 8.84 mg/kg and has been ranked as being low in P fertility status (Mzee, 2001). Another study by Mnguu (1997) using selected rice growing soils of Morogoro and Coast region revealed Bray 1 extractable P as ranging from 1.2 to 24.5 mg/kg, which shows that the soil had low to medium P supply. In Igunga and Nzega the available P of rice growing soils ranged from 9.1 to 32.3 mg/kg, and these values was considered low (Msolla, 1991). The extractable Bray 1 phosphorus in unfertilised rice soils of Morogoro and Coast region ranged from 2.1 to 40.3 mg/kg, and 70% of these soils were expected to respond to phosphorus application as they were below the critical limit of 15 mg/kg (Shekifu, 1999). Phosphorus content of rice growing soils varies depending on the nature of parent materials, the conditions in which they were developed, content and type of clay minerals, presence of high content of iron and aluminium oxides, and the kind of management they were subjected to (Jones, 1982). Phosphorus deficiency is the most important factor limiting rice yields in many soils. The deficiency in available P is reported to be related to the generally low organic matter, low pH, presence of P-fixing compounds and the inability of farmers to use fertilisers (Owusu-Bennoah *et al.*, 1991).

### 2.2.3 Potassium

Potassium occurs in soils in primary minerals and 2:1 layer silicate clays as non-exchangeable K, as well as exchangeable K on silicate clays and K in soil solution. A dynamic equilibrium exists among these forms but the main source of K for plants is water soluble and exchangeable K (Ponnamperuma and Deturck, 1993; Jones 1982). In tropical wetland rice soils the amount of exchangeable K ranges from 0.0 to 2.6 cmol (+)/kg (Ponnamperuma and Deturck, 1993). Some 63 soil samples from 10 Asian countries revealed that the exchangeable K ranged from 0.06 to 1.21 cmol(+)/kg. In Sri Lanka 75% of the rice soils in the wet zone had an exchangeable K content of less than 0.15 cmol(+)/kg, which is considered below the critical K level. In the Philippines the exchangeable K in some major rice growing soils ranged from 0.2 to 0.9 cmol (+)/kg soil (Jones, 1982). Several workers have reported the levels of exchangeable K in some rice growing soils of Tanzania. Mzee (2001) reported exchangeable K levels in some soils of Morogoro, Coast and Mbeya regions as ranging from 0.1 to 1.51 cmol(+)/kg soil, considered to range from low to high levels. Another work by Msolla (1991) revealed that exchangeable K of some soils of Igunga and Nzega ranged from 0.07 to 0.47 cmol(+)/kg, with the majority of soils being low in exchangeable K. Mnguu (1997) reported the value of exchangeable potassium to range from 0.21 to 1.19 cmol(+)/kg in some rice growing soils of Morogoro and Coast regions where 10% of the soils were considered deficient and 90% was above critical level of 0.26 cmo(+)/kg. In West Africa the exchangeable K levels ranged from 0.17 to 0.57 cmol(+)/kg (Buri *et al.*, 1999). Low exchangeable K in rice growing soils is mainly due to excessive weathering of primary minerals, excessive leaching of cations, relatively higher exchangeable Na (Buri *et al.*, 1999) and quantity and type of clay mineral (Grimme, 1980).

### 2.2.4 Zinc

After N, zinc (Zn) is the most important nutrient limiting wetland rice yields (Ponnamperuma and Deturck, 1993). Zinc occurs chiefly as the sulphide mineral sphalerite. In soils, zinc is predominantly associated with the clay fraction. Zinc exists in limited amounts on exchangeable sites of clay minerals and organic matter (complexes) and is adsorbed on the surfaces of amorphous oxides of iron and aluminium. A small fraction of total Zn is present in the soil solution (Jones, 1982). These forms differ in their solubility and strength (reversibility) and thus availability to plants (Phogat *et al.*, 1994). As a measure of available Zn, DTPA extractable zinc levels of 0.3 to 11 mg/Kg are common in agricultural soils (Sillanpaa, 1982). Mnguu (1997) reported that the quantities of extractable zinc by DTPA ranged from 0.8 to 3.3 mg/kg, with an average of 2.3 mg/kg, in some soils of Morogoro and Coast regions. In Igunga and Nzega soils extractable zinc ranged from 0.63 to 2.25 mg/kg and it was considered that 75% of these soils were deficient in extractable Zn (Msolla, 1991). Mghase (2001) who worked on three ecosystems of rice growing soils of Ifakara reported that the values of DTPA extractable zinc were: 0.02 to 0.18 with a mean of 0.09 mg/kg for an upland ecosystem, 0.24 to 4.88 with a mean of 2.34 mg/kg for a lowland non-flooded ecosystem and 0.65 to 1.7 mg/kg with a mean of 1.4 mg/kg for a lowland flooded ecosystem, and it was considered that the upland ecosystem was deficient of zinc while in the lowland ecosystem zinc was sufficient. Mzee (2000) reported the value of available zinc for some rice growing soils of Morogoro, Coast and Mbeya regions to range from 0.12 to 1.77 mg/kg, where 60%

of soils were found to be below critical range, hence not able to supply adequate zinc for crop growth.

Submergence has been reported to decrease the availability of zinc (Jones 1982), hence many flooded soils are at risk of being zinc deficient. The inadequacy of soils to supply zinc to plant has been found to be caused by high pH (sodic, saline-sodic or calcareous soils), high organic matter content (continuously wet soils or peat soils), high available phosphorus or silicon, high Mg/Ca ratio and low available zinc (Ponnamperuma and Deturck, 1993).

### 2.2.5 Copper

Copper is present in soil as oxides, carbonates, silicates or sulphides of primary minerals (Jones, 1982) and it also occurs in the soil solution, on normal exchange and specific sorption sites and in biological residues (Singh and Nongkyrih, 1999). Copper availability to plants depends on chemical forms of copper in the soil as well as on soil properties (Jones, 1982). A value of 0.2 mg/kg copper soluble in diethylene triamine pentaacetic acid (DTPA) + $CaCl_2$ (pH 7.3) has been found to be a critical level in rice soils (Ranthawal *et al.*, 1978; Tanaka and Yoshida, 1970). The available copper in some rice growing soils of Morogoro, Coast and Mbeya ranged from 0.41 to 3.70 mg/kg and was considered to have adequate supply of copper to plants. Mghase (2001) working on soils of ARI-Katrin, Ifakara, reported that the DTPA copper values ranged from 0.06 to 0.17 with an average of 0.12 mg/kg for an upland ecosystem, 0.87 to 3.69 with an average of 2.39 mg/kg for a lowland non flooded ecosystem, and 2.88 to 3.83 with an average of 3.3 mg/kg for a lowland flooded ecosystem. The upland ecosystem was considered to be deficient in copper while lowland ecosystem was sufficient in copper. Charterjee and Khan (1997) also reported a range of 0.3 to 5.8 mg/kg of DTPA extractable copper in different lowland rice fields of Birhum, India, which indicates that the soils were sufficient in available copper for plant growth considering 0.66 mg/kg as the critical limit.

Soil submergence causes a net decrease in the total content of the active fractions of copper, but increases the proportion of inactive residues, there by causing a decrease in the plant availability of copper in soils. The variation in available copper content can be explained by soil properties. Soil pH and $CaCO_3$ content have been found to have significant negative correlation while organic carbon, clay content and CEC are positively correlated with available copper (Charterjee and Khan, 1997).

### 2.2.6 Iron

Iron in soils occurs as primary and secondary minerals, hydrated oxides and their organic and inorganic derivatives. The aerobic-anaerobic cycles in rice soils have a pronounced effect on the weathering of ferromagnesian minerals and on degradation and formation of iron containing secondary minerals. Depending upon abundance, iron regulates the chemistry of rice soils (Jones, 1982). The critical value of iron in rice soils ranged from 2.5 to 5.0 mg/kg (Ranthawal *et al.*, 1978; Sims and Johnson, 1991). Mnguu (1997) reported the available DTPA extractable iron to range from 57.4 to 678.8 with a mean of 227. 0 mg/kg in some rice soils of Morogoro and Coast regions, and these values provided adequate available iron. In the rice soils of ARI-Katrin, Ifakara, the levels of DTPA extractable iron ranged from 12.16 to 43.46 with a mean value of 27.49 mg/kg for an upland ecosystem, 95.61 to 367.04 and average of 235.88 mg/kg for a lowland nonflooded ecosystem, and 83.70 to 286.94 with an average of 217.81 for a lowland flooded ecosystem, and these values were above the critical value (2.5 to 4.5 mg/kg established by Tanaka and Yoshida, 1970) for deficiency (Mghase, 2001). Charterjee and Khan (1997) reported that the iron content in Alfisols of different lowland rice fields of West Bengal in India ranged from 20 to 178 mg/kg and considered it sufficient in available iron. Low amounts of total iron are seldom related to plant deficiencies in iron; rather low iron solubility is. Thus, available iron in soils is explained by soil properties. It has been found that the iron content was positively correlated with organic carbon (r=0.66), clay (r=0.35) and CEC (r=0.77), but was negatively correlated with pH (r=-0.75) and $CaCO_3$ content (r=-0.77) (Charterjee and Khan, 1997).

## 2.3 Rice response to nutrient application

### 2.3.1 Nitrogen

Nitrogen is the most common nutrient applied to rice soils. Nitrogen has been reported to have significant effects on yields and yield attributes of rice. Response of rice to nitrogen depends on rice variety, time of application, rate of application, soil nitrogen content sources of nitrogen and nitrogen management. Murty *et al.* (1992), using late, medium and early maturity varieties, found that the increase in yield was higher (15%) in the late variety, when 80 kg N/ha was applied, and 12% at 120 kg

N/ha. However, the increase was lower (5-8%) in the medium and early variety. Dalai and Dixit (1987) reported increases in number of panicles/m$^2$, length of panicles, spikelets per panicles, and 1000 grain weight when N levels were increased from 0, 30, 60, 90 to 120 kg N/ha. Using medium maturing duration rice varieties in India, Sharma and Gupta (1992) obtained similar results with rainfed upland rice. Nitrogen application also significantly increase the dry matter yield of rice grown in greenhouse conditions using soils from Dakawa rice farm by 164% and 218% over the control on application of 100 and 200 kg N/ha, respectively (Semoka and Shenkalawa, 1985). Temu (1985) obtained similar results with rice soils of Mbarali in Mbeya.

With respect to time of application it has been found that split application gave higher response of N at each level of N fertiliser applied. Mohapatra *et al.* (1997) reported that the application of prilled urea at the rate of 80 kg N/ha in three splits gave the highest grain yield of 6.0 ton/ha as compared to single application, which gave 5.1 ton/ha while the control gave 4 ton/ha. Also Mongia (1992) observed significant grain yield responses of 20-41.9 kg grain/kg N with 60 kg N/ha urea and 25-39.7 kg grain/kg N with 120 kg N/ha, and the higher responses were obtained at each level of N from plots where nitrogen was applied in 2 or 3 splits.

Soil nitrogen content also affects the response of rice to applied nitrogen. In India Gogoi and Kalita (1992) reported that in soils with low nitrogen status a higher increase in grain yield was observed when 40 kg N/ha was applied than in the soils with medium to high nitrogen status. Different sources of nitrogen and management practices have a profound effect on the rice response to applied nitrogen. Pathak and Sarkar (1997) showed that although nitrogen application produced higher straw and grain yields than control, the highest yield were obtained from combination of green manure (*sesbania*) and urea, followed by urea alone, while straw application was inferior. The positive response of rice productivity to nitrogen application was attributed to vigorous growth and increased physiological efficiency at higher nitrogen level as a result of better uptake, leading to greater dry matter production (Mae, 1997 and Murty *et al.*, 1992).

### 2.3.2 Phosphorus

Phosphorus fertilisation has a profound effect on rice yields. A study in India showed that the application of 30, 60 or 90 kg $P_2O_5$/ha (equivalent to 13.2, 26.4, and 39.6 kg P/ha, respectively) increased the rice yield by 8.45, 24.9 and 31.6%, respectively, over the control (Raju *et al.*, 1992). Similar results were obtained in acid soils of Nagland where the highest yield was 16.4 tons/ha at 45 kg P/ha while that of the control was 6.4 tons/ha (Sharma and Tripathy, 1999). Mongia *et al.* (1998) also reported significant positive effect on both grains and straw yields of rice when phosphate was applied and that the highest response was obtained at 80 kg P/ha. In a pot experiment using soils from some rice growing areas of Morogoro, Coast and Mbeya regions Mzee (2001) obtained significant increase in dry matter yield with increased levels of P where the greatest yield increase was obtained at 160 mg P/kg (equivalent to 320 kg P/ha). Similarly Shekifu (1999) obtained significant increases in dry matter yields when 30 mg P/kg (equivalent to 60 kg P/ha) were applied using some rice soils of Morogoro and Coast regions. Mnguu (1997) obtained a yield response of 79.6% when phosphorus was applied in soils which were deficient in phosphorus, but no response in soils high in extractable phosphorus content. Semoka and Shenkalawa (1985) reported an increase in dry matter yield with application of phosphorus at 60 kg P/ha, and that the increase was associated with phosphorus concentration in plant.

