ASSESSMENT OF SOIL FERTILITY STATUS OF SELECTED PADDY GROWING AREAS OF TANZANIA

BY

YOUZE ORGENESS MNGUU

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT FOR THE DEGREE OF MASTER OF SCIENCE (SOIL SCIENCE AND LAND MANAGEMENT) OF SOKOINE UNIVERSITY OF AGRICULTURE

ABSTRACT

Nitrogen, phosphorus, zinc and iron deficiency or limited availability are the main soil fertility constraints limiting rice yield worldwide. The objective of this study was to develop diagnostic criteria for assessing the fertility status of the selected rice growing areas of Tanzania in terms of the availability of the above nutrients. Soil samples were collected from 10 different areas where rice is grown for both laboratory analyses and a glasshouse experiment. The laboratory analyses included the screening of suitable indices for available N, P, Zn and Fe in soils. Nitrogen availability was assessed by total N, OC and the alkaline-$KMnO_4$ indices, P by Bray-1, Olsen and the filter paper strip methods while available Zn and Fe were assessed by 0.1N HCl, 0.005M DTPA at pH 7.3 and 0.01M EDTA-$(NH_4)_2CO_3$ at pH 8.6. The response of rice (*Oryza sativa* L) variety Super India to these nutrients was assessed in a glasshouse experiment where plants were grown for 51 days.

The results showed that all the soils used in this study were deficient in N and hence required fertilization with N while 60% of the soils responded to P application. All the soils had adequate levels of K and Zn although three of the soils appeared to be borderline cases between

adequate and deficient. The extractable Fe content was very high in all soils. Of the nutrient availability indices tested, OC correlated significantly with the DM yield while Olsen extractable P was found suitable for P assessment with a critical level of 20 mg/kg soil. None of the indices tested was found suitable for Zn and Fe assessment.

Basing on these results, OC and Olsen methods were recommended for use in assessing N and P availability in the soils, respectively. No reliable extractant for micronutrients Zn and Fe was obtained in this study. Field experiments are recommended to confirm these findings.

DECLARATION

I, YOUZE ORGENESS MNGUU, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is a result of my original work and that it has never been submitted for a degree award in any other University.

Signature _____

Date 28/12/17

COPYRIGHT

ACKNOWLEDGEMENTS

The author is indebted to all individuals who in one way or another facilitated the accomplishment and success of this study. Since it is not possible to mention their names, I wish to extend to them my sincere acknowledgments.

Special thanks should go to my supervisor, Prof. J.M.R. Semoka for his tireless guidance and encouragement throughout the period of this study. His readiness for help has been the key to the success of this study.

My appreciation also goes to the Ministry of Agriculture Livestock Development and Cooperatives for granting a study leave and to the Sokoine University of Agriculture and NORAD for their joint financial support during my study.

I am also grateful to all technical staff in the Soil Science Laboratory of Sokoine University of Agriculture for their assistance during the analytical part of the study. Messrs Malekela, Shamte, Salum and Miss Kafui and Mrs Mhaiki deserves special thanks.

Lastly, I wish to thank all extension staff, project leaders and farmers for allowing me to collect soil samples from their farms and for their assistance in soil sampling.

TABLE OF CONTENTS

Page

ABSTRACT ii

DECLARATION iii

COPYRIGHT v

ACKNOWLEDGEMENTS vi

TABLE OF CONTENTS viii

LIST OF TABLES xii

LIST OF FIGURES xiv

LIST OF APPENDICES xv

LIST OF ABBREVIATIONS xvi

1.0 INTRODUCTION. 1

2.0 LITERATURE REVIEW. 6

2.1 Nutrients availability and their deficiency symptoms 6

2.1.1 Nitrogen 6

2.1.2 Phosphorus 8

2.1.3 Potassium 9

2.1.4 Zinc 11

2.1.5 Iron 12

2.2 Testing for availability of plant nutrients 14

2.2.1 Soil Testing 14

2.2.1.1 Nitrogen 15

2.2.2.2 Phosphorus 20

2.2.1.3 Potassium 23

Page

2.2.1.4 Zinc 24

2.2.1.5 Iron 31

2.2.2 Plant analysis 32

2.4 Rice response to nitrogen, phosphorus, potassium, zinc and iron 34

2.4.1 Nitrogen 34

2.4.2 Phosphorus 36

2.4.3 Potassium 37

2.4.4 Zinc 38

2.4.5 Iron 38

3.0 MATERIALS AND METHODS 40

3.1 Materials 40

3.1.1 Soils 40

3.1.2 Test crop 40

3.1.3 Fertilizers 40

3.2 Methodology 42

3.2.1 Soil sampling and sample preparation 42

3.2.2 Laboratory analysis 42

3.2.2.1 Soil analysis 42

3.2.2.2 Plant analysis 43

3.3 Nutrient availability indices 44

3.3.1 Nitrogen 44

3.3.2 Phosphorus 45

3.3.3 Zinc and iron 47

Page

3.4 Pot experiment 48

3.4.1 Preparation of potted soils . . . 48

3.4.2 Cultural practises in the glasshouse 49

3.5 Data analysis and interpretation 49

4.0 **RESULTS AND DISCUSSION** 51

4.1 Physico - chemical properties of the soils 51

4.2 Nutrients availability indices 54

4.2.1 Nitrogen 54

4.2.2 Phosphorus 57

4.2:3 Zinc 60

4.2.4 Iron 63

4.3 Rice response to different nutrients . . 65

4.3.1 Performance of rice plants 65

4.3.2 Dry matter (DM) yield and percent yield (PY) 66

4.4 Evaluation of nutrients availability indices 72

4.4.1 Nitrogen 72

4.4.2 Phosphorus 74

4.4.3 Zinc 77

4.4.4 Iron 79

4.5 Nutrients concentration in rice shoots and uptake 79

Page

4.5.1 Nitrogen 79

4.5.2 Phosphorus 81

4.5.3 Potassium 84

4.5.4 Zinc 86

4.5.5 Iron 89

5.0 CONCLUSIONS AND RECOMMENDATIONS 92

6.0 REFERENCES 93

7.0 APPENDICES 121

LIST OF TABLES

Page

Table 1. Description of the sites selected for fertility assessment 41

Table 2. Some physico - chemical properties of the soil used in pot experiment 52

Table 3. Nitrogen contents of the experimental soils as determined by three methods 55

Table 4. Extractable phosphorus as determined by three extractants 58

Table 5. Extractable zinc as determined by 0.1N HCl, 0.005M DTPA and 0.01M EDTA-$(NH_4)_2CO_3$ . . . 61

Table 6. Extractable Fe as determined by 0.1N HCl, 0.005M DTPA and 0.01M EDTA-$(NH_4)_2CO_3$ . . . 64

Table 7. Rice response to nitrogen (N), phosphorus (P), potassium (K), zinc (Zn) and iron (Fe) applied to soils from different rice growing areas of Tanzania 67

Table 8. Percentage yield (PY) data for response of rice to application of nitrogen (N), phosphorus (P), potassium (K), zinc (Zn) and iron (Fe) to different soils 68

Table 9. Correlation coefficients (r) for relationship between N determined by three methods and DM yield of the control treatments 73

Page

Table 10. Correlation coefficients (r) for relationship between extractable P and DM yield of the control treatments 73

Table 11. Correlation coefficients (r) between extractable Zn and the dry matter yield of the control treatment 78

Table 12. Correlation coefficients (r) between extractable Fe and the DM yield of the control treatment 78

Table 13. Effects of N, P, K, Zn and Fe application on N concentration in rice shoots 80

Table 14. Effects of N, P, K, Zn and Fe application on P concentration in rice shoots 82

Table 15. Effects of N, P, K, Zn and Fe application on K concentration in rice shoots 85

Table 16. Effect of N, P, K, Zn and Fe application on Zn concentration in rice shoots 87

Table 17. Effects of N, P, K, Zn and Fe application on Fe concentration in rice shoots . . . 90

LIST OF FIGURES

Page

Figure 1. Relationship between P extracted by Bray-1, Olsen and Pi method and percentage yield of rice . . 76

LIST OF APPENDICES

Page

Appendix 1. Extractable Mn and Cu (mg/kg) extracted by different extractants from the experimental soils 121

Appendix 2. Effects of N, P, K, Zn and Fe application on nutrients uptake by rice plants 122

Appendix 2a. Effects on N uptake 122

Appendix 2b. Effects on P uptake 123

Appendix 2c. Effects on K uptake 124

Appendix 2d. Effects on Zn uptake 125

Appendix 2e. Effects on Fe uptake 126

LIST OF ABBREVIATIONS

AICRIP	All India Coordinated Rice Improvement Project
CEC	cation exchange capacity
DM	dry matter
DAP	days after planting
DTPA	diethylene triamine pentaacetic acid
EDDHA	ethylene di-o hydrophenylacetic acid
EDTA	ethylene diamine tetraacetic acid
e.g.	for example
etc.	and so forth
EUF	electroultrafiltration
IITA	International Institute for Tropical Agriculture
IRRI	International Rice Research Institute
KARI	Kenya Agricultural Research Institute
NAFCO	National Agricultural and Food Cooporation
NORAD	Norwegian Agency for Development
NA	not available
ns	non significant
OC	organic carbon
pH	hydrogen ion concentration
ppm	parts per million
PY	percent yield
r	correlation coefficient
r.p.m.	revolutions per minute
SA	sulphate of ammonia

SUA	Sokoine University of Agriculture
TEA	triethanolamine
TSP	triple superphosphate
USA	United States of America
USDA	United States Department of Agriculture

CHAPTER ONE

1.0 INTRODUCTION

Rice is an important food crop in tropical and sub-tropical regions. It is one of the major cereal crops grown in Tanzania. It is grown in many parts of the country covering an area of over 365 000 ha in varied ecosystems ranging from upland to irrigated lowland. Of this area, lowland rice is mainly grown in large scale farms like Kapunga rice farms and covers an area of approximately 20 000 ha. Small scale farmers irrigation schemes like Lower Moshi also contribute substantially to rice production in the country. The most important rice growing regions in Tanzania include Tabora, Shinyanga, Morogoro, Kilimanjaro, Mbeya and Coast (Bureau of Statistics, 1992).

Recent data indicate that rice yield in these areas is declining at a fast rate. For example, in Ruvu rice farm (Coast region), rice yield declined from 4.8 tons/ha in 1978/80 to 2.4 tons/ha in 1992/93 (Anonymous, 1995). The national average rice yield indicates a decline from 1.47 tons/ha in 1981 to 0.98 tons/ha in 1990/91 (Bureau of Statistics, 1993). Low rice yields in these areas among other things, may be due to soil fertility problems. This

is deduced from the fact that in areas where fertilizers are used, good response in rice yield has been realised indicating that the nutrients added through the fertilizers were limiting.

Adequate supply of plant nutrients both macronutrients and micronutrients is important for high rice yields. Macronutrients and micronutrients are equally important in the nutrition of rice plants only that the former are required in relatively large amount compared to the latter. Also adequate supply of organic matter is important in soil fertility because it is the main source of N that holds a key role in the productivity of rice soils (Neue, 1989).

In mineral nutrition of rice plants, nutrient deficiency problems frequently encountered are those due to nitrogen, phosphorus, zinc and iron (De Datta, 1981). Of these nutrients, nitrogen is considered to be the most important macronutrient in rice production and its deficiency is a widespread nutritional disorder of rice (De Datta, 1981; Neue, 1989). Phosphorus is the second most limiting nutrient in rice production especially in some soil types (Patnaik, 1978). Neue (1989) reported that most tropical soils on which rice is grown are low in available P. Zinc deficiency ranks third among the nutritional disorders

that limit lowland rice yield (De Datta, 1981). Iron is another important micronutrient in rice production next to Zn and inadequate available Fe has become a major problem in a number of cultivated soils (Kabata-Pendias and Pendias, 1985).

Most soils have been found to be deficient in one of the essential plant nutrients (Jones, 1982). This makes fertilizer use a prerequisite practise to supplement the availability of the deficient nutrients to the growing plants. In Tanzania, fertilizer recommendations which are currently in use were compiled by Mowo *et al.* (1993). In the case of rice, the recommendations are based on a few field experiments which were assumed to be representative of all rice growing areas of the region. In drawing up fertilizer recommendations, Mowo *et al.* (1993) did not take into consideration the nutrient status of soils because of scarcity of data on this aspect. This is a major shortcoming of these recommendations. Equally important but also lacking is the absence of suitable soil testing methods screened under Tanzanian conditions.

A recent study by Semoka *et al.* (1996) in soils of Morogoro region showed that all the soils tested responded to N application, 60% responded to P application in addition to N while 40% required N, P and Zn for optimum

yield. In addition, 20% of the soils also appeared to be Fe deficient. Earlier work by Bashiru (1992) and Msolla *et al.* (1994) indicated that Zn deficiency was an important constraint in paddy production in Morogoro and Tabora regions respectively. Fe has also shown to be associated with Zn deficiency in some of the study areas (Bashiru, 1992). These studies were however limited in geographical coverage and thus do not give good indications of the status of these nutrients in many areas where rice is grown.

Scarce information is available on suitable indices for assessing N and P availability in rice soils of Tanzania. Semoka *et al.* (1996) found no correlation between organic carbon and rice DM yield in a glasshouse study indicating that this parameter was not a suitable index for assessing N supply capacity of soils. In the case of P, Shekiffu (1995) reported that the Pi method was better than the Olsen and Bray-1 methods for assessing P status of wetland soils of Morogoro region under glasshouse conditions. No similar work has been done in other rice growing areas of Tanzania.

Limited information is also available on the extent of fertilizer use specific to rice growing areas. In areas where fertilizers are used together with good cultural

practises, for example, Mbarali rice farm and Lower Moshi irrigation scheme, yields are high indicating that the nutrients added through the fertilizers are limiting. However, most smallholder farmers do not use fertilizers. Yet, an appropriate fertilizer technology is an important prerequisite for increasing rice production. It is therefore apparent that studies are required to assess the fertility status of soils in rice growing areas in terms of nutrient supply and adequacy so as to increase soil productivity in these areas and hence rice yields.

The specific objectives are:

(a) To assess the suitability of selected indices of N, P, Zn and Fe for use in testing soils from selected rice growing areas of Tanzania.

(b) To identify nutrient deficiencies in these soils.