### 2.3.3 Potassium

Potassium nutrition has been reported to increase the grain and straw yield of crops by stimulating the activity of nitrate reductase to promote the formation of peptides and proteins, thereby increasing the quality of grain (Beringer, 1980). The response of rice to potassium depends on the fertility level of the soil, cultiva and season. In a pot experiment, Semoka and Shenkalawa (1985) obtained a positive response to potassium when it was applied in combination with 200 kg N/ha and 60 kg P/ha, when exchangeable potassium was 0.52 to and 0.32 cmol(+)/kg in topsoil and subsoil, respectively. Mnguu (1997) also reported a slight increase in dry matter yield when potassium was applied in potassium deficient soil of Kigogoni in Coast region. In Southeast China on some calcareous alluvial bog deficient in phosphorus, zinc and potassium, application of potassium alone increased the yields of rice by 5.7 to 8.5% over the control. However when a combination of the deficient elements was applied yield increases over the control ranged from 31.7 to 50.7 percent (Jones, 1982). In an experiment with three rice cultivas at three sites in the Philippines, the average response to 50 kg K/ha without phosphorus was 0.33 tons/ha and 1.1 tons/ha when 26 kg P/ha was applied. In the absence of phosphorus, IR20 variety failed to respond to potassium whereas IR8 and IR26 yielded an extra 500 kg grain/ha (IRRI, 1974). In India the average response of Kharif rice to 60 kg K/ha was 6.7 kg grain/kg K, while that of another cultivar, Rabi rice was 8.48 kg grain/kg K, and high yielding cultivars responded better to potassium fertilisation than local varieties (Kanwa, 1974). Also potassium improved yields on iron toxic and poorly drained soils high in organic matter (Ponnamperuma and Deturck, 1993). The positive response of rice to potassium has been reported to be partly due to increased area of the flag leaf which is the major source of assimilates for grain yield (Beringer, 1980).

### 2.3.4 Zinc

Rice response to zinc varies with the severity of deficiency and environmental variables. Nonetheless, a greater increase in yields is brought about by zinc application on permanently wet soils, sodic soils and calcareous soils. Msolla (1991) reported percentage increases in dry matter yield of 11.14 and 19.55 over the control with application of zinc at 5 mg/kg and 10 mg/kg, respectively in the soils of Igunga and Nzega in Tabora region. Zinc application at the rate of 5 kg/ha significantly increased the plant height, number of tillers, dry matter yield content, panicle length, number of grains per panicle, percentage of filled grains and 1000 grain weight in saline and non saline soil, but at lower salinity the yields and yield attributes were higher (Khan *et al.*, 1992). Singh *et al.* (1999) reported that the increased dry matter weight of rice due to zinc application in deficient soils of Meghalaya fields in India was 82.7 percent while in zinc sufficient soils it was only 34.8 percent. In the Philippines, yield responses to 20 kg $ZnSO_4$ ranged from 2.1 to 4.9 tons/ha on zinc deficient soils which were well supplied with other nutrients (Ponnamperuma and Deturck, 1993). In aeric Haplaquept soils of Bangladesh zinc application at 3 kg Zn/ha increased the grain yield to 3983 kg/ha as compared to the control which gave 3272 kg/ha (Islam *et al.*, 1997). Combined application of nitrogen and zinc has been reported to increase the grain and straw yields by 7.2 and 12.9 percent, respectively, over application of nitrogen alone (Khanda and Dixit, 1996). The source and method of zinc application was also reported to influence yields. Khanda and Dixit (1995) found that $ZnSO_4$ increased the grain and straw yield by 2.5 and 4.2 percent, respectively, over Zn-EDTA. This was reported to be due to optimal supply of zinc from $ZnSO_4$. Also soil application of zinc has been found to be superior over foliar application and has been explained as being due to optimal supply of zinc at all phenophases from the day of planting (Khanda and Dixit, 1995).

### 2.3.5 Copper

Copper has favourable effect in the growth maturation and yield of rice. Substantial increase in yields of rice has been reported as a result of soil and foliar application of copper in soils deficient in copper. Copper application has been found to increase the straw and grain yield, nitrogen concentration and uptake. Vankateswarlu and Misra (1987) reported significant increases in straw and grain yields when copper was applied at 5 kg $CuSO_4$/ha. In India application of copper at 25 kg Cu/ha as $CuSO_4$ was found to increase rice grain yields from 0 to 1780 kg/ha with a mean of 460 kg/ha (Patel and Singh, 1995). Tandon (1995) reported the increase in rice yield due to copper was 340 kg/ha over NPK when it was applied as basal dressing.

### 2.3.6 Iron

Large responses to soil and foliar application of iron to paddy have been observed in different soils. In India Kanwa and Randhawal (1978) reported rice grain yield increases due to soil and spray application of iron in combination with NPK as compared with NPK alone, resulting in responses of 35.59 and 29.66 q/ha, respectively. Thus soil application has been proved better than foliar application of iron under the reduced conditions. Application of iron in the form of inorganic salts, as a basal dressing, was reported to increase rice yields to the tune of 1880 kg/ha over NPK alone (Malewar and Ismail, 1995). Nayyer (1999) reported the response of rice to iron application from 310 to 3900 kg/ha. Tandon (1995) reported that application of 25 kg FeSO4/ha with 20 tons/ha farmyard manure gave maximum rice yields and iron uptake over other treatments. Thus, the degree of response to applied iron is conditioned by soil and other environmental factors, variety characters, cultural practices, organic matter and nutrient interactions.

# CHAPTER THREE

## 3.0 MATERIAL AND METHODS

### 3.1 Soils

Soils samples were collected from Kihurio, Ndungu (small-scale farmers in traditional farms and in a modern irrigation scheme), Gonja, and Kisiwani, which are important rice-growing areas of Same district.

### 3.2 Soil sampling and sample preparation

#### 3.2.1 Soil sampling for routine analysis

Thirty composite surface samples, three for each location, were collected at the depth of 0-20 cm. Sampling sites were chosen which, in the experience of residents, represented areas which gave low rice yields and those which gave high yields. The selected sites are given in Table 1. From each site, sub-samples were collected randomly from the selected fields and mixed to obtain a composite sample. The composite samples so obtained were air-dried and ground to pass through a 2-mm sieve for laboratory analysis.

#### 3.2.2 Soil sampling for pot experiments

After routine analysis of the soils, those sites which indicated low levels of Zn were sampled for pot experiments to study the response of rice to Zn fertilisation. (Copper and other micronutrients like iron were found to be in adequate quantities in those soils.) The representative bulk samples were collected from the three sites namely

Table 1. Areas of Same district from where the experimental soils were collected

| Rice growing Area | Locations sampled (and rice yields) | Fertiliser use |
|---|---|---|
| Kihurio | Kimunyu (low yields) 1km from the Same-Kihurio road | Manure |
| | Darajani (high yields) 200m from Same-Kihurio road | None |
| Ndungu | Ndungu Irrigation project: Block LTB 1-2 (low yields) Block LTB 1-2 (high yields) | *SA or Urea |
| | Ndungu traditional farms outside project (low yields) | None |
| Gonja | Kizerui (low yields) 1 km from the Same - Gonja road | None |
| | Brani (high yields) 1 km from Same –Gonja road | None |
| Kisiwani | Mbugani (low yields) 2 km from Same-Gonja road | None |
| | Kwahwai (high yields) 50 m from Same-Gonja road | None |

*SA- Sulphate of Ammonia.

Kihurio (Kimunyu), Ndungu (small-scale traditional farms outside the Ndungu Agricultural Development Project) and Kisiwani (Mbugani). The soils were sampled from different sampling points around the sites (section 3.2.1) which had revealed low levels of Zn upon analysis, and bulked to give the representative bulk samples. These soil samples were air dried and sieved to pass through an 8mm sieve for the pot experiment.

### 3.3 Soil analysis

Analyses for soil pH, cation exchange capacity, exchangeable bases, electrical conductivity, particle size analysis, total nitrogen, organic carbon, extractable phosphorus and extractable micronutrients were made:

#### 3.3.1 Soil pH

Soil pH was measured in water using pH-meter at the ratio of 1:2.5 soil: water as described by Maclean (1982).

#### 3.3.2 Cation exchange capacity and exchangeable bases

The CEC of the soil was determined using the ammonium acetate saturation method as described by Chapman (1965). Five g of the soils were saturated with neutral normal $NH_4OAC$, shaken for 30 minutes and filtered. The filtrate was used to determine exchangeable K, Ca, Mg and Na using atomic adsorption spectrophotometry. Excess $NH_4OAC$ entrapped by the samples was removed by washing twice with methanol. The $NH_4^+$ -saturated soil was equilibrated with 4%

KCl, shaken for 30 minutes and filtered. The filtrate was used for the determination of $NH^{4+}$ by micro-kjeldahl distillation in the presence of 40%NaOH and the $NH_3$ liberated was collected in 4% boric acid (with mixed indicator) and titrated with standard 0.1 N $H_2SO_4$. The titre was used for estimation of CEC of the soil.

### 3.3.3 Electrical conductivity

The Electrical conductivity was determined in a 1:2.5 soil-water suspension using an electrical conductivity meter as per method of Moberg (2000).

### 3.3.4 Particle size analysis

The particle size analysis was determined by the Hydrometer method after dispersion with sodium hexametaphosphate as described by Day (1965). The textural class was determined using the USDA textural class triangle (USDA, 1975).

### 3.3.5 Total nitrogen

Total Nitrogen was determined using micro-kjeldahl digestion-distillation method as described by Bremner and Mulvaney (1982). One g of soil was digested with concentrated $H_2SO_4$ in presence of mixed catalyst ($K_2SO_4$, $CuSO_4$ and selenium powder mixed in the ratio of 10:10:1 by weight). The digest was distilled in the presence of 40% NaOH. The ammonia liberated was collected in 4% boric acid (with mixed indicator) and then titrated with standard $H_2SO_4$. The titre was used to calculate the total N of the soil sample.

### 3.3.6 Organic carbon

The organic carbon was determined using the Walkey and Black method (Allison, 1965). To a 1g soil sample, 10 ml of 1M $K_2Cr_2O_7$ and 20 ml of concentrated $H_2SO_4$ were added to oxidise organic carbon. The amount of dichromate reduced was used to estimate the organic carbon content of the soil.

### 3.3.7 Phosphorus

Soil samples were analysed for available P using the Bray-I procedure (Bray and Kurtz, 1945) and Olsen method (Olsen *et al.*, 1954) depending on their pH. For samples with pH>7 the Olsen method was used while for those with pH<7 the Bray-I method was used. In the Bray-I method the extracting solution containing $NF_4$ + 0.025HCl was used. A sample of 3g air-dried soil was placed in a plastic bottle, with 20 ml of extracting solution added, shaken for one minute and filtered. In the Olsen method, 40 ml of 0.5 NaOH as an extracting solution were added to 2g air-dried soil sample, shaken for 30 minutes in a reciprocating shaker and filtered. The P was determined in the filtrates by spectrophotometry at 884nm following colour development by the molybdenum blue method (Murphy and Riley, 1962).

### 3.3.8 Micronutrients

DTPA extractable micronutrients in all soil samples were determined using the procedure by Lindsay and Norvell (1978). The extractant contained 0.005M DTPA (diethylenetriaminepentaacetic acid), 0.01M $CaCl_2.2H_2O$ and 0.1M TEA (Triethanolamine) adjusted to pH 7.3. Twenty g of air-dried soil were mixed with

40ml of extracting solution and shaken for two hours and then filtered. The micronutrients: zinc, copper and iron was determined by atomic adsorption spectrophotometer, using appropriate standards.

### 3.4 Pot experiments

Pot experiments were conducted which lasted for 56 days (3rd May –29th June) in the glasshouse at SUA, Morogoro. The soil samples from the three selected sites that showed lowest levels of nutrients (section 3.4) (Kimunyu, Mbugani and Ndungu small-scale traditional farm outside of project area) were used in this study. Four kg of soil was weighed into 4-litre plastic pot. The plastic pots had drainage holes at the bottom, which were plugged with cotton wool to prevent water loss during flooding. Two sets of trials were carried out for each soil. The treatments were designated as shown below:

Experiment 1: For exploring limiting macronutrients

The treatments were:

i. Absolute control: No nutrient added

ii. $N_{100}$ (0.05 g N/kg soil)

iii. $P_{80}$ (0.04 g P/kg soil)

iv. $K_{80}$ (0.04 g K/kg soil)

v. $N_{100} + P_{80}$

vi. $N_{100} + K_{80}$

vii. $N_{100} + P_{80} + K_{80}$

Experiment 2: For exploring limiting micronutrient

The treatments were:

i. Absolute control: No nutrient added

ii. $N_{100} + P_{80} + K_{80} + Zn_{0}$

iii. $N_{100} + P_{80} + K_{80} + Zn_{5}$ (2.5 mg Zn/kg soil)

iv. $N_{100} + P_{80} + K_{80} + Zn_{10}$ (5 mg Zn/kg soil)

v. $N_{100} + P_{80} + K_{80} + Zn_{15}$ (7.5 mg Zn/kg soil)

- The subscript numbers indicate the rate of the different nutrients in kg/ha.