(c) To assess response of rice to application of these nutrients.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Nutrients availability and their deficiency symptoms

2.1.1 Nitrogen

Nitrogen (N) is the most limiting nutrient in rice production world wide (Buresh and De Datta, 1991; Chandler, 1979). In rice plants, large quantities of N are required at early and mid tillering (IITA, 1984). During the panicle initiation stage, adequate N increases the number of spikelets per panicle (De Datta, 1981).

Nitrogen deficiency is characterised by poor growth rate, narrow and short leaves which are erect and yellowish green to yellow in colour (De Datta, 1981). The old leaves of N deficient plants become light straw coloured and then die (De Datta, 1981). Nitrogen deficiency also reduces tillering (IITA, 1984).

The main sources of N are soil organic matter, biologically fixed N, organic manure and chemical fertilizers. Of the total amount of N taken by plants, about 60 to 80% is derived from the native pool (De Datta, 1987). The most important natural N supply to rice soils

is the fixation of atmospheric N by blue green algae and anaerobic bacteria (Patnaik, 1978). Azolla which harbours a symbiont, *Anabaena azollae*, has also been reported to be important in fixing atmospheric N in rice soils (Patnaik, 1978).

The two important forms of N in soils are NH_4- and NO_3^--N. The former is the predominant form of organic N in wetland rice soils (De Datta and Cruswell, 1982) and the most stable form of N in submerged soils (Watanabe and Inubushi, 1986). The availability of any of these forms is dependent on soil conditions. For instance, in lowland rice soils which fluctuate between dry and flooded conditions, N forms vary considerably. When the soil dries, the process of mineralisation of organic matter increases to liberate NH_4^+ which is then converted to NO_3. Nitrate so formed is prone to leaching and denitrification losses during flooding (IRRI, 1993). In submerged soils NH_4^+ accumulates to as high as 300 ppm within 20 days of flooding (Ponnamperuma, 1965). The presence of NH_4-N benefits soil fertility because both leaching and denitrification losses are lower than for NO_3-N (Chaterjee and Maiti, 1985).

2.1.2 Phosphorus

Phosphorus (P) is required by rice plants for various functions. It plays an important role in root development, earlier flowering and ripening and enables the plants to counteract the unfavourable effects of late transplanting (Jones *et al.*, 1982; IITA, 1984). It induces good tillering, ensures normal grain development and improves food value of rice. In the soil population, P plays a vital role in N fixing free living organisms and plants (Neue, 1989). It is also involved in the supply and transfer of energy for all the biochemical processes in rice plants (De Datta, 1981).

Deficiency symptoms of P in rice plants are characterised by stunted growth and few tillers. The leaves of P deficient plants are narrow and short, erect and dirty green with purplish tint and the older leaves die prematurely (Jones *et al.*, 1982).

The behaviour of P in flooded soils is markedly different from that of upland soils. In wetland rice soils Chang (1976) postulated that the reduction of Fe-phosphate was the main source of available P. He also pointed out that the transformation of various P compounds and increased diffusion also contributed to increased availability of P

in flooded soils and subsequently increased P uptake by rice plants.

Previous studies have shown that, most soils in which rice is grown are low in P (Neue, 1989). Low levels of P in these soils is linked to high P fixation . Jones *et al.* (1982) reported P deficiency as the most important factor limiting rice yields in Ultisols, Oxisols, Sulfaquepts and some Vertisols mainly because of the high P fixing capacities of these soils. On submergence, P availability in these soils increases thereby reducing the severity of P deficiency.

2.1.3 Potassium

Potassium (K) in plants is mainly concerned with regulatory roles. It has also been found to increase the capacity of rice roots to oxidise Fe^{2+} to Fe^{3+} (Tanaka and Yoshida, 1970), increases disease resistance and enhances P response in P deficient soils (IITA, 1984).

Potassium deficiency in rice is characterised by dark green leaves, short thin stems and stunted plants. Under extremely deficient conditions, tillering may be reduced, leaf tips and leaf margins dry and the older leaves become reddish brown with an early senescence (Jones *et al.*,

1982).

Potassium occurs in soils in four forms which are always in equilibrium viz: soluble K, exchangeable K, non - exchangeable K and mineral K (Haby *et al.*, 1990). Potassium in soil solution and exchangeable K are the forms readily available to plants. Flooding has been found to enhance release of exchangeable K to soluble form (IITA, 1984). The release of K into the soluble form is a consequence of ion exchange with Fe^{2+}, Mn^{2+} and NH_4^+ (Neue, 1989). Neue (1989) further commented that high clay content and relatively young parent material of many flooded soils account for good K supply in such soils. However, the influence of changes in physico-chemical properties of the soil due to flooding in enhancing K release from non-exchangeable K is not well understood (Goswami and Banerjee, 1978) although it is known that much of the K in soils is found in non - exchangeable and mineral forms (Alias *et al.*, 1986).

In rice production, K deficiency in flooded soil is less common than those of N and P (Neue, 1989). The spread of K deficiency among other things has been aggravated by the increasing use of high yielding rice varieties and intense cropping because these practises deplete K faster than it is replenished naturally (Brady, 1984 ; Kemmler, 1980).

Van Uexkull (1978) cited by IITA (1984) reported that, with time K will be needed in almost all soils.

2.1.4 Zinc

Zinc (Zn) is one of the essential elements required for the growth of higher plants. It plays an important role in the formation of growth hormones (auxins). It is an important constituent of many enzymes that are involved in protein synthesis like dehydrogenases, proteinases and peptidases (Marshner, 1990). It is also important in seed production, grain maturation and is involved in nitrogen metabolism.

Zinc deficiency is characterised by stunted growth, reddish brown blotches in the lower leaves, delayed maturity of plants followed by low yields in severe cases (Katyal and Ponamperuma, 1974). Yoshida *et al.* (1973) indicated Zn deficiency as being characterised by chlorotic or brown blotches in the midrib of younger leaves and streaks developing in lower leaves, accompanied by decrease in the size of the blade, uneven growth and delayed maturity. Zinc deficiency in grain crops frequently occurs in the early part of the growing season (Sedberry *et al.*, 1979).

Zinc deficiency is nowadays a worldwide concern especially in lowland rice culture where it is considered to be more widely spread than any other micronutrient deficiency (De Datta, 1981). Zinc has been reported to affect rice production in India where high yielding-fertilizer-responsive varieties of rice (*Oryza sativa* L) are intensively grown under wetland conditions (Mandal and Mandal, 1986).

Flooding generally decreases Zn availability as compared to well aerated soils. For instance, in acid soils, much decrease in Zn availability is due to flooding. This phenomenon is explained by the increase in pH with flooding and the dependence of Zn^{2+} adsorption on pH (Neue and Bloom, 1989). These workers further pointed out that prolonged flooding can increase the potential for Zn deficiency in soils. In Tanzania, Zn deficiency has been reported to decrease rice yield in Nzega and Igunga districts in Tabora region (Msolla, 1991) and some parts of Morogoro district (Bashiru, 1992; Semoka and Shenkalwa, 1985; Semoka *et al.*, 1996).

2.1.5 Iron

Iron (Fe) plays an important role in plant nutrition (Mandal, 1961). Studies on nutrient requirement in rice by

Gericke (1930) cited by Mandal (1961) indicated that Fe requirement in rice is greater than in wheat, barley, oat and rye both grown under the same condition. He further revealed that rice plants require available Fe in the growth medium longer than any other element except nitrogen and potassium.

Fe deficiency is one of the first nutritional disorder to be recognized in rice (Lopes, 1980). It is a widespread nutritional disorder in calcareous soils under both upland and wetland conditions and is also found in some flooded soils where organic matter is too low to produce soil reduction (Sanchez, 1976). However, in some flooded rice fields, Fe poses a big problem as continuous flooding for a few weeks increases the level of soluble Fe from 0.1 to 100 ppm (Ponnamperuma, 1978). This increase of soluble Fe can result in toxicity also referred to as "bronzing" which occur if the content of Fe in the leaves reaches 300 ppm (Tanaka and Yoshida, 1970). Bronzing is described as a nutrition disorder that results from malfunctioning of rice roots due to precipitation and surface coating of root tip by ferric oxide thus inhibiting nutrients and water uptake by roots (Kosaki and Juo, 1986). Iron toxicity in rice is frequent in heavy textured soils (Tanaka and Yoshida, 1970) and is often associated with K' deficiency. However, the occurrence of Fe deficiency

symptoms depends more on the factors responsible for Fe uptake than on critical concentration of water-soluble Fe(II) alone (Jones *et al.*, 1982).

2.2 Testing for availability of plant nutrients

2.2.1 Soil Testing

Soil testing is an important and indispensable tool for the assessment of plant nutrient availability in soils (Sahrawat, 1983; Beringer, 1985). It was found to be the most reliable technique to provide information about the deficiency or adequacy of nutrients in the soil and in the estimation of fertilizer needs (Singh and Takkar, 1981). For the soil test values to be meaningful, they have to be correlated with the crop response to the added nutrients in the soil. One of the shortcoming of soil testing for nutrients availability is that it does not account for crop-specific nutrient requirement and the interaction between nutrients (Beringer, 1985). Therefore, soil testing values alone might not provide the best indices for assessing nutrient availability to plants and in predicting fertilizer recommendations.

Beringer (1985) also indicated that, soil test data for fertilizer recommendation vary with environmental conditions and with the type of the nutrient required by

a crop. This means that, no single soil test procedure is expected to be adequate to predict nutrient availability in all situations. In view of this fact, more soil specific methods are needed to effectively evaluate the available quantity of a nutrient in that soil so as to predict the fertilizer requirement by a crop (Beringer, 1985). Different soil test methods are available for different plant nutrients.

2.2.1.1 Nitrogen

Rice like any other crop is more often deficient in N than in any other nutrient (De Datta, 1981), yet there is no widely accepted methods of testing soils for N in rice growing soils (IRRI, 1992). The necessity of having an acceptable index for evaluating N in soils lies on the fact that more than 50% of N needed by rice plants is derived from soil organic N (IRRI, 1992). Organic N gives a measure of the potential of a soil to supply N to plants when conditions are ideal for mineralisation (Dahnke and Johnson, 1990). Likewise, methods for evaluating the amount of N mineralised from soil organic matter are needed for accurate fertilizer recommendations which will give efficient use of fertilizers and reduce risks of polluting underground water (Cabrera and Kissel, 1988). Soil N availability tests can either be biological or

chemical.

A. Biological methods

The biological methods of soil testing involve incubation of the soil to promote mineralization of soil N. Two such methods commonly used are aerobic incubation and waterlogged incubation (Keeney and Bremner, 1971). These two methods give estimates of NO_3- and NH_4-N produced during microbial decomposition of organic matter in the soil. However, it must be remembered that the rate at which these organisms mineralise N is controlled by several unpredictable environmental conditions such as temperature, moisture and aeration (Dahnke and Johnson, 1990). As a result, mineralisable N under laboratory conditions may not always be proportional to the amount of the N mineralized in the field. Therefore, the results from these methods only give an indication of the potential of soils to supply N under ideal conditions rather than the amount of N that will become available under field conditions.

In Tanzania, Singh *et al.* (1976) evaluated different indices for N availability in soils of Morogoro and obtained positive but non significant correlation (r = 0.25) between percentage yield of maize and aerobic

incubation method. They established a critical level of 54 ppm using this method.

B. Chemical methods

The chemical soil tests for N are often used because they are usually rapid and more precise than the biological methods (Keeney and Bremner, 1971). Chemical methods have however been criticised because of the fact that no chemical treatment of the soil is likely to stimulate the microbial processes responsible for mineralisation of soil N or to release selectively the fraction of soil N that is made available for plant growth by the microorganisms (Keeney and Bremner, 1971). Some of the chemical methods for testing N availability include total N, organic carbon, hot alkaline $KMnO_4$ method, electroultrafiltration (EUF), etc. Out of the above methods, total N, organic carbon and hot alkaline $KMnO_4$ are reviewed below.

Organic carbon

Organic carbon (OC) is often used as a basis of organic matter estimates which is believed to be the main source of N in lowland rice (Dei and Yamasaki, 1979; De Datta, 1981; Neue, 1989 ; IRRI, 1993). The determination of OC to assess the N supply capacity of soils has been widely

adopted because it is rapid, simple and no special equipment is required (Nelson and Sommers, 1990).

Different results on the suitability of this method in estimating N supplying capacities of soils have been reported. Sahrawat (1983) found OC to be a good index of assessing N availability in rice soils in pot experiment. Similar findings were reported by Singh and Tripathi (1970) in soils of India. In Tanzania, Singh *et al.* (1976) found a significant correlation (r = 0.77) between OC and percentage yield of maize in some soils of Morogoro. The critical level established in their study was 1.75%. Semoka *et al.* (1996) on the other hand obtained non significant correlation (r = 0.31) between OC and rice DM yield in soils of Morogoro indicating its inadequacy in predicting N supplying capacities of soils

Total N

Two methods have gained a general acceptance for the determination of total N; namely wet oxidation procedures and dry oxidation procedures (Bremner and Mulvaney, 1982). Of these two methods, wet oxidation has been adopted by many workers. In Philippines, Sahrawat (1983) reported that total N was a good index for assessing N supplying capacities of soils. In Tanzania, Singh *et al.* (1976)

obtained a non significant correlation between total N with maize growth data in soils of Morogoro indicating its failure to predict the N supplying capacities of the soils. The critical level established in their study using this method was 0.15%. Other workers (IRRI, 1993) have also indicated doubt on its suitability in assessing N supplying capacities of continuously irrigated rice systems. This is due to lack of sufficient understanding of the processes that influence organic matter decomposition and turnover, microbial population mediating these processes, root growth and activity in submerged soils.

Alkaline $KMnO_4$

Although Keeney and Bremner (1966) regarded this method as giving less satisfactory results in assessing N supplying capacities of soils, Bajaj *et al.* (1967) and Singh *et al.* (1976) obtained a significant relationship between extractable N using this method and rice yields and recommended it for use in assessing N supplying capacities of rice soils of India and Morogoro (Tanzania) respectively. The critical level obtained by Singh *et al.* (1976) in soils of Morogoro was 190 ppm. In USA, Stanford (1978) also indicated the suitability of this method in assessing N availability in soils.