The source of P was triple superphosphate (TSP) while source of N was sulphate of ammonia. Potassium was applied as potassium sulphate and zinc as zinc sulphate ($ZnSO_4.7H_2O$). With the exception of the P source, analytical reagents were used in all cases in order to minimise contamination. An absolute control treatment was included in this study to evaluate rice yields under natural fertility status. For other treatments, all nutrients except second dose of N were thoroughly mixed with the soil samples before sowing. The first dose of N was 50 kg N/ha. The treatments were replicated three times and arranged in the completely randomised design in the glasshouse.

The soils were moistened to field capacity and equilibrated for one day before sowing. Fifteen pre-germinated rice seeds (super SSD5 variety) were planted in each pot and thinned to 4 plants 14 days after planting (DAP). Water content of the soil was maintained at field capacity, 0.3 bar, for the first 21 DAP, it was determined that

100 mls of water for the first 10 days and 200 mls of water for 10-21 days were enough to maintain the field capacity. Then flooding was done. The second dose of N (50 kg N/ha) was applied 36 days after planting.

### 3.5 Harvesting of rice shoots

The plants were allowed to grow for 56 days and shoots were harvested by cutting at 1 cm above the soil surface. The shoots were dried at $70^0C$ to constant weight. The samples were weighed to obtain dry matter yield (DM), ground with a cyclone sample mill and sieved though 1-cm sieves ready for plant analysis for N, P, K and Zn. The uptake of each nutrient applied was determined by using the following expression of uptake:

Uptake (mg/pot) = Concentration of nutrient (%) X Dry matter yield (g/pot)

### 3.6 Plant analysis

Plant samples were digested using the wet oxidation procedure of Moberg (2000). 0.5g of grounded plant sample was weighed and placed into digestion tubes. 5 ml of 68% $HNO_3$ were added into each tube and the mixture was left to stand overnight. The tubes were then placed in a digestion block with temperature set at $125^0C$ for 1 hour, taken off and cooled. After cooling, 5 ml $H_2O_2$ were added into each tube and heated at $70^0C$ on the digestion block until the reaction stopped. This treatment was repeated until the digest was colourless. The digest was then heated on the digestion block at $180^0C$ to near dryness. After cooling 10 ml of 10% $HNO_3$ were added and the dissolved digest transferred quantitatively to 100 ml volumetric flask, which was filled to the mark with distilled water. The solution was analysed for P, K and Zn. Phosphorus and Zinc were determined by atomic absorption spectrophotometer at 884nm after colour development using the molybdenum blue method (Murphy and Riley, 1962), and 213.9nm respectively. Potassium was determined using a flamespectrophotometer fitted with a filter usually at 768nm. Nitrogen was determined by the micro-Kjeldahl digestion and distillation method (Bremner and Mulvaney, 1982).

### 3.7 Data analysis

The dry matter yields in response to application of N, P, K and Zn, and the uptake of these nutrients by rice plants were subjected to analysis of variance using the MSTATC computer program. The treatment means were compared using the Duncan's New Multiple Range Test.

# CHAPTER FOUR

## 4.0 RESULTS AND DISCUSSION

## 4.1 Soil fertility status of some rice growing soils of Kihurio, Ndungu, Gonja, and Kisiwani

### 4.1.1 Macronutrient contents

The macronutrient contents in the soils of the study are shown in Table 2. The data indicates wide variations in macronutrients contents of soils used in this study.

#### 4.1.1.1 Total Nitrogen

Total N values ranging from 0.04 to 0.28% (Table 2) were rated as being very low total N to low (Landon, 1991). The values of total N obtained in this study also indicates that all soils sampled from Mbugani, Ndungu and Kimunyu, and some soils from Kwahwai and Kihurio Darajani had total N below the critical level of 0.15% established by Singh *et al.* (1976) for maize in soils of Morogoro. Some of these soils, for example Mbugani, Kwahwai and Darajani are also cultivated to maize at times. Only soils from Gonja and some parts of Kwahwai had total N above this critical level. Thus use of nitrogen fertilizers is necessary for increased yields. Mnguu (1997) also reported low total N in some selected paddy growing soils of Tanzania. Semoka *et al.* (1996) also reported N deficiency in paddy soils of Morogoro. These continue to give evidence that N is limiting in many soils of Tanzania.

#### 4.1.1.2 Organic Carbon

The organic carbon data for the soils in the area studied ranged from 0.56 to 3.87%. According to Baize (1993), soils from Kwahwai and Kizerui had very high OC although in some parts of Kwahwai there were very low OC levels. Mbugani, Brani, Ndungu and Kihurio Darajani had low to medium OC, while Kimunyu soils had very low to medium OC. These levels are similar to those from other studies done in rice soils of Tabora, Morogoro, Coast and Mbeya regions (Msolla, 1991; Semoka *et al.*, 1996; Mnguu, 1997; Shekifu, 1999). Thus, many soils from these regions seem to be low in organic carbon.

#### 4.1.1.3 Phosphorus

The phosphorus content in the soils under the study is also shown in Table 2. The Bray 1 extractable P ranged from 0.80 to 15.46 mg/kg. All soils from all sites tested with Bray 1 had low P supply except one part of Kihurio Darajani (Landon, 1991). The Olsen extractable P ranged from 9.11 to 25.13 mg/kg. Based on the categories by Landon (1991), the Olsen P from these sites ranged from medium to high. Msolla (1991) reported low P in soils of Igunga and Nzega. Mnguu (1997) reported a medium to high Olsen P values for soils from some selected rice growing soils of Tanzania. It is therefore evident that P application will be necessary in the former category of soils, as well as in some soils in the later category (sections 4.4.1-4.4.3).

Table 2. The macronutrient contents in some rice growing soils of Same District

| Location | Sample No. | N % | OC % | Bray1 P (mg/kg) | Olsen P (mg/kg) | Exchangeable bases and CEC (cmol(+)/kg | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | K | Ca | Mg | Na | CEC |
| Kisiwani: | | | | | | | | | | |
| Kwahwai | 1 | 0.13 L* | 3.9 VH* | - | 9.1 M* | 0.58 H* | 26.4 | 5.6 | 1.56 | 35.2 |
| | 2 | 0.26 L | 3.7 VH | - | 25.1 H | 0.50 H | 21.9 | 4.7 | 1.43 | 34.6 |
| | 3 | 0.28 L | 0.1 VL | - | 20.5 H | 0.62 H | 23.1 | 4.8 | 1.62 | 33.4 |
| Mbugani | 1 | 0.08 VL | 1.6 M | - | 11.1 M | 0.67 H | 27.6 | 6.9 | 2.02 | 35.5 |
| | 2 | 0.11 L | 2.5 M | - | 16.9 H | 0.78 H | 27.4 | 9.2 | 1.93 | 34.2 |
| | 3 | 0.20 L | 2.7 H | - | 15.3 H | 0.77 H | 24.7 | 5.6 | 1.61 | 35.1 |
| Gonja: | | | | | | | | | | |
| Kizerui | 1 | 0.21 M | 3.3 H | 2.2 VL | - | 1.35 H | 16.5 | 4.6 | 1.81 | 26.1 |
| | 2 | 0.20 L | 3.5 VH | 1.8 VL | - | 1.59 H | 16.6 | 4.3 | 1.83 | 20.7 |
| | 3 | 0.17 L | 3.1 H | 2.7 VL | - | 1.66 H | 16.3 | 4.3 | 1.47 | 26 |
| Brani | 1 | 0.19 L | 1.5 M | 3.6 L | - | 0.44 M | 12.2 | 2.8 | 1.03 | 20.5 |
| | 2 | 0.22 M | 1.0 L | 3.1 L | - | 0.69 H | 13.3 | 2.9 | 1.12 | 14.3 |
| | 3 | 0.18 L | 1.1 L | 4.5 L | - | 0.32 M | 14.0 | 3.2 | 0.91 | 14.3 |
| Ndungu | | | | | | | | | | |
| Outside project | 1 | 0.09 VL | 1.5 M | 5.1 L | - | 0.17 L | 8.7 | 2.1 | 0.90 | 17.4 |
| | 2 | 0.05 VL | 1.0 L | 4.6 L | - | 0.14 L | 9.1 | 2.4 | 0.89 | 10.9 |
| | 3 | 0.07 VL | 1.1 L | 0.8 VL | - | 0.18 L | 9.5 | 2.2 | 1.03 | 9.2 |
| LTB 1-2 high yield | 1 | 0.08 VL | 1.8 M | 1.3 VL | - | 0.09 L | 10.9 | 1.6 | 0.39 | 10.9 |
| | 2 | 0.08 VL | 1.3 M | 4.0 L | - | 0.06 L | 4.6 | 2.4 | 0.37 | 9.2 |
| | 3 | 0.11 L | 1.0 L | 2.5 VL | - | 0.07 L | 5.0 | 1.3 | 0.39 | 6.6 |
| LTB 1-2 | 1 | 0.11 L | 2.1 M | 6.8 M | - | 0.09 L | 5.4 | 0.9 | 0.96 | 10.5 |
| low yield | 2 | 0.10 L | 2.1 M | 1.8 VL | - | 0.07 L | 3.8 | 1.4 | 0.57 | 11.8 |
| | 3 | 0.13 L | 2.3 M | 2.3 VL | - | 0.10 L | 4.4 | 1.5 | 0.50 | 9.78 |
| Kihurio: | | | | | | | | | | |
| Darajani | 1 | 0.14 L | 2.3 M | 1.8 VL | - | 0.51 H | 10.7 | 2.4 | 0.63 | 10.8 |
| | 2 | 0.15 L | 2.1 M | 1.7 VL | - | 0.60 H | 9.8 | 2.4 | 0.68 | 12.8 |
| | 3 | 0.24 M | 2.3 M | 15.5 M | - | 0.54 H | 10.5 | 2.6 | 0.70 | 13 |
| Kimunyu | 1 | 0.09 VL | 1.5 M | - | 20.8 H | - | - | - | - | - |
| (high salt) | 3 | 0.04 VL | 0.6 VL | - | 15.6 H | - | - | - | - | - |
| | 3 | 0.05 VL | 1.1 L | - | 18.1 H | - | - | - | - | - |
| Kimunyu | 1 | 0.06 VL | 1.5 M | - | 21.8 H | - | - | - | - | - |
| (low salt) | 2 | 0.08 VL | 1.5 M | - | 23.9 H | - | - | - | - | - |
| | 3 | 0.05 VL | 0.7 L | - | 20.2 H | - | - | - | - | - |

- Not determined

*Letters associated with N, OC, P and K levels are ratings according to Landon (1991), Baize (1993) or EUROCONSULT (1989) where; VL = Very Low, L = Low, M = Medium, H = High, VH = Very High

#### 4.1.1.4 Potassium

The range of exchangeable K in the area under the study was 0.06 to 1.66 cmol(+)/kg soil (Table 2). The soils from all parts of Ndungu had low exchangeable K, and the rest of soils from other locations had medium to high exchangeable K (Landon, 1991). Thus it appears that these soils with low K may require K fertilisation for optimum crop growth. Mnguu (1997) reported high exchangeable K in some selected rice growing soils of Tanzania. On the other hand, soils from Igunga and Nzega in Tabora region were similarly reported to have low exchangeable K (Msolla, 1991).

#### 4.1.1.5 Calcium, magnesium and sodium

The values of $Ca^{2+}$, $Mg^{2+}$ and $Na^{+}$ for soils tested are shown in Table 2. The ranges of these values were: $Ca^{2+}$ 3.80 to 27.62 cmol(+)/kg, $Mg^{2+}$ 0.90 to 9.2262 cmol(+)/kg, $Na^{+}$ 0.37 to 2.0262 cmol(+)/kg. The soils from Kwahwai and Mbugani were considerably richer in $Ca^{2+}$ and $Mg^{2+}$. According to Landon (1991) $Ca^{2+}$ contents in these soils are of medium to high, while $Mg^{2+}$ is of adequate level (within 3-4% of CEC). The $Na^{+}$ levels in these soils ranges from low to high (Msanya *et al.*, 1996), but all the soils with high Na were not sodic (Landon, 1991). Thus these exchangeable bases are generally not limiting to rice production.

The CEC ranged from 6.6 to 35.50 cmol(+)/kg. The soils from Kwahwai, Mbugani, and Kizerui had high CEC, and the rest of the soils had low CEC (Landon, 1991). It appears that high level of exchangeable $Ca^{2+}$, high clay contents and also high organic matter in the Kwahwai and Kizerui soils contributed to the high CEC in these soils.