2.2.2.2 Phosphorus

Methods of determining phosphorus(P), its various forms and availability to plants have been essential in developing principles and knowledge of the nature and behaviour of P in soils (Olsen and Sommers, 1990).

Most of the soil tests for P have shown to be inadequate in determining P-supplying capacity in lowland soils (Sanchez, 1976). Likewise, none of the common soil extractants have been able to detect soluble P which becomes available under flooding conditions (Chang, 1976). Some of the commonly used methods for evaluating P availability in soils are Olsen, Bray-1, Bray-2, Mehlich, Truog, iron hydroxide impregnated filter paper strip (Pi) etc. For the purpose of this study only Bray-1, Olsen and Pi methods will be reviewed.

Olsen method

This method was originally developed for use in calcareous soils (Olsen *et al.*, 1954). It consists of a buffered solution of $NaHCO_3$ which precipitates Ca^{2+} as $CaCO_3$ thus making Ca-P more extractable by lowering Ca activity (Thomas and Peaslee, 1973). This method has proven to work better in a number of soils. For instance, in Tanzania,

Mutagwaba (1986) reported the Olsen method to be superior to the Bray-1 in extracting P in soils of Mbeya region. Ussiri (1992) reported a significant correlation (r = 0.90) between Olsen extractable P and maize growth data in Benchmark soils of Morogoro (Tanzania). Semoka *et al.* (1996) on the other hand reported that the Olsen method was not as effective in extracting P in rice soils of Morogoro as the (Pi) method. The critical levels established from these studies were: 34.60 ppm (Mutagwaba, 1986), 10.5 ppm (Ussiri, 1992) and 20.0 ppm (Semoka *et al.*, 1996).

Bray-1 method

The Bray-1 extracting solution (0.03N NH_4F + 0.025N HCl) as developed by Bray and Kurtz (1945) has been employed widely to determine the available P in a number of soils. The combination of HCl and NH_4F is designed to remove easily acid soluble forms of P, largely Ca-P other than apatite and portions of Al and Fe phosphates (Olsen and Sommers, 1990). The method is very sensitive to the ratio of soil to extracting solution and the shaking time, therefore, the extractable P may not be the same at various laboratories (Randal and Grava, 1971).

In Tanzania, various workers obtained different results

using this method. For instance, Mutagwaba (1986) reported a nonsignificant correlation between Bray-1 extractable P and maize DM yield in some soils of Mbeya region. Similar results were obtained by Semoka *et al.* (1996) in some rice soils of Morogoro. Ussiri (1992) on the other hand obtained a significant correlation (r = 0.65) between Bray-1 extractable P and maize dry matter yield indicating that it was adequate in assessing P availability in some soils of Morogoro. The critical levels established in these studies were: 4.35 ppm (Mutagwaba (1986), 3.51 ppm (Ussiri, 1992) and 20.0 ppm (Semoka *et al.*, 1996).

Pi method

This method was developed by Menon *et al.* (1989a) and was found to work well in acid as well as alkaline and calcareous soils. These workers obtained the best correlation (r = 0.94) between Pi extractable P and DM yield and P uptake by maize grown in acid soil fertilized with partially acidulated phosphate rock differing widely in water-soluble P.

In Tanzania, recent work by Semoka *et al.* (1996) indicated that this method was superior to the Olsen and Bray-1 methods in assessing P availability in rice soils of Morogoro district. The critical level obtained in their

study was 35.0 mgP/kg.

2.2.1.3 Potassium

Soil test for available K usually relies on the estimate of exchangeable K (Haby *et al.*, 1990). An estimate of exchangeable K, which usually include soil solution K^+, is the standard index of K availability in the USA and Canada (Haby *et al.*, 1990). A number of extractants have been employed in the determination of exchangeable K in soils. Most of these methods use NH_4^+ or Na^+ as a cation to replace K^+ on exchange sites. These methods include neutral NH_4OAc, acid NH_4^+ and NaOAc, double acid, Mehlich III, electroultrafiltration (EUF) etc. In this review, only neutral NH_4OAc method will be dealt with in detail.

Neutral NH_4OAc method

This method involves either centrifugation and decantation or Buchner funnel filtration also reffered to as leaching (Knudsen and Peterson, 1982). Centrifugation and leaching procedures are all adapted to flame photometer or atomic absorbtion spectrophotometry.

Ahmad *et al.* (1973) assessed available K using total K, NH_4OAc, CH_3COOH, cold H_2SO_4 and boiling HNO_3 in Indian soils

using maize as a test crop in a pot experiment. They found that cold H_2SO_4 and NH_4AOc were the most suitable indices for assessing K availability. They also found that NH_4AOc works better in soils with pH less than 7. The critical level of exchangeable K in pot experiment and farmers fields in India was found to be 0.26 meq/100g soil (Jones *et al.*, 1982).

2.2.1.4 Zinc

In recent years, a large number of methods have been employed to assess the status of plant available Zn in soils. The most commonly used methods fall into three categories namely extraction by water and neutral salt solutions (Stewart and Berger, 1955), inorganic acids (Chang and Bray, 1953) and chelating agents buffered to various pH levels (Jensen and Lamm, 1961). This review will focus on the use of inorganic acids and chelating agents in assessing the available Zn status in soils.

(a) Extraction of Zn by inorganic acids

Strong and dilute inorganic acid extractants remove soluble Zn, exchangeable Zn, Zn from acid soluble compounds as well as occluded Zn (Trieweiler and Lindsay, 1969). A major criticism on the use of strong acid

extractants is levelled on the fact that many of the soluble compounds in the soil are destroyed and occluded Zn that is normally inaccessible to plants is released (Trieweiller and Linsay, 1969). In calcareous soils, the use of strong acid extractants is objectionable because of the abundance of acid soluble carbonates which decompose and contribute to the available Zn fraction. In order to overcome this problem, Viets and Lindsay (1973) used titratable alkalinity as an estimate of nonavailable fraction of Zn released by the acid extractants. Another limitation in using acid extractants in assessing Zn status of calcareous soils is that, a single acid extraction may be partially or totally neutralised and its effectiveness decreased.

Extraction with 0.1N HCl

This extractant was modified from 1N HCl extractant of Wear and Sommer (1948). Tucker and Krutz (1958) found 0.1N HCl to be more easily adopted in routine testing although it overestimated the available Zn to plants. These workers indicated that, soils containing less than 3.0 ppm of HCl extractable Zn were likely to be Zn deficient while those with 3 to 6 ppm extractable Zn were moderately deficient. Wear and Evans (1968) used three extractants viz: 0.1N HCl, 0.05N HCl + 0.025N H_2SO_4 and 0.05N EDTA at pH 7 in

assessing available Zn in soils and obtained a best correlation (r = 0.89) between 0.1N HCl extractable Zn and Zn uptake by maize plants. Similar observations on the performance of 0.1N HCl were obtained by Coffman and Miller (1973) and Sakal *et al.* (1984). Coffman and Miller (1973) further revealed that, 0.05N HCl + 0.25N H_2SO_4 extracted 70% as much Zn as 0.1N HCl and about 25% more than that extracted by EDTA-$(NH_4)_2CO_3$. These workers suggested that 0.05N HCl + 0.25N H_2SO_4 and 0.1N HCl extractants extract Zn from the same pool.