Generally these results show that there were wide variations in terms of macronutrient status in the soils of the area studied. This variation was both within and between the sites. Also the fertility status of these soils may be rated as being generally on the low side.

#### 4.1.2 Soil reaction, micronutrient status and soil texture

Table 3 shows the soil reaction, micronutrient contents and textural properties of the soils of the study area.

##### 4.1.2.1 Soil pH

The soil pH ranged from 5.37 to 8.10. This pH range is categorised as medium to high (Landon, 1991). The higher pH values were obtained from Kisiwani (Kwahwai and Mbugani), and Kihurio (Darajani and Kimunyu). The pHs of most of the soils in the study area were within the satisfactory range for rice production. However, those soils with high pH levels (7-8.5) may have some fertility problems like low P and low micronutrient availability (Landon, 1991).

##### 4.1.2.2 Electrical conductivity

The electrical conductivity of these soils ranged from 0.10 to 9.50 dS/m. According to EUROCONSULT (1989), most of the soils were salt free (<4 dS/m), with the exception of Kimunyu soils which were moderately saline (8-15 dS/m). Landon (1991) pointed out that rice is of medium tolerance to salts and would not grow at 11 dS/m or above. Therefore, all soils studied were suitable for rice production, and Kimunyu soils would also be suitable when efforts to prevent further accumulation of salts are applied. In fact, farmers in Kimunyu remarked that during the season when rainfall was particularly high, with water running past the Kimunyu site (probably washing away the salts), rice yields were generally high.

#### 4.1.2.3 Micronutrient contents

The DTPA extractable Zn, ranged from 0.08 to 8.99 mg/kg. Most of the soils in the study area have Zn levels below the critical level of 1 mg/kg proposed by Landon (1991), with the exception of soils from Kwahwai, Kizerui and Brani. The soils from Ndungu under the irrigation project had Zn levels slightly below the critical range. Generally most of the soils in this study may be deficient in Zn or might become deficient in the near future if measures to correct them will not be applied. Msolla (1991) also reported low DTPA Zn contents in some rice growing soils of Igunga and Nzega in Tabora region. On the other hand, Mnguu (1997) reported higher Zn contents in some selected rice growing areas of Tanzania. The relatively higher Zn levels in Kwahwai, Kizerui, Brani and Darajani may be related to the fact that these sites are adjacent to streams flowing from high up in the mountains, which usually deposit sediments during the rains, which may enrich the soils with this element.

Table 3. Soil reaction and micronutrient contents in some rice growing soils of Same district

| Location | Sample No. | pH ($H_2O$) | EC (dS/m) | Zn (mg/kg) | Cu (mg/kg) | Fe (mg/kg) | SAND % | SILT % | CLAY % | TC |
|---|---|---|---|---|---|---|---|---|---|---|
| Kisiwani: | | | | | | | | | | |
| Kwahwai | 1 | 7.2 | 0.24 | 3.74 H* | 11.5 | 137.93 | 21 | 21 | 58 | C |
| | 2 | 7.1 | 0.23 | 3.99 H | 11.5 | 139.42 | 16 | 24 | 60 | C |
| | 3 | 7.1 | 0.25 | 4.49 H | 11.1 | 138.67 | 19 | 24 | 57 | C |
| Mbugani | 1 | 7.5 | 0.29 | 0.58 L | 6.2 | 3.9** | 23 | 10 | 67 | C |
| | 2 | 7.8 | 0.26 | 0.67 L | 7.0 | 3.4** | 27 | 12 | 61 | C |
| | 3 | 7.0 | 0.28 | 0.69 L | 7.6 | 3.9** | 25 | 12 | 63 | C |
| Gonja: | | | | | | | | | | |
| Kizerui | 1 | 6.5 | 0.13 | 2.26 H | 10.9 | 71.9 | 10 | 22 | 68 | C |
| | 2 | 6.5 | 0.12 | 2.18 H | 9.8 | 72.1 | 13 | 21 | 66 | C |
| | 3 | 6.8 | 0.11 | 1.73 H | 8.5 | 72.0 | 15 | 24 | 61 | C |
| Brani | 1 | 5.8 | 0.41 | 1.48 H | 8.0 | 148.4 | 8 | 19 | 73 | C |
| | 2 | 5.7 | 0.43 | 1.81 H | 8.6 | 148.8 | 10 | 17 | 73 | C |
| | 3 | 6.2 | 0.45 | 1.91 H | 9.9 | 148.4 | 6 | 21 | 73 | C |
| Ndungu: | | | | | | | | | | |
| Outside | 1 | 5.7 | 0.28 | 0.86 L | 6.0 | 70.2 | 43 | 8 | 49 | SC |
| project | 2 | 6.5 | 0.07 | 0.46 L | 5.6 | 70.1 | 43 | 9 | 48 | SC |
| | 3 | 5.9 | 0.06 | 0.46 L | 5.5 | 70.2 | 45 | 8 | 47 | SC |
| LTB 1-2 | 1 | 5.9 | 0.07 | 0.95 L | 4.8 | 170.9 | 65 | 14 | 21 | SCL |
| high yield | 2 | 5.8 | 0.06 | 0.64 L | 4.2 | 171.2 | 64 | 14 | 22 | SCL |
| | 3 | 5.4 | 0.05 | 0.84 L | 3.7 | 170.8 | 65 | 13 | 22 | SCL |
| LTB 1-2 | 1 | 6.0 | 0.09 | 0.84 L | 4.0 | 108.8 | 62 | 14 | 24 | SCL |
| low yield | 2 | 5.9 | 0.16 | 0.82 L | 24. | 173.6 | 62 | 14 | 24 | SCL |
| | 3 | 5.9 | 0.16 | 0.90 L | 4.9 | 173.4 | 62 | 14 | 24 | SCL |
| Kihurio: | | | | | | | | | | |
| Darajani | 1 | 6.8 | 0.16 | 1.06 H | 2.5 | 65.30 | 67 | 9 | 24 | SCL |
| | 2 | 6.9 | 0.16 | 1.19 H | 2.8 | 64.59 | 67 | 9 | 24 | SCL |
| | 3 | 7.0 | 0.13 | 1.37 H | 2.8 | 64.94 | 68 | 9 | 23 | SCL |
| Kimunyu: | 1 | 7.9 | 9.37 | 0.56 L | 4.3 | 34.2 | 26 | 9 | 65 | C |
| high salt | 3 | 8.1 | 9.20 | 0.08 L | 2.8 | 35.3 | 23 | 10 | 67 | C |
| | 3 | 8.1 | 9.93 | 0.21 L | 3.0 | 40.1 | 26 | 9 | 65 | C |
| Kimunyu: | 1 | 8.0 | 8.82 | 0.77 L | 4.7 | 36.4 | 7 | 16 | 77 | C |
| low salt | 2 | 7.9 | 8.01 | 0.66 L | 4.5 | 37.4 | 7 | 19 | 74 | C |
| | 3 | 8.0 | 8.77 | 0.46 L | 3.5 | 30.1 | 23 | 7 | 70 | C |

*Letters associated with Zn levels are ratings according to Landon (1991) where; L = Low, H = High.

**Fe levels which are rated as low according to Tandon (1995).

C: Clay

SCL: Sandy Clay Loam

SL: Sandy Loam

TC: Textural Class.

The DTPA extractable Cu ranged from 2.54 to 24.01 mg/kg. All the soils under the study have higher DTPA Cu than the critical level of 0.2 to 0.4 mg/kg reported by Tandon (1995). Thus all the soils had sufficient Cu for plant growth.

The DTPA Fe levels in the soils under the area of study ranges from 3.39 to 173.55 mg/kg. Soils from Mbugani had DTPA Fe content below the critical level of 4.5 mg/kg reported by Tandon (1995). The rest of the soils had Fe contents above this critical level. Thus, all the soils should have sufficient Fe for plants. The exception was Mbugani soil, which was deficient in Fe and required Fe application (section 4.3.2). Semoka *et al.* (1996) also reported Fe deficiency in some soils of Dakawa, Morogoro.

**4.1.2.4 Soil texture**

Soils from all parts of Ndungu and Kihurio Darajani were of medium texture while the rest were heavy textured (clayey) (Table 3). The textural properties of these soils favour rice production as pointed out by Landon (1991) and De Datta (1981) in that medium to heavy textured soils were appropriate for rice production due to their good water holding capacity and good nutrient supply.

It is concluded here that even though the physical properties of these soils are appropriate for rice production there seems to be some soil fertility constraints, with wide variations, which severely limit rice production (see section 4.2.1-3) which should be addressed.

## 4.2 Effect of N, P, and K on rice dry matter yields

### 4.2.1 Effect of N, P and K on rice dry matter yields from a Ndungu soil outside of the irrigation scheme area

The response of rice to N, P and K applied to the Ndungu soil is shown in Table 4. There was a significant ($P<0.05$) increase in dry matter yields due to application of N, P and K over the control. The control gave the lowest dry matter yield. Application of all these nutrients in combination gave higher responses than application of each nutrient singly. The highest dry matter yields (12.07 g/pot) were obtained when all the nutrients were included.

Table 4. Rice dry matter yields from a pot experiment using a soil from Ndungu

| Treatment | Dry matter yield (g/pot) |
|---|---|
| Absolute control | 2.44f |
| $N_{100}P_0K_0$ | 8.26c |
| $N_0P_{80}K_0$ | 4.34d |
| $N_0P_0K_{80}$ | 3.29e |
| $N_{100}P_0K_{80}$ | 9.46b |
| $N_{100}P_{80}K_0$ | 9.74b |
| $N_{100}P_{80}K_{80}$ | 12.07a |
| CV (%) | 5.00 |

Means in the column followed by the same letter(s) are not significantly different ($P<0.05$) according to Duncan's New Multiple Range Test.

The significant response of rice to N, P and K indicates that these nutrients were limiting at the Ndungu site. The lowest dry matter yield of the control reflects the inability of the soil to supply N, P or K, hence a reflection of low fertility status of this soil. This is because in this area rice cultivation has been undertaken for over 100 years, without use of fertilisers.

These low rice yields are also supported by the low levels of N, P and K in this soil (Table 2). The results of soil analysis (Table 2) for this soil shows that the total N content of this soil was 0.07%, which is rated as being very low according to Landon (1991). The Bray 1 extractable P value of this soil was 4.74 mg/kg which is also classified as low (EUROCONSULT, 1989). In addition the extractable K value of this soil, at 0.16 cmol(+)/kg, is very low according to Landon (1991), below the critical level of 0.26 cmol(+)/kg soil according to Jones *et al.* (1982). Therefore, the yield responses obtained upon addition of these nutrients in the present study are consistent with these low levels of the nutrients in soil.

Nitrogen gave the highest response among the single nutrients applied, indicating that N was probably the most limiting nutrient in this soil. This was expected due to low organic matter and total N levels (Table 2) which show that this soil has low N supplying capacity. Phosphorus or K in combination with N gave higher dry matter yields than those from each single nutrient. Thus, it appears that P and K were also limiting in this soil. The highest response due to application of all three nutrients together was due to better supply of all these nutrients. This is in accordance with the law of the minimum, stating that if two or more factors are limiting or nearly so, addition of one will have little effect on growth and yield, whereas provision of both or all will have a much greater influence on yields (Tisdale *et.al.*, 1993). These preliminary pot results indicate the need to undertake field studies so as to optimise use of these major nutrients (as fertilisers) to maximise rice yields in Ndungu as well as in the other sites used in the present study (section 4.2.2 and 4.2.3).

Similar responses of N and P as obtained in present study have been reported by Temu (1985) for soils of Mbarali (Mbeya region), by Semoka and Shenkalawa (1985) and Semoka *et al.* (1996) for soils of Morogoro district in Tanzania. Mzee (2001) has also reported the response of rice to P application. Mnguu (1997) reported a significant increase in dry matter yields due to K in one soil which had exchangeable K value lower than the critical limit of 0.26 cmol(+)/kg but no response in soils which had exchangeable K values higher than the critical limit. Thus, these preliminary results from the present study show that the soils of Ndungu are deficient in N, P and K, and that without use of the fertilisers supplying these elements, yields in small farmers' fields will continue to be low and possibly to continue declining.

### 4.2.2 Effect of N, P and K on rice dry matter yields from a soil in the Mbugani area of Kisiwani

The dry matter yields for Mbugani soil are presented in Table 5. Like in Ndungu soil, there were significant ($P<0.05$) increases in dry matter yields due to N, P and K.

The dry matter yields of the control was the lowest (2.98 g/pot). Application of all these nutrients together gave the highest dry matter yields (11.05 g/pot) as opposed to application of each nutrient singly. In this soil, there were smaller yield responses than in Ndungu soil though levels of NPK added were same.

Table 5. Rice dry matter yields from a pot experiment using a soil from Mbugani area, Kisiwani

| Treatment | Dry matter yields (g/pot) |
|---|---|
| Absolute control | 2.98g |
| $N_{100}P_0K_0$ | 5.83d |
| $N_0P_{80}K_0$ | 4.90e |
| $N_0P_0K_{80}$ | 4.38f |
| $N_{100}P_0K_{80}$ | 7.30c |
| $N_{100}P_{80}K_0$ | 8.04b |
| $N_{100}P_{80}K_{80}$ | 11.05a |
| CV (%) | 4.40 |

**Means in the column followed by the same letter(s) are not significantly different (P<0.05) according to Duncan's New Multiple Range Test.**

The significant increases in dry matter yields upon use of N, P and/or K show that the nutrients applied were limiting in this soil also, as was the case with the Ndungu soil (section 4.2.1). The low rice yields of the absolute control are supported by the low level of the total N content in this soil (Table 2), which ranged from 0.08 to 0.20%, and is classified as being low (Landon, 1991). However, the levels of P and K were higher than in the Ndungu soil. The Olsen P value was ranged from 11.10 to

16.90 mg/kg, which is considered adequate for rice (Landon, 1991). Also the exchangeable K was 0.67 to 0.78 cmol(+)/kg which is above the critical value of 0.26 cmol(+)/kg suggested by Jones *et al.* (1982). The smaller yields response in this soil than in Ndungu indicated that there was some other nutrient limiting yields, and it was later observed that in addition to NPK and Zn, Fe was also deficient at this site (section 4.3.2 and 4.5.2).

### 4.2.3 Effect of N, P and K on rice dry matter yields from a soil in the Kimunyu area of Kihurio

The effect of added N, P and K on rice dry matter yields from Kimunyu soil is shown in Table 6. There was a significant ($P<0.05$) increase in dry matter yields due to application of N or N in combination with P and/or K over the control. There was no significant increase in dry matter yields when K or P were applied singly. The highest dry matter yields (6.29 g/pot) were obtained when N, P and K were all included, while the control gave the lowest dry matter yields (1.90 g/pot). These dry matter yields were the lowest as compared to those from Ndungu and Mbugani.

The significant response to rice due to N alone or in combination with P and K over the control indicates that N was the most limiting nutrient in this soil. This is also reflected by the low dry matter yields of the control, which had no significant difference with the dry matter yields in treatments without N (K or P). The low levels of N and OC in this soil (Table 2) are consistent with these low yields. The soil test results in Table 2 show that the total N content of this soil was 0.06%,

Table 6. Rice dry matter yields from a pot experiment using a soil from Kimunyu, Kihurio

| Treatment | Dry matter yields (g/pot) |
|---|---|
| Absolute control | 1.90d |
| $N_{100}P_0K_0$ | 4.14bc |
| $N_0P_{80}K_0$ | 3.24cd |
| $N_0P_0K_{80}$ | 2.179d |
| $N_{100}P_0K_{80}$ | 4.98abc |
| $N_{100}P_{80}K_0$ | 5.69ab |
| $N_{100}P_{80}K_{80}$ | 6.29a |
| CV (%) | 22.84 |

Means in the column followed by the same letter(s) are not significantly different ($P<0.05$) according to Duncan's New Multiple Range Test.

which is rated as being very low while the OC of this soil, at 1.03 to 1.22%, is low according to Landon (1991).

The lack of response due to P in this soil may be due to relatively higher levels of P in this soil (Table 2). This soil had Olsen P content range of 19.41 to 21.45 mg/kg, which is rated as being high according to Landon (1991). However, the increase in dry matter yields when P and/or K when were applied in combination with N imply a greater demand of these nutrients when plants are supplied with a high level of N.

The lowest rice dry matter yields in this soil as compared to those from Ndungu and Mbugani may be due to differences in some physical chemical properties of these soils. This soil had a high pH range of 7.95 to 8.01 (Table 2) which may have affected the availability of some nutrients like P. In addition, the soil had a high EC range of 8.53 to 9.50 dS/m, which is categorised as saline (Mnkeni 1996). Rice has medium tolerance to salts (50% yield reduction with EC 10 dS/m) (Landon, 1991). Thus, presence of salts in this soil may have contributed to a general reduction of yields in this soil.

### 4.3 Effect of zinc supplementation on rice dry matter yields

#### 4.3.1 Effect of zinc on rice dry matter yields from the Ndungu soil, outside of the irrigation scheme area

Table 7 shows the dry matter yields in response to zinc application, in addition to N, P and K, to the Ndungu soil. The absolute control recorded the lowest dry matter yield. Use of Zn in addition to NPK gave higher ($P<0.05$) yields as compared to addition of only NPK. The highest dry matter yields (22.09 g/pot) were obtained when 10 kg Zn/ha was added. There was, however, a decline in dry matter yields at 15 kg Zn/ha treatment.

The significant increase in dry matter yields due to Zn addition indicates that zinc was another limiting nutrient at this site. This soil had DTPA extractable zinc of 0.60 mg/kg (Table 3) which is below the 1 mg Zn/kg suggested by Msolla (1991) to be the critical level This shows that this soil is not only deficient in N, P and K (section 4.2.1) but also deficient in zinc for optimum rice growth and maximum yields.

Table 7. Dry matter yields for experiment 2 using Ndungu soil in response to zinc application.

| Treatment | Dry matter yield (g/pot) |
|---|---|
| Absolute control | 2.27e |
| $N_{100}P_{80}K_{80}Zn_0$ | 12.20d |
| $N_{100}P_{80}K_{80}Zn_5$ | 14.94c |
| $N_{100}P_{80}K_{80}Zn_{10}$ | 22.09a |
| $N_{100}P_{80}K_{80}Zn_{15}$ | 19.00b |
| CV (%) | 2.49 |

Means in the column followed by the same letter(s) are not significantly different ($P<0.05$) according to Duncan's New Multiple Range Test.

Therefore, despite the addition of N, P and K in optimum levels, much higher yields were realised when zinc was applied in addition to NPK. Therefore, it is apparent that zinc is deficient in Ndungu soils and its supplementation is necessary in these soils to increase rice yields. The highest dry matter yields obtained at 10 kg Zn/ha suggest that this level supplied optimum amounts of zinc for improved rice growth, leading to high yields in this soil. The decline in dry matter yields at the rate of 15 kg Zn/ha may imply that this high zinc rate may not be required, or that it induced deficiency of some other nutrients. Msolla (1991) recommended a dose of 10 kg Zn/ha for rice growing soils of Tabora which, have some properties that are generally resemble those of this soil.

It is interesting to note that the problem of zinc deficiency may be widespread in Tanzania, for deficiency in Zn has been reported by Msolla (1991) in rice growing soils of Igunga and Nzega in Tabora region, by Bashiru (1992) and by Semoka *et al.* (1996) in rice growing soils of Morogoro, and now in Ndungu soils.

**4.3.2 Effect of zinc on rice dry matter yields from the Mbugani soil, Kisiwani**

Table 8 shows the response of rice to Zn application in the Mbugani soil in terms of dry matter yields. There was significant ($P<0.5$) increase in dry matter yields due to zinc application. Like in Ndungu the absolute control recorded the lowest dry matter yields. The zinc control treatment (NPK) recorded lower dry matter yields than those from the treatments where zinc was applied. Unlike Ndungu, the highest dry matter yields was obtained when the highest zinc rate (15 kg Zn/ha) was applied. However, this soil produced generally lower dry matter yields than those from the Ndungu soil.

The significant increase in dry matter yields due to zinc shows that zinc was limiting in this soil also, as was discussed for Ndungu soil. These low yields confirm the low levels of zinc in this soil (Table 3). The DTPA zinc level of this soil was 0.65 mg/kg, which is below the critical level of 1.0 mg/kg given by Msolla (1991).

The highest dry matter yields obtained due to use of 15 kg Zn/ha in this soil contrary to Ndungu soil (Section 4.3.1) may be due to differences in some physical-chemical properties of these soils (Table 3) which may have affected zinc availability. The Mbugani soils had a high pH of 7.0-7.9 and high $Ca^{2+}$ which are important factors

Table 8: Rice dry matter yield from pot experiment using Mbugani soil

| Treatment | Dry matter yield (g/pot) |
|---|---|
| Absolute control | 2.77e |
| $N_{100}P_{80}K_{80}Zn_0$ | 10.95d |
| $N_{100}P_{80}K_{80}Zn_5$ | 13.48c |
| $N_{100}P_{80}K_{80}Zn_{10}$ | 15.86b |
| $N_{100}P_{80}K_{80}Zn_{15}$ | 17.76a |
| CV (%) | 2.42 |

Means in the column followed by the same letter(s) are not significantly different ($P<0.05$) according to Duncan's New Multiple Range Test.

affecting the solubility and, hence, availability of zinc to the plants. There is a negative relationship between pH or $Ca^{2+}$ and zinc availability (Marschner, 1990; Ponnamperuma and Deturck, 1993; Prasad *et al.*, 1996). Therefore, higher zinc rates were required so as to increase the amount of zinc in soil solution after precipitation of $Zn(OH)_2$ and/or adsorption of zinc at high soil pH levels. The relatively lower yields in this soil due to application of all four nutrients together, as compared to that of Ndungu soil may be associated with the low iron content in this soil (Table 3) which was manifested by severe chlorosis that developed in all treatments during the early days of plant growth. Foliar application of 5% $FeSO_4$ corrected this chlorosis, and rice growth continued normally.

Therefore, these results show that Mbugani soils are deficient not only in zinc, in addition to N, P and K, but also are deficient in Fe.

#### 4.3.3 Effect of zinc on rice dry matter yields from the Kimunyu soil, Kihurio

The dry matter yields response of rice to zinc application in addition to N, P and K to the Kimunyu soil is shown in Table 9. The absolute control recorded the lowest dry matter yields. Zinc in addition to N, P and K gave significantly ($P<0.05$) higher dry matter yields as compared to addition of NPK only. The highest dry matter yields were obtained when the highest zinc rate (15 kg Zn/ha) was used. However, the dry matter yields obtained from this soil were generally the lowest compared to those from Ndungu and Mbugani, Kisiwani.

The significant increase in dry matter yields due to zinc indicates that zinc was limiting in this soil, as was also discussed for Ndungu and Mbugani soils. The low levels of the DTPA zinc in this soil (Table 3) also support the low yields in the absolute control and the NPK only treatment. This soil had DTPA zinc range of 0.28 to 0.63 mg/kg, which is below the critical level of 1.0 mg/kg given by Msolla (1991).

The significant increase in dry matter yields due to zinc application is due to favourable effect of zinc to rice growth in saline condition. Khan *et al.* (1992) reported that zinc enhanced absorption of K and Ca in saline and sodic conditions, hence alleviating the adverse effects of sodicity and/or salinity.

Table 9. Rice dry matter yields from pot experiment using the Kimunyu soil

| Treatment | Dry matter yield (g/pot) |
|---|---|
| Absolute control | 1.70c |
| $N_{100}P_{80}K_{80}Zn_0$ | 5.69b |
| $N_{100}P_{80}K_{80}Zn_5$ | 6.47ab |
| $N_{100}P_{80}K_{80}Zn_{10}$ | 7.00ab |
| $N_{100}P_{80}K_{80}Zn_{15}$ | 8.67a |
| CV (%) | 23.00 |

Means in the column followed by the same letter(s) are not significantly different ($P<0.05$) according to Duncan's New Multiple Range Test.

The lowest dry matter yields obtained from this soil as compared to those from Ndungu and Mbugani may be due to the fact that this soil is salt-affected as was discussed in section 4.1.2 and 4.2.3.

Khan *et al.* (1992) also reported significant increase in rice dry matter yields due to zinc application at high levels of soil salinity.

## 4.4 Effect of N, P and K on nutrient uptake by rice plants

### 4.4.1 Nutrient uptake by rice plants grown in Ndungu soil

#### 4.4.1.1 Nitrogen

The uptake of N by rice plants on Ndungu soil are shown in Table 10. The control treatment gave the lowest uptake of N (23.07 mg/pot) which did not differ significantly ($P<0.05$) from those treatments without N. Application of N significantly increased N uptake. The highest N uptake occurred when N, P and K were applied together.

Table 10. Effect of N, P and K application on nutrient uptake in Ndungu soil

| Treatment | Nutrients uptake (mg/pot) | | | | | |
|---|---|---|---|---|---|---|
| | N | P | K | Zn | Ca | Mg |
| Absolute control | 23.07d | 1.44e | 11.62e | 0.032e | 6.45c | 5.73e |
| $N_{100}P_0K_0$ | 113.5c | 5.42c | 78.83c | 0.125c | 23.8b | 18.08c |
| $N_0P_{80}K_0$ | 48.08d | 3.11d | 27.80d | 0.066d | 11.68c | 9.15d |
| $N_0P_0K_{80}$ | 34.16d | 2.08e | 34.18d | 0.051d | 10.09c | 8.10d |
| $N_{100}P_0K_{80}$ | 170.7b | 6.27c | 104.55b | 0.148b | 26.53ab | 20.11c |
| $N_{100}P_{80}K_0$ | 187.7b | 7.37b | 98.79b | 0.160b | 31.73a | 23.93b |
| $N_{100}P_{80}K_{80}$ | 257.7a | 9.28a | 129.50a | 0.185a | 32.56a | 27.70a |
| CV (%) | 18.73 | 10.66 | 9.04 | 8.53 | 19.14 | 11.83 |

Means in the column followed by the same letter(s) are not significantly different ($P<0.05$) according to Duncan's New Multiple Range Test.