In Tanzania, Nzabayanya and Mnkeni (1985) and Mkangwa (1992) also revealed the superiority of 0.1N HCl in extracting Zn from the soil. Nzabayanya and Mnkeni (1985) tested different extractants in evaluating Zn status of soils of Morogoro region and obtained a better correlation between 0.1N HCl Zn and maize DM yield than with other extractants. Similar findings were reported by Mkangwa (1992) in soils of Iringa district. The critical levels established in these studies were 3.3 ppm (Nzabayanya and Mnkeni, 1985) and 0.28 ppm (Mkangwa, 1992).

(b) Extraction with chelating agents

Chelating agents provide some of the most promising means of testing the availability of micronutrients in soils.

The advantage of using chelating agents over strong acid extractants is that, the pH of the extracting media can be selected and maintained more closely to the normal pH of the soils (Lindsay, 1972). These chelating agents react with free metal ions in soil solution to form a soluble complex thus simulating the absorption action of roots.

Extraction with DTPA

The DTPA (diethylene triamine pentaacetic acid) method was developed by Lindsay and Norvell (1969) for assessing available Zn, Fe, Mn and Cu in soils. It was found to offer the most favourable combination of stability constants for simultaneous complexing of the above elements. It consists of 0.005M DTPA and 0.01M $CaCl_2$. The presence of 0.01M $CaCl_2$ enables the extractant to attain the equilibrium with $CaCO_3$ which minimizes the dissolution of $CaCO_3$ from calcareous soils. The pH of 7.3 buffered with triethanolamine (TEA) is used to prevent excessive dissolution of trace elements which is highly pH dependent.

Using this extractant, Lindsay (1972) managed to separate 77 Colorado soils into Zn deficient and non Zn deficient categories. In Califonia, Brown *et al.* (1971) examined 92 soils for extractable Zn and tested each soil in the

greenhouse for response to Zn application. They revealed that this extractant was successful in delineating Zn deficient from non Zn deficient soils in 83 cases out of 100 i.e. the extractant had a predictive value of 83%. They established a critical level of 0.5 ppm for DTPA extractable Zn. Haq and Miller (1972) compared 0.01N EDTA (pH 8.6), 0.005M DTPA (pH 7.3), EDDHA (pH 7.0) and 0.05N HCl in 0.025N H_2SO_4 for Zn extraction in different soils and related the extractable Zn to Zn concentration in maize grown for 16 days in the greenhouse. Among the extractants used they found that DTPA extractable Zn correlated better ($r = 0.602$) with maize DM yield and when pH was included in the regression equation, the correlation coefficient increased to 0.759. From these findings, they suggested that DTPA could efficiently be used to estimate available Zn in soils below pH 7.0 and that the inclusion of pH in the regression model may improve its suitability.

Seedberry *et al.* (1979) on the other hand reported that DTPA extracted less Zn as compared to NH_4OAc, EDTA-$(NH_4)_2CO_3$, EDTA + 1N NH_4OAc and 1N HCl. In Tanzania, Kamasho and Singh (1982) compared four extractants for extracting Zn in volcanic soils of Mbeya region. In their work they revealed better correlation between DTPA extractable Zn and Zn uptake with sorghum. They established a critical

value of 3.7 ppm for DTPA extractable Zn. In soils of Morogoro district, Nzabayanya and Mnkeni (1985) found DTPA to be a relatively inferior extractant when compared with the double acid (HCl + H_2SO_4) extractant. They obtained a significant correlation (r = 0.78) between DTPA extractable Zn and maize dry matter yield which was lower than that for the double acid extractant (r = 0.93). They obtained a soil critical level of 0.85 ppm for DTPA Zn. Bashiru (1992) also working in soils of Morogoro district reported that the DTPA extractant was superior to other extractants tested in extracting Zn from the soils. The critical level obtained with DTPA in this study was 1.95 ppm. Msolla *et al.* (1994) found EDTA-$(NH_4)_2CO_3$ with a critical value of 0.86 ppm to be better than DTPA and 0.1N HCl in paddy soils of Nzega and Igunga districts in Tabora region.

Extraction with EDTA-$(NH_4)_2CO_3$

EDTA (ethylene diamine tetraacetic acid) extractant at various concentrations ranging from 0.007M to 0.05M buffered at neutral pH has been used extensively as an extractant for copper, manganese and zinc (Viets and Lindsay, 1973). This extractant has been found to be more effective in extracting adsorbed ions than NH_4OAC and gives a good recovery of cations like copper and zinc as well as

certain anions such as PO_4^{3-} (Viro, 1955). The EDTA extractant is however disadvantageous in calcareous soils because it dissolves water soluble carbonates that are not part of the exchange complex (Viro, 1955).

Trieweiller and Lindsay (1969) proposed the use of EDTA-$(NH_4)_2CO_3$ buffered at pH 8.6 in assessing zinc in neutral and calcareous soils. This extractant has an advantage in that it prevents the dissolution of carbonates and oxides thereby avoiding extraction of occluded zinc. In testing the suitability of this extractant, Trieweiller and Lindsay (1969) compared it with dithizone and 0.1N HCl in 42 Colorado soils using maize as a test crop. They obtained significant correlations between extractable Zn and DM yield of 0.87, 0.89 and 0.80 for EDTA-$(NH_4)_2CO_3$, dithizone and 0.1N HCl, respectively. They reported a critical level of 1.4 ppm zinc to separate zinc deficient from non zinc deficient soils. In India, Singh and Takkar (1981) using the EDTA-$(NH_4)_2CO_3$ extractant established a soil critical level of 1.0 ppm zinc.

In Tanzania, Msolla (1991) used three extractants viz: 0.005M DTPA, 0.1M EDTA-$(NH_4)_2CO_3$ and 0.1N HCl in assessing zinc status of Igunga and Nzega districts (Tabora region) using rice as a test crop and recommended the use of 0.1M EDTA-$(NH_4)_2CO_3$ over other extractants. The author

established a soil critical level of 0.86 ppm zinc for EDTA-$(NH_4)_2CO_3$ extractant. Bashiru (1992) on the other hand obtained better performance using 0.005M DTPA over 0.1M EDTA-$(NH_4)_2CO_3$, 0.1N HCl and double acid extractants in Benchmark soils of Morogoro district. Mkangwa (1992) also used three extractants namely 0.1N HCl, 0.01M EDTA-$(NH_4)_2CO_3$ and 0.005M DTPA and revealed that EDTA-$(NH_4)_2CO_3$ was inferior to 0.1N HCl in extracting zinc from soils of Iringa district. In his study, the soil critical level obtained using EDTA-$(NH_4)_2CO_3$ extractant was 1.29 ppm zinc.

2.2.1.5 Iron

Most of the extractants used to evaluate the available Fe in soils have also been used simultaneously in the determination of other micronutrients (Martens and Lindsay, 1990). They include DTPA, EDTA, 0.1N HCl, EDDHA, etc. There is however little work done to evaluate their suitability in rice soils probably because of the increased availability of Fe in many paddy soils after flooding. The review on the chemistry of these extractants have been covered on section (a) and (b) of 2.2.1.4.