The low N uptake in absolute control and in the treatments without N indicates that N availability in this soil was not adequate. The significant increase in N uptake due to N application emphasises the impact of N fertilisation on N nutrition of the crop. The higher N uptake obtained when N was applied in combination of either P or K as well as the highest N uptake when N, P and K were applied together may be due to positive interaction of N with these other nutrients (Tisdale *et al.*, 1993). The present observations also agree with the results reported by Semoka and Shenkalawa (1985) who obtained a positive interaction between N and P on N uptake in soils of

Morogoro. The N uptake trends were also consistent with the dry matter yields (Table 4) and N concentration trends in the rice shoots (Appendix 1a).

**4.4.1.2 Phosphorus**

Phosphorus uptake by rice plants is shown in Table 10. Plant P uptake ranged from 1.44 to 9.28 mg/pot. The absolute control had lowest P uptake and did not differ significantly ($P<0.05$) even when K alone was also applied. Nitrogen treatments in conjunction with P resulted in significantly higher P uptake over the control. The highest P uptake was obtained in the NPK treatment.

The lowest P uptake in the absolute control and K alone treatment is due to the fact that this soil was severely deficient in P as demonstrated by its low P content (Table 2) and low P concentration in the rice shoots (Appendix 1a). The significant increase in P uptake due to P application can be explained in terms of increased P availability for plant as a result of increased P levels in the soil. The higher P uptake where N was also applied may be due to positive interaction between N and P in P uptake whereby increase in P uptake was a result of increased N supply which increased root growth and absorbing capacity for P (Jones *et al.*, 1982). The highest P uptake obtained when N, P and K were applied in combination can be explained in terms of the combined contribution of all deficient macronutrients added to the optimum uptake of P. However, at this rate of P use there was only a slight increase in P concentration in the rice shoots (Appendix 1a). Mnguu (1997) and Mzee (2001) have reported similar results from some selected rice growing soils of Tanzania deficient in P. The P uptake trends were also consistent with the dry matter yields trends (Table 4).

#### 4.4.1.3 Potassium

Potassium uptake by rice plants from Ndungu soil is shown in Table 10. The absolute control had the lowest K uptake. All K and other treatments resulted in significant increase in K uptake over the control. The rice plants that received N in addition to K had significantly ($P<0.05$) greater K uptake than those without N. Combined N, P and K gave the highest K uptake.

The lowest K uptake in the absolute control is due to the low exchangeable K status in this soil (Table 2) that reduced K availability for plants. The significant increase in K uptake due to K application is due to increased K supply of the soil due to added K as well as favourable effect of P and N on K uptake. Highest K uptake due to application of N, P and K in combination suggest that it is important to supply adequate amount of N and P for better K uptake. This K uptake trend is also consistent with the trends of dry matter yields and K concentrations in rice shoots (Appendix 1a). Mnguu (1997) also reported significant increase in K uptake when N and K were applied together.

#### 4.4.1.4 Zinc, calcium and magnesium

The Zn, Ca and Mg uptake as influenced by N, P and K in Ndungu soil is also shown in Table 10. There was significant increase in Zn, Ca and Mg uptake when N, P and

K were used relatively to the control. The highest uptake of Zn, Ca and Mg were obtained when N, P and K were all applied together.

The significant increase in uptake of Zn, Ca and Mg over the control can be explained in terms of the increased demand for these nutrients as a result of improved plant growth due to use of N, P and K. Calcium and Mg seemed to be in adequate levels in this soil (Table 2), and the increased demand as a result of NPK use was easily met. However, Zn was deficient in this soil (Table 3) and N, P and K could not correct this deficiency (Appendix 1a). But since N, P and K together gave the highest Zn uptake, it appears that use of NPK may induce severe Zn deficiencies in this soil over time if measures to correct this deficiency, through use of Zn will not be taken into account.

### 4.4.2 Nutrient uptake in rice plants grown in Mbugani soil

#### 4.4.2.1 Nitrogen

The uptake of N in Mbugani soil due to use of N, P and K is shown in Table 11. The lowest N uptake (33.30 mg/pot) was obtained in the absolute control. Nitrogen application significantly ($P<0.05$) increased N uptake. The treatments without N had low N uptake, which did not differ significantly with that of the control. In treatments where N was used in combination with K or P, N uptake was significantly higher than when N alone was used. There was greater N uptake by rice plants in this soil than in Ndungu soil.

The low N uptake in the treatments without N illustrate that this soil could not supply adequate N for plant growth as was also reflected by the low dry matter yields in the absolute control and treatments without N (Table 5).

Table 11. Effect of N, P and K application on nutrient uptake in Mbugani soil

| Treatment | Nutrients uptake (mg/pot) | | | | | |
|---|---|---|---|---|---|---|
| | N | P | K | Zn | Ca | Mg |
| Absolute control | 33.30f | 1.78g | 31.88e | 0.028e | 7.06d | 6.02e |
| $N_{100}P_0K_0$ | 147.9d | 4.86d | 119.40c | 0.074c | 18.35bc | 20.41c |
| $N_0P_{80}K_0$ | 83.07e | 3.79e | 64.94d | 0.055d | 15.04bc | 11.97d |
| $N_0P_0K_{80}$ | 59.81ef | 2.97f | 75.53d | 0.042de | 13.15cd | 11.27d |
| $N_{100}P_0K_{80}$ | 201.2c | 5.73c | 170.9b | 0.087bc | 19.65b | 23.63c |
| $N_{100}P_{80}K_0$ | 237.2b | 8.28b | 170.0b | 0.904b | 30.29a | 28.50b |
| $N_{100}P_{80}K_{80}$ | 320.0a | 11.60a | 263.3a | 0.160a | 29.63a | 36.83a |
| CV (%) | 10.29 | 7.52 | 10.97 | 11.36 | 18.57 | 13.38 |

Means in the column followed by the same letter(s) are not significantly different ($P<0.05$) according to Duncan's New Multiple Range Test.

This is due to the fact that this soil had low N (Table 3). The significant increase in N uptake due to use of N illustrates that N fertilisation is necessary in this and other N deficient soils for optimum N uptake and yields. The highest N uptake due to application of N, P and K together indicates that adequate supply of other deficient nutrients is important for optimum N uptake. These results are consistent with the dry matter yields (Table 5) as discussed in section 4.2.2 and also with the trend of N concentrations in rice plants (Appendix 1b). The relatively higher N uptake in this soil compared to that of Ndungu is thought to be due to the relatively higher total N and OC levels in this soil (Table 2).

#### 4.4.2.2 Phosphorus

Uptake of P by rice plants in Mbugani soil is shown in Table 11. The P uptake ranged from 1.78 to 11.6 mg/pot. The absolute control had the lowest P uptake. There was significant ($p<0.05$) increase in P uptake due to use of P. The treatments that received N had significantly ($P<0.05$) higher P uptake than when P alone was applied. The treatment with N, P and K together gave the highest P uptake. The rice plants from this soil had higher P uptake than the rice plants from Ndungu.

The lowest P uptake in the absolute control indicates that P availability was low despite the presence of adequate level of Olsen P extractable P in this soil (Table 2). It appears that Olsen P is not a good index for this soil. The significant increase in P uptake due to P use confirms that P fertilisation is necessary to improve P availability to rice plants in this soil. Higher P uptake due to N application as compared to P alone may be due to favourable interaction of N and P uptake. Jones *et al.* (1982) reported that N supply increased P uptake due to its effect on root growth. The highest P uptake due application of N, P and K in combination is due to the fact that adequate supply of these nutrients in optimum levels had a positive impact in improving availability of P for plant uptake. This trend on P uptake is also consistent with the dry matter yields (Table 5) and P concentrations (Appendix 1b) of rice plants.

The relatively higher P uptake by rice plants grown in this soil compared to those of Ndungu is due to relatively higher level of extractable P in this soil than that of Ndungu. This soil had adequate Olsen extractable P while Ndungu soil had low Bray 1 extractable P according to Landon (1991).

#### 4.4.2.3 Potassium

Uptake of K by the rice plants from Mbugani soil is shown in Table 11. The absolute control recorded the lowest K uptake. Use of K significantly ($P<0.05$) increased K uptake over the control. Also, the treatments without K increased K uptake over the control. N treated rice plants had significantly taken up more K than the rice plants treated with K alone. The highest K uptake occurred when N, P and K together.

The lowest K uptake in the absolute control indicates that there is low K availability to plants in this soil. The significant increase in K uptake due to K application shows that added K increased amount of K available for plants through increased K concentration in the soil. The significant increase in K uptake in N and P but treatments without K indicates that greater availability of these nutrients improved K uptake. These results are also consistent with the dry matter yields (Table 5) and K concentrations in rice shoots (Appendix 1b).

#### 4.4.2.4 Zinc, calcium and magnesium

Table 11 shows Zn, Ca and Mg uptake by rice plants grown in Mbugani soil. The absolute control recorded the lowest uptake of all these nutrients. There was significant ($P<0.05$) increase in Zn and Ca uptake in N treated rice plants over the absolute control. On the other hand Mg uptake increased significantly ($P<0.05$) in all the treatments over the control.

The lowest Zn, uptake in the absolute control appears to be caused by low Zn level in the soil (Table 3). The significant increase in Zn and Ca uptake due to N application and the significant increase in Mg uptake due to N, P and K over the control is thought to be due to better utilisation of these nutrients upon use upon N, P or K. These results are consistent with the dry matter yield trends (Table 5).

### 4.4.3 Nutrient uptake in rice plants grown in Kimunyu soil of Kihurio.

#### 4.4.3.1 Nitrogen

The N uptake by rice plants grown in Kimunyu soil is shown in Table 12. The absolute control treatment had lowest N uptake, which was not significantly ($P<0.05$) different from that in treatments without N. Nitrogen increased N uptake only slightly. Significant ($P<0.05$) increase in N uptake was obtained when N or P, or N, P and K were applied together. Rice plants grown in this soil took up less N than those grown in Ndungu and Mbugani.

The lowest N uptake in the absolute control and the lack of significant differences with treatments without N, shows that this soil could not supply N for optimum plant growth. This is consistent with low total N and OC in this soil (Table 2), which is a typical feature of saline and sodic soil (Mnkeni, 1996). Slight increases in N

Table 12. Effect of N, P and K application on nutrient uptake in Kimunyu soil

| Treatment | Nutrients uptake (mg/pot) | | | | | |
|---|---|---|---|---|---|---|
| | N | P | K | Zn | Ca | Mg |
| Absolute control | 14.35c | 0.84d | 14.85d | 0.020c | 7.55e | 5.57b |
| $N_{100}P_0K_0$ | 56.95b | 1.90bcd | 60.98b | 0.066ab | 9.73bc | 6.55b |
| $N_0P_{80}K_0$ | 24.84c | 2.20cd | 24.80c | 0.045b | 11.93bcd | 7.96ab |
| $N_0P_0K_{80}$ | 17.82c | 1.25c | 28.51cd | 0.027c | 8.17e | 5.67b |
| $N_{100}P_0K_{80}$ | 59.16b | 2.80b | 78.46a | 0.068a | 14.45bc | 9.03ab |
| $N_{100}P_{80}K_0$ | 77.25ab | 4.87a | 72.08ab | 0.066a | 14.70b | 11.24a |
| $N_{100}P_{80}K_{80}$ | 88.46a | 5.24a | 78.75a | 0.069a | 17.72a | 8.59ab |
| CV (%) | 26.31 | 25.75 | 14.41 | 11.20 | 12.52 | 25.60 |

Means in the column followed by the same letter(s) are not significantly different ($P<0.05$) according to Duncan's New Multiple Range Test.

uptake due to N application indicate that N fertilisation is necessary in this soil, although it appears that there might be some factors that reduce its availability. The significant increase in N uptake due to NP as well as NPK is due to positive interaction of N and P as explained by Semoka and Shenkalawa (1985), and also due to favourable effect of K in saline and sodic soils (Mnkeni, 1996). These results are also consistent with the N concentrations in the rice shoots (Appendix 1c) where all the treatments except the one which received N, P and K together, had N concentrations below the critical level of 1.8 to 2.5% suggested by Wallihan *et al.* (1974).

#### 4.4.3.2 Phosphorus

The P uptake by rice plants from Kimunyu soil is shown in Table 12. The P uptake by the rice plants from the absolute control was the lowest. There was a significant ($P<0.05$) increase in P uptake over the control when P was applied in combination with N. The P uptake by rice in this soil is lowest compared to those in Ndungu and Mbugani.

The low P uptake by rice plants in the absolute control indicates that this soil had low P, which was available for plant absorption despite its high Olsen P (Table 2). It appears that Olsen P is not a good index for this soil. The slight increase in P uptake due to application of P alone, which did not differ significantly with the absolute control, also indicates that there is a problem of low P availability in this soil. The significant increase in P uptake due to application of P in combination with N can be explained in terms of improved utilisation of P when N was adequate.

The lowest P uptake of rice plants from this soil compared to those in Ndungu and Mbugani may also be due to some chemical properties of this soil that differ from those of the other soils. The high pH reduces P availability, and the high EC (salinity) hinders P uptake due to excess uptake of $Cl^-$, causing nutrient imbalances and decreased uptake of phosphate (Abro *et al.*, 1988). These results are also consistent with the trends of dry matter yields (section 4.2.3) and the P concentrations (Appendix 1c), where all the treatments gave P concentration below the critical level of 0.1% established by Tanaka and Yoshida (1970).

#### 4.4.3.3 Potassium

The uptake of K by the rice plants from Kimunyu soil is as shown in Table 12. The absolute control treatment gave the lowest K uptake. The treatment that received N had significantly ($P<0.05$) more K uptake than the K alone treatment.

The lowest K uptake in the absolute control again indicates that this soil could not supply adequate amount of K for plant growth. This is reflected by the K concentration levels in the rice shoots (Appendix 1c). The significant increase in K uptake due to N application over the K alone can be explained in terms of positive interaction between N and K that influences K uptake. Tisdale *et al.* (1993) reported that there was greater potential for response to K (and other nutrients) when supply of N was adequate than if N was deficient.

Similar findings were reported by Bohra and Doerffling (1993) who observed increases in K uptake by rice with increasing K levels in saline soils using both salt sensitive and salt tolerant rice varieties.

#### 4.4.3.4 Zinc, calcium and magnesium

Table 12 shows Zn, Ca and Mg uptake by rice plants grown in the Kimunyu soil. The absolute control recorded the lowest uptake of these nutrients. The rice plants that received N, P and K together had highest Zn, Ca and Mg uptake.

Lack of significant increase in the uptake of these nutrients due to N, P and K suggest that added N, P and K does not increase the availability of Zn, Ca and Mg from the native pools. This is reflected by the low concentrations of Zn, Ca, and Mg in the rice shoots (Appendix 1c), where Zn concentrations were below the critical limit of 15 to 20 mg/kg established by Tandon (1995). On the other hand, Ca and Mg concentration were in sufficient levels based on the critical levels of 0.15 and 0.1 for Ca and Mg, respectively, reported by Tanaka and Yoshida (1970).

### 4.5 Effect of zinc on the nutrient uptake of the rice plant

#### 4.5.1 Effect of zinc on nutrient uptake by rice plants grown in Ndungu soil

##### 4.5.1.1 Zinc

Table 13 shows the nutrient uptake by rice plants grown on the Ndungu soil. The absolute control had the lowest Zn uptake and Zn concentration in the rice shoots. The Zn control treatment had significantly ($P<0.05$) higher zinc uptake than the absolute control. There was significant increase in Zn uptake at each level of Zn added over the absolute control and the zinc control. The rice shoot Zn concentrations also followed the similar trend.

The lowest Zn uptake in the absolute control indicates a low supply of Zn in this soil (Table 3). The increase in Zn uptake in the Zn control treatment shows that N, P and K enhance plant ability to take up more Zn. However, the Zn concentration in the rice shoots in the absolute and the Zn control was below the critical concentration of 20 mg/kg established by Katyal and Vlek (1985), thereby confirming that this soil

Table 13. Effect of zinc on nutrient uptake and zinc concentrations by the rice plant

| Treatment | Zn uptake (mg/pot) | Zn concentration (mg/kg) | Nutrients uptake (mg/pot) | | | | |
|---|---|---|---|---|---|---|---|
| | | | N | P | K | Ca | Mg |
| Absolute control | 0.03d | 12.47c | 24.6e | 1.3e | 11.4e | 8.6c | 5.9c |
| $N_{100}P_{80}K_{80}Zn_0$ | 0.19c | 14.62c | 187.5d | 9.2d | 134.9d | 24.8b | 23.5b |
| $N_{100}P_{80}K_{80}Zn_5$ | 0.31b | 20.09b | 221.2c | 11.3c | 159.2c | 32.2b | 28.6b |
| $N_{100}P_{80}K_{80}Zn_{10}$ | 0.45a | 20.22b | 262.8b | 16.2a | 237.3a | 38.8ab | 38.5a |
| $N_{100}P_{80}K_{80}Zn_{15}$ | 0.49a | 25.66a | 330.0a | 13.9b | 204.9b | 49.5a | 39.1a |
| CV (%) | 12.54 | 8.55 | 7.03 | 7.05 | 3.52 | 25.85 | 10.62 |

Means in the column followed by the same letter(s) are not significantly different ($P<0.05$) according to Duncan's New Multiple Range Test.

was deficient in Zn and that NPK alone could not increase Zn availability to the optimum level.

The significant increase in Zn uptake at each level of Zn applied indicates that Zn is necessary in addition to NPK in this soil. The Zn treated rice plants also had increased Zn concentration to the range of 20.09 to 25.66 mg/kg, which is above the critical concentration of 20 mg/kg established by Katyal and Vlek (1985). The increased Zn uptake is also consistent with the increased dry matter yields except at 15 kg Zn/ha rate, which resulted in highest Zn concentration but a decline in dry matter yields.

Several workers have reported increase in Zn uptake and concentration upon Zn application. Msolla (1991) reported significant increase in Zn uptake and concentration at 5 and 10 mg Zn/kg in Zn deficient soils of Igunga and Nzega. Semoka *et al.* (1996) reported similar results in some selected soils of Morogoro. In India, Trivedi *et al.* (1998) also reported significant increase in Zn uptake at each successive Zn levels up to 11.2 kg Zn/ha.

#### 4.5.1.2 Nitrogen, phosphorus, potassium, calcium and magnesium

Table 13 shows the uptake of N, P K, Ca and Mg in rice plants from the Ndungu soil as affected by Zn. The absolute control had the lowest uptake of each of these nutrients. There was significant ($P<0.05$) increase in the uptake of N due to zinc application together with NPK, over the Zn control. However, there was a significant ($P<0.05$) decrease in P and K uptake at the level of 15 kg Zn/ha. There was no significant effect of Zn on Ca uptake. Significant increase in Mg uptake was only realised at 10 and 15 kg Zn/ha.

The lowest uptake of N, P and K in the absolute control continues to show that this soil was deficient in these nutrients. This is due to the fact that this soil had low levels of N, P and K (Table 2). This is also comparable with the concentrations of these nutrients in the absolute control (Appendix 2a) which were all below the critical levels of 1.8 to 2.5% for N, 0.1% for P and 1% for K established by Mikkelsen (1971), thus confirming that these nutrients were deficient. However, the lowest uptake of Ca and Mg in the absolute control are not consistent with their concentration in the rice shoots. This may be due to the fact that these nutrients were present in sufficient levels in this soil (Table 2).

The significant increase in N uptake due to Zn application together with NPK can be explained in terms of the synergistic effect of NPK added as discussed in section 4.3.1. The significant decrease in P and K uptake at 15 kg Zn/ha may be due to induced nutrient imbalances or antagonism due to high zinc concentration obtained under this treatment. This may also account for the slight decrease of shoot N, P and K concentrations (Appendix 2a; Tisdale *et al.*, 1993).

Mzee (2001) also reported significant decrease in K uptake due to Zn, and lack of a significant effect of Zn on Ca and Mg uptake in some selected rice growing areas of Tanzania.

### 4.5.2 Effect of Zn on nutrient uptake by rice plants from Mbugani soil

#### 4.5.2.1 Zinc

The nutrient uptake by rice plants as influenced by Zn is shown in Table 14. The absolute control recorded the lowest Zn uptake and concentration in the rice shoots. The Zn control treatment had significantly ($P<0.05$) higher Zn uptake and concentration over the absolute control. Application of different levels of Zn significantly ($P<0.05$) increased Zn uptake and Zn shoot concentration over the absolute control and Zn control treatments. The amount of Zn taken up by rice plants from this soil was relatively lower than that from Ndungu.

The lowest Zn uptake and Zn concentration in rice shoots from this soil indicates that this soil could not supply enough Zn for plant growth due to low level of Zn in this soil (Table 3). This soil had DTPA Zn of 0.58 to 0.69 mg/kg, which is considered deficient as it is below the critical level of 1 mg/kg reported by Msolla (1991). The significant increase in Zn uptake due to NPK over the absolute control suggests that these macronutrients contributed to increased Zn uptake by plants due to their positive effect on growth. The lower Zn concentrations in the absolute control and Zn control, below the critical level of 15 to 20 mg/kg for rice reported by Tandon (1995), confirms that this soil was deficient in Zn, which could not be corrected by application of NPK alone.

The significant increase in Zn uptake and concentration due to Zn addition shows that zinc deficiency in this soil can be corrected through Zn application. Added Zn may have resulted in increased Zn availability by increasing soil Zn level, hence increased uptake. The Zn treated rice plants had shoot Zn concentration above the critical concentration of 15 to 20 mg/kg in rice reported by Tandon (1995). These results are consistent with the dry matter yields (Table 5).

The relatively lower Zn uptake and concentration in the rice plant from this soil as compared to those from Ndungu might have been brought by differences in physical and chemical properties that affect Zn availability to plants as discussed in section 4.3.2.

Table 14. Effect of zinc on nutrient uptake and zinc concentrations by the rice plant from Mbugani soil

| Treatment | Zn uptake (mg/pot) | Zn concentration (mg/kg) | Fe uptake (mg/pot) | Fe concentration (mg/kg) | Nutrients uptake (mg/pot) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | N | P | K | Ca | Mg |
| Absolute control | 0.03d | 10.80c | 4.81c | 719.7b | 39.63b | 1.95c | 35.52c | 9.43c | 8.00b |
| $N_{100}P_{80}K_{80}Zn_{0}$ | 0.14c | 13.08bc | 8.69bc | 1639.0a | 274.50a | 12.08b | 278.20ab | 29.36b | 36.99a |
| $N_{100}P_{80}K_{80}Zn_{5}$ | 0.22b | 15.34ab | 13.64ab | 1011.0ab | 281.30a | 13.01b | 236.80b | 44.72ab | 39.56a |
| $N_{100}P_{80}K_{80}Zn_{10}$ | 0.29a | 18.14a | 14.63a | 920.4ab | 355.7a | 15.26a | 304.70a | 40.16ab | 41.80a |
| $N_{100}P_{80}K_{80}Zn_{15}$ | 0.32a | 18.19a | 12.08ab | 833.8ab | 273.9a | 15.38a | 275.80ab | 49.54a | 41.40a |

Means in the column followed by the same letter(s) are not significantly different ($P<0.05$) according to Duncan's New Multiple Range Test

#### 4.5.2.2 Iron

The iron uptake by rice plants and concentration are shown in Table 14. Since uniform yellowing and stunted growth was observed in all rice plants from all the treatments during early days of growth, which was later diagnosed as Fe deficiency, and since Fe was not included in the treatments, Fe was sprayed uniformly in all the treatments. The absolute control recorded the lowest Fe uptake and concentration. There was an increase in Fe uptake due to NPK and Zn over the control.

The increased Fe uptake due to application of NPK and Zn illustrates that these nutrients enhanced Fe uptake. These preliminary findings indicate the need for further research to address the Fe deficiency as well as the response of rice to Fe supplementation in this site.

#### 4.5.2.3 Nitrogen, phosphorus, potassium, calcium and magnesium

The N, P, K, Ca and Mg uptake by rice plants from Mbugani soil are shown in Table 14. The rice plants from the absolute control had the lowest uptake of these nutrients. Zinc applications in addition to NPK slightly increased N and P uptake. The P uptake was significantly ($P<0.05$) increased at higher Zn rate (10 and 15 kg Zn/ha) over the Zn control. There was no significant effect of Zn on Ca and Mg uptake over the Zn control treatment.

The lowest N, P and K uptake in the absolute control shows that the availability of these nutrients is limited in this soil as discussed in section 4.3.2. This is also comparable to the concentration of these nutrients in rice shoots (Appendix 2b). The lowest Ca and Mg uptake in the absolute control is contrary to their concentrations in the shoots (Appendix 2b) probably because of low dry matter yields.

The significant increase in P uptake due to Zn application at 10 and 15 kg Zn/ha may be due to the fact that this soil had a relatively higher P level (Table 2) and relatively lower Zn availability as discussed above. Thus, the positive effect of Zn on growth might have favoured greater P uptake.

### 4.5.3 Effect of zinc on nutrient uptake by rice plants from Kimunyu soil

#### 4.5.3.1 Zinc

Zinc uptake and Zn concentration as influence by addition Zn are shown in Table 15. The absolute control had the lowest Zn uptake and shoot Zn concentration. Application of Zn significantly ($P<0.05$) increased uptake of Zn by rice over the absolute control, but only slightly over the Zn control. The significant increase in Zn uptake over the Zn control was realised at the rate of 15 kg Zn/ha. The Zn concentration in rice shoots significantly increased at each successive level of Zn.