With regard to their suitability in assessing Fe status of soils, Lindsay and Norvell (1969) recommended DTPA to be used in assessing available Fe and Zn in soils. Another

report by Wallace *et al.* (1955) indicated EDDHA (ethylene di-o hydroxyphenylacetic acid) as being the most effective chelate in extracting Fe from soils. Its value in extracting Fe from soils is due to the fact that it has little buffering capacity, is not fixed by clays and is not easily decomposed by the soil microbes (Wallace *et al* .1955). Randhawa *et al.* (1978) using DTPA extractant obtained a critical range of 2.5 to 4.5 ppm Fe.

2.2.2 Plant analysis

Plant analysis presents another approach in determining nutrients availability in soils. In modern agriculture, plant analysis has become a useful tool for rapid diagnosis of the nutritional needs of crop plants (Brar *et al.*, 1980). This technique is based on the fact that, the amounts of nutrients in plant tissues are related to the available forms of the same nutrients in soils. One of the disadvantage of using plant analysis in assessing nutrients availability in the soil is that, once the nutrient disorder is detected, it is often too late to alleviate the problem without considerable loss of yield (Sanchez, 1976; Sahrawat, 1983). Furthermore, the nutrient concentration in plants has been found to be greatly affected by such factors as plant organ sampled, growth stage, environmental conditions and the supply to the

plant roots of other plant nutrients (Jones and Vernon, 1990).

The use of specific plant part for plant analysis has been emphasised by many workers. For instance, Jones and Case (1990) suggested the use of recently matured leaves at appropriate stages of growth, whereas Yoshida *et al.* (1973) advocated the use of "Y" leaf in rice plants.

Basing on field data from Philippines, optimum leaf N concentration was found to be 1.8 to 2.5% (Wallihan *et al.*, 1974). In Tanzania, Temu (1985) recommended the use of N concentration in index leaves as the best index for assessing the N nutritional status of rice as compared with N concentration in rice shoots and rice straws. He suggested a critical N concentration of 2.37% for the "Y" leaf.

With regard to P, Tanaka and Yoshida (1970) reported that plants whose P in leaf blade is 0.1% or lower are P deficient. Those whose concentration in straws at maturity is 1% suffer from P toxicity. Jones *et al.* (1990) reported that concentration values ranging from 0.4 to 0.8% P are sufficient for maize at 30 to 45 days after planting. According to Fageria (1976) the critical P concentration in the tops of 100-day-old plants grown in culture

solution was found to be 0.4%.

According to Tanaka and Yoshida (1970), when K content in straws at harvest or that of leaf blade at tillering is 1%, then the plants are likely to suffer from K deficiency.

The critical limits of Zn in whole shoot of rice plants after 4 weeks was reported by Katyal and Ponnamperuma (1974) to be 15 ppm. Tanaka and Yoshida (1970) indicated that critical Zn concentration of rice shoots was 10 ppm.

The critical concentration of Fe in the rice plants was reported by Tanaka and Yoshida (1970) to be 70 ppm in the leaf blade at tillering stage. They reported that a concentration of 300 ppm at tillering stage was likely to cause toxicity.

2.4 Rice response to nitrogen, phosphorus, potassium, zinc and iron

2.4.1 Nitrogen

Among the common nutrients applied to rice, N gives the highest response in terms of grain yield. This response is dependent on rice varieties, rate of N applied, time of application, soil N content, season of planting, N

management and type of N source (De Datta, 1981). Although very high rates of N have been reported to decrease rice yield (De Datta, 1981), levels of up to 100 kg N/ha have been reported to increase rice yield (Tanaka *et al.* 1984). Many workers have found increases in rice yield with increasing levels of N (e.g. Meelu and Bhandury, 1981; Singh *et al.*, 1995; Hari *et al.*, 1996). Meelu and Bhandury (1981) reported increases in rice yield with increasing N levels up to 200 kg N/ha. A similar trend was reported by Hari *et al.* (1996) when N levels were increased from 0 to 200 kg N/ha. They obtained grain yield of 4 tons/ha in the control plot and 8.3 tons/ha when 200 kg N/ha was used. Semoka and Shenkalwa (1985) also reported the highest rice DM and grain yields in a greenhouse experiment using Dakawa soils at 200 mg N/ kg soil.

According to De Datta (1981), semidwarf rice varieties have higher N response than the tall varieties. Prasad and De Datta (1979) emphasized that modern improved varieties when grown without N fertilizer even in the absence of deficiency or toxicity symptoms of other nutrient elements give low yields, and the yields are even lower than those of the unimproved varieties.

With regard to timing of N application, Dzowela (1974) reported that split application increased plant response

to the applied fertilizer. He recommended half of the N dose to be applied at transplanting and the other half as a top dressing before the booting stage.

Different plant response has been observed from applying different sources of N. For instance, De Datta (1981) reported different response to the application of urea and sulphate of ammonia. He pointed out that for soil with low Fe, N fertilizers that do not contain sulphur are preferred. The reason for this is that in soils without adequate Fe, hydrogen sulphide (H_2S) develops in reduced soils and this adversely affects rice growth. When Fe is adequate, S is precipitated as ferrous sulphide (FeS) which is non toxic to rice plants.

2.4.2 Phosphorus

Rice like any other cereal crop requires a considerable amount of P for proper growth and yield (De Datta, 1981). However, less response to P application is observed in wetland rice than in upland rice with similar P requirement. Despite this fact, response to P has been reported in various rice growing areas particularly on Ultisols, Oxisols, Sulfaquepts, Andosols and Vertisols (Goswami and Banerjee, 1978). Data from the all India Coordinated Rice Improvement Project (AICRIP, 1977)

indicated that rice responded to P when applied with adequate N and in the absence of N in some highly P deficient soils. In Tanzania, Semoka and Shenkalwa (1985) obtained a significant increase in DM yield from the application of P in Dakawa rice soils. A recent study by Semoka *et al.* (1996) indicated that three soils out of ten taken from rice growing area of Morogoro region significantly responded to P application.

2.4.3 Potassium

The response of rice to K application depends on the fertility level of the soil, rice variety and season (Jones *et al.*, 1982). In the Philippines, field experiments have shown that when K was applied at a rate of 50 kg/ha without P a yield of 0.33 tons/ha was obtained but yield was increased to 1.1 tons/ha when 26 kg P/ha was applied together with K (IRRI, 1974). The varieties that showed no response to K in the absence of P were IR20, IR8 and IR26. The study further showed that IR8 and IR26 responded to K application by yielding 1.4 tons/ha and 1.3 tons/ha, respectively, in the presence of P. Reports from long term fertility trials in IRRI have indicated that with intensive rice monoculture systems, the response per unit of applied K increases with time compared with N applied alone (IRRI, 1973; 1974). This suggests that K

should be applied in rice soils that were continuously grown with high yielding varieties to which only N and P had been added.

2.4.4 Zinc

The response to Zn application varies with varieties, severity of deficiency, rate of Zn application and environmental conditions (Jones *et al.*, 1982). In India, Raju *et al.* (1986) found the yield of rice to be 3.36 tons/ha by applying 110 kg N/ha but yield increased to 3.9 tons/ha when 18.2 kg Zn/ha was applied in addition to N. Subramanyan and Mehta (1974) in India also showed that rice grown in Zn deficient soils (dithizone Zn = 0.6 ppm) yielded 50% more when treated with 10 kg Zn/ha. In Tanzania, Msolla (1991) and Bashiru (1992) also found rice response to Zn application in Tabora and Morogoro regions, respectively. Msolla (1991) obtained good response when 10 kg Zn/ha was used in field experiments. Bashiru (1992) obtained an increase in DM yield of rice when the zinc rate was increased from 2.5 to 5 mg Zn/kg.