The lowest Zn uptake and concentration in the rice plants from the absolute control indicates that this soil could not supply adequate Zn for plant growth. This was because this soil has low DTPA extractable Zn (Table 3). This was further confirmed by the low Zn concentration in the rice shoots from the absolute control and Zn control which were 9.31 and 10.31 mg/kg, respectively, and which were lower than the critical range of 15-20 mg/kg reported by Tandon (1995). The significant increase in Zn uptake due to Zn application over the absolute control indicates that this soil was, indeed, Zn deficient and required Zn to be added. The non significant increase in Zn uptake over the Zn control at Zn levels below 15 kg Zn/ha suggest that higher Zn levels may be required in this soil for better growth and yields of rice. The Zn treated rice plants had significantly higher Zn concentration to the range 16.31 to 23.84 mg/kg which is above the critical range of 15 to 20 mg/kg reported by Tandon (1995), confirming the need for zinc in this soil.

Table 15. Effect of zinc on nutrient uptake and zinc concentrations by the rice plant from Kimunyu soil

| Treatment | Zn uptake (mg/pot) | Zn concentration (mg/kg) | Nutrients uptake (mg/pot) | | | | |
|---|---|---|---|---|---|---|---|
| | | | N | P | K | Ca | Mg |
| Absolute control | 0.02d | 9.31d | 13.65d | 0.44c | 14.85b | 8.82b | 5.52c |
| $N_{100}P_{80}K_{80}Zn_0$ | 0.06c | 10.31d | 77.69bc | 4.94ab | 73.96a | 17.46b | 10.92b |
| $N_{100}P_{80}K_{80}Zn_5$ | 0.11bc | 16.32c | 70.39c | 4.23b | 69.74a | 22.35a | 15.28b |
| $N_{100}P_{80}K_{80}Zn_{10}$ | 0.14b | 19.49b | 86.15b | 5.39a | 88.44a | 13.98b | 13.43b |
| $N_{100}P_{80}K_{80}Zn_{15}$ | 0.21a | 23.84a | 113.10a | 5.49a | 95.10a | 22.21a | 21.57a |
| CV (%) | 12.95 | 22.22 | 9.53 | 23.51 | 22.21 | 14.63 | 18.32 |

**Means in the column followed by the same letter(s) are not significantly different (P<0.05) according to Duncan's New Multiple Range Test.**

### 4.5.3.2 Nitrogen, phosphorus, potassium, calcium and magnesium

The data for N, P, K Ca and Mg uptake by rice plants from this soil are shown in Table 15. The absolute control recorded the lowest uptake of these nutrients. Zn at 5 or 10 kg Zn/ha led to only a slight increase in N, P and K uptake over the Zn control. At 15 kg Zn/ha there was a significant ($P<0.05$) increase in N uptake over the Zn control. There was no significant increase in Ca uptake over the Zn control.

The lowest N, P and K uptake by rice plants from the absolute control shows that the availability of these nutrients was low as discussed in section 4.4.3. The slight increase in N, P and K uptake over the N control may be due to favourable effect of Zn in saline soils as was also observed by Khan *et al.* (1992). The non-significant effect of Zn on Ca and Mg uptake may mean that probably there are no interactions among these nutrients. The trends of these results are comparable to those of shoot nutrient concentration (Appendix 2c).

# CHAPTER FIVE

## 5.0 CONCLUSIONS AND RECOMMENDATIONS

### 5.1 Summary and conclusions

The results indicated that most of the soils sampled had low total N, and 53% of soils were deficient in P, while all the soils had adequate levels of exchangeable bases, although soils from Ndungu had low K supply. Also, most of the soils had marginal to low levels of Zn, but all had adequate levels of Cu and Fe with the exception of Mbugani soil which had low Fe content. However, all the soils had suitable physical conditions for rice cultivation.

Application of N, P or K generally increased rice dry matter yields from all the soils tested in glasshouse experiments, and the application of all three nutrients together gave the highest dry matter yields. Zinc application in addition to NPK further increased rice dry matter yields in all the soils. The Zn application at 15 kg Zn/ha level resulted in highest rice dry matter yields from soils of Mbugani and Kimunyu but not Ndungu. The study also showed that increased uptake of each nutrient applied was consistent with the rice dry matter yields.

From the results of the present study, it was tentatively concluded that:

1. Among the macronutrients N, P and K were the major soil fertility constraints in the soils studied that are responsible for low rice yields.
2. There were micronutrient deficiencies in the area studied, whereby most of the soils had low Zn levels, and Mbugani soils were also deficient in Fe, which also limits rice yields.

3. Application of N, P, K as well as Zn supplementation (in addition to NPK) is necessary in these areas for improvement of rice growth and yields; also Fe supplementation is important for the case of Mbugani.

## 5.2 Recommendations

From the findings of the present study, the following are recommended:

i. Field experiments should be carried out to confirm the results of the present study, that may ultimately lead to the development of site specific fertiliser recommendations for N, P, K and Zn so as to improve soil fertility for rice production.

ii. Further research is recommended on the effect of Fe supplementation on rice yields for the soils of Mbugani

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## APPENDICES

Appendix 1. Effect of N, P and K application on nutrient concentrations of rice plants

Appendix 1a. Effect of N, P and K application on nutrient concentrations in plants from Ndungu soil

| Treatment | Nutrients concentration | | | | | |
|---|---|---|---|---|---|---|
| | N(%) | P(%) | K(%) | Zn(mg/kg) | Ca(%) | Mg(%) |
| Absolute control | 0.95d | 0.059d | 0.47d | 14.11b | 0.26a | 0.24a |
| $N_{100}P_0K_0$ | 1.78b | 0.066bcd | 0.95b | 15.00ab | 0.29a | 0.22a |
| $N_0P_{80}K_0$ | 1.11d | 0.072bc | 0.64c | 15.35ab | 0.27a | 0.21a |
| $N_0P_0K_{80}$ | 1.03d | 0.063cd | 1.04ab | 14.70ab | 0.31a | 0.25a |
| $N_{100}P0K_{80}$ | 1.79b | 0.063abcd | 1.11a | 15.65ab | 0.27a | 0.21a |
| $N_{100}P_{80}K_0$ | 1.91ab | 0.075ab | 1.06ab | 16.49a | 0.33a | 0.25a |
| $N_{100}P_{80}K_{80}$ | 2.14a | 0.077a | 1.073ab | 16.19a | 0.27a | 0.23a |

Means in the column followed by the same letter(s) are not significantly different (P<0.05) according to Duncan's New Multiple Range Test.

Appendix 1b. Effect of N, P and K application on nutrient concentrations in plants from Mbugani soil

| Treatment | Nutrients uptake (mg/pot) | | | | | |
|---|---|---|---|---|---|---|
| | N(%) | P(%) | K(%) | Zn(mg/kg) | Ca(%) | Mg(%) |
| Absolute control | 1.12d | 0.61d | 1.09d | 9.21d | 0.24b | 0.21c |
| $N_{100}P_0K_0$ | 2.54b | 0.84b | 2.05ab | 11.58bcd | 0.32ab | 0.35a |
| $N_0P_{80}K_0$ | 1.69c | 0.77bc | 1.439cd | 11.23bcd | 0.27ab | 0.24c |
| $N_0P_0K_{80}$ | 1.37d | 0.68cd | 1.73bc | 9.65cd | 0.30ab | 0.26bc |
| $N_{100}P_0K_{80}$ | 2.77ab | 0.78bc | 2.34a | 13.9ab | 0.27ab | 0.32ab |
| $N_{100}P_{80}K_{80}$ | 2.92a | 1.029a | 2.12ab | 12.60abc | 0.38a | 0.36a |
| $N_{100}P_{80}K_{80}$ | 2.89a | 1.05a | 2.38a | 15.28a | 0.27ab | 0.33a |

Means in the column followed by the same letter(s) are not significantly different (P<0.05) according to Duncan's New Multiple Range Test.

Appendix 1c. Effect of N, P and K application on nutrient concentrations in plants from Kimunyu soil

| Treatment | Nutrients uptake (mg/pot) | | | | | |
|---|---|---|---|---|---|---|
| | N(%) | P(%) | K(%) | Zn(mg/kg) | Ca(%) | Mg(%) |
| Absolute control | 0.74c | 0.44a | 0.69c | 9.88a | 0.51a | 0.33a |
| $N_{100}P_0K_0$ | 1.44ab | 0.46a | 0.96bc | 10.66a | 0.45ab | 0.17b |
| $N_0P_{80}K_0$ | 0.75c | 0.67a | 0.72c | 13.90a | 0.41ab | 0.25ab |
| $N_0P_0K_{80}$ | 0.79bc | 0.57a | 1.25ab | 12.31a | 0.38ab | 0.27ab |
| $N_{100}P_0K_{80}$ | 1.13bc | 0.60a | 1.38ab | 12.97a | 0.32ab | 0.18ab |
| $N_{100}P_{80}K_0$ | 1.35bc | 0.91a | 1.26ab | 11.27a | 0.24b | 0.24ab |
| $N_{100}P_{80}K_{80}$ | 2.03a | 0.83a | 1.65a | 14.66a | 0.24b | 0.16b |

Means in the column followed by the same letter(s) are not significantly different (P<0.05) according to Duncan's New Multiple Range Test.

Appendix 2. Effect of Zinc application on nutrient concentrations of rice plants

Appendix 2a: Effect of Zinc application on nutrient concentrations of rice plants grown in Ndungu soil

| Treatment | Nutrients concentration | | | | | |
|---|---|---|---|---|---|---|
| | N(%) | P(%) | K(%) | Zn(mg/kg) | Ca(%) | Mg (%) |
| Absolute control | 1.085b | 0.056b | 0.499b | 13.76c | 0.376a | 0.266a |
| $N_{100}P_{80}K_{80}Zn_0$ | 1.330ab | 0.076a | 1.106b | 15.65c | 0.203b | 0.193b |
| $N_{100}P_{80}K_{80}Zn_5$ | 1.482ab | 0.075a | 1.066a | 20.49b | 0.203b | 0.191b |
| $N_{100}P_{80}K_{80}Zn_{10}$ | 1.610a | 0.073a | 1.078a | 20.21b | 0.176b | 0.175b |
| $N_{100}P_{80}K_{80}Zn_{15}$ | 1.528a | 0.073a | 1.074a | 25.66a | 0.261b | 0.206b |

Means in the column followed by the same letter(s) are not significantly different (P<0.05) according to Duncan's New Multiple Range Test.

Appendix 2b. Effect of Zinc application on nutrient concentration of rice plants grown in Mbugani soil

| Treatment | Nutrients concentration | | | | | |
|---|---|---|---|---|---|---|
| | N(%) | P(%) | K(%) | Zn(mg/kg) | Ca(%) | Mg (%) |
| Absolute control | 1.412c | 0.007c | 1.46b | 10.80c | 0.34a | 0.292ab |
| $N_{100}P_{80}K_{80}Zn_0$ | 2.508a | 0.111a | 2.54a | 13.08bc | 0.27a | 0.13a |
| $N_{100}P_{80}K_{80}Zn_5$ | 2.088ab | 0.097b | 1.76b | 15.34ab | 0.33a | 0.29ab |
| $N_{100}P8_{80}K8_{80}Zn_{10}$ | 2.240a | 0.096b | 1.92b | 18.14a | 0.25a | 0.26b |
| $N_{100}P_{80}K_{80}Zn15$ | 1.540bc | 0.087b | 1.50b | 18.19a | 0.28a | 0.23b |

Means in the column followed by the same letter(s) are not significantly different (P<0.05) according to Duncan's New Multiple Range Test.

Appendix 2c. Effect of Zinc application on nutrient concentrations of rice plants grown in Kimunyu soil

| Treatment | Nutrients concentration | | | | | |
|---|---|---|---|---|---|---|
| | N(%) | P(%) | K(%) | Zn(mg/kg) | Ca(%) | Mg (%) |
| Absolute control | 0.45c | 0.022b | 0.89a | 9.31d | 0.81a | 0.52a |
| $N_{100}P_{80}K_{80}Zn_0$ | 1.37ab | 0.068a | 1.25a | 10.31d | 0.50a | 0.29ab |
| $N_{100}P_{80}K_{80}Zn_5$ | 1.19b | 0.072a | 1.13a | 16.32c | 0.51a | 0.37ab |
| $N_{100}P8_{80}K8_{80}Zn_{10}$ | 1.38ab | 0.078a | 1.31a | 19.49b | 0.31a | 0.19b |
| $N_{100}P_{80}K_{80}Zn15$ | 1.80a | 0.074a | 1.10a | 23.84a | 0.39a | 0.38ab |

Means in the column followed by the same letter(s) are not significantly different (P<0.05) according to Duncan's New Multiple Range Test.