2.4.5 Iron

Scarce information is available regarding the response of Fe in rice plants. However, studies in calcareous soils of

Africa have shown dramatic response of corn to Fe fertilizers although few studies have compared sources and rates of Fe or ways to control Fe deficiency (Lopes, 1980). For instance, in Egypt, Lopes (1980) indicated that spraying corn plants with $FeSO_4$ and soil application of FeEDDHA at a rate of 2.5 kg/ha gave best results as compared to other Fe sources.

In rice production, response to applied Fe depends on such soil factors as soil organic matter and soil pH. A study in this aspect by Okajima *et al.* (1970) indicated that rice response to applied Fe depends largely on soil reaction. In their study they failed to correct Fe deficiency by using Fe-EDDHA at pH values of 8.5 but obtained good response by using acid treatment of sulphuric acid and $FeSO_4$.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

3.1.1 Soils

Ten soil samples were collected from some important rice growing areas of Mbeya, Morogoro and Coast regions. The characteristics of the selected sites are given in Table 1.

3.1.2 Test crop

Rice (*Oryza sativa* L) cultivar Supper India which is commonly grown in the sampled areas was used as a test crop in all soils.

3.1.3 Fertilizers

Fertilizers used in pot experiment were: monocalcium phosphate ($Ca(H_2PO_4)_2.H_2O$) as a source of P, Sulphate of ammonia ($(NH_4)_2SO_4$) as a source of N, potassium sulphate (K_2SO_4) as a source of K, zinc oxide (ZnO) as a source of Zn and ferrous sulphate ($FeSO_4.7H_2O$) as a source of Fe. Analytical reagents were used in all cases to minimize contamination.

Table 1. Description of the sites selected for fertility assessment

Region	Site name	Duration of cultivation (years)	Fertilizer used
Morogoro	Mkindo irrigation scheme (phase 1 area)	11	TSP and urea
	Kilangali rice farm (area 2A ext. 1)	28	SA or urea
	Mlali irrigation scheme	NA	Nil
	Mbigiri prison farm (Mgomba rice farm)	23	Nil
Coast	Ruvu NAFCO (plot no.4)	18	TSP and urea
	Ruvu secondary school rice farm	19	Nil
	Kigongoni rice farm (area B3 plot no.2)	NA	urea and TSP
Mbeya	Kapunga rice farm (plot No.B71)	5	TSP, urea and NPK
	Majengo irrigation scheme (S1 area)	12	TSP and urea
	Malenga irrigation scheme (S2 area)	8	TSP and urea

NA = Data not available

3.2 Methodology

3.2.1 Soil sampling and samples preparation

Bulk composite soil samples from the top 0 to 20 cm were collected from the above sites. The depth of 0 to 20 cm was chosen to represent the rooting depth of rice plants. At each site, a composite sample was obtained by taking at least 8 subsamples in an area of one hectare and mixing them thoroughly. The composite samples were air dried and ground to pass through 8 mm sieve for glasshouse pot experiment. A subsample of one kg from each location was ground to pass through 2 mm sieve and used for laboratory analysis.

3.2.2 Laboratory analysis

3.2.2.1 Soil analysis

Analyses for soil pH, cation exchange capacity (CEC), exchangeable potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na) and particle size distribution were made.

Soil pH

Soil pH was measured in water at a 1:2.5 soil: water ratio using a pH meter as described by Peech (1965).

CEC and exchangeable bases

The CEC of the soil was determined using ammonium acetate saturation method as described by Chapman (1965). Five grammes of the soil were saturated with neutral normal NH_4OAc, shaken for 30 minutes and then filtered. The filtrate was used to determine exchangeable K, Mg, Na and Ca using atomic absorption spectrophotometry. Excess NH_4OAc entrapped by the soil was removed by washing four times using methyl alcohol. The NH_4-saturated soil was equilibrated with 4% KCl, shaken for 30 minutes and then filtered . The filtrate was saved for the determination of NH_4^+ for estimation of CEC of the soil.

Particle size analysis

The particle size distribution was determined by the hydrometer method as described by Day (1965). The textural class was determined using USDA textural class triangle (USDA, 1975).

3.2.2.2 Plant analysis

Plant samples were digested using a wet oxidation procedure of Okabelo *et al.* (1993) with the following modification: The digestion mixture contained selenium

powder, lithium sulphate, hydrogen peroxide and concentrated sulphuric acid in the ratio of 0.42:14 by weight and 350:420 by volume, respectively. Nine ml of the digestion mixture were added to 0.3 g of the ground plant samples and digested at 360°c for 1.5 hours. One drop of hydrogen peroxide was added to samples that were not colourless solution and heated for few minutes. After cooling, 25 ml of distilled water were added to dissolve sediments and the volume was made up to 100 ml ready for the analysis of N, P, K, Zn and Fe.

3.3 Nutrient availability indices

3.3.1 Nitrogen

Three indices for N were used namely total N, organic carbon and alkaline $KMnO_4$.

Total N was determined using micro-Kjeldahl digestion-distillation method as described by Bremner (1965). One gram of soil was digested with concentrated H_2SO_4 in the presence of K_2SO_4, $CuSO_4$ and selenium powder as a catalyst in the ratio of 10:10:1 by weight. The digest was distilled after adding 50 ml of 40% NaOH. The ammonia liberated was collected in 4% boric acid-mixed indicator and then titrated with standard H_2SO_4. The titre was used to calculate the total N of the soil sample.

The organic carbon was determined using the Walkley and Black method (Allison, 1965). To one gram of soil, 10 ml of $K_2Cr_2O_7$ and 20 ml of concentrated H_2SO_4 were added to oxidize organic carbon. The amount of dichromate reduced was used to estimate the organic carbon content of the soil after multiplying by 1.33 as a recovery factor. With the alkaline $KMnO_4$ method, the available NH_4-N was determined following the procedure of Subbiah and Asija (1956) with slight modification as follows: The mixture of 5 g air dried soil, 20 ml of distilled water and 100 ml of 0.32% $KMnO_4$ was put in 800 ml Kjeldahl flask and mounted on a distillation rack. The mixture was heated while adding 100 ml of 2.5% NaOH through the side arm. The distillate was collected in 10 ml of 0.1N H_2SO_4 containing methyl red indicator for 30 minutes and then titrated with standard 0.23N NaOH. The titre was used to calculate the amount of N in the soil sample.

3.3.2 Phosphorus

Each soil sample was analyzed for available P using three methods namely: Bray-1 (Bray and Kurtz, 1945), Olsen method (Olsen *et al.*, 1954) and filter paper strip (Pi) method (Menon *et al.*, 1989a).

In the Bray-1 method (Bray and Kurtz, 1945), the

extracting solution contained NH_4F + 0.025N HCl. A sample of 3 g of air dry soil was put in a centrifuge tube, 20 ml of the extracting solution were added, shaken for one minute, filtered and the P was determined in the filtrate.

In the Olsen method, 40 ml of 0.5 M $NaHCO_3$ were added to 2 g air dried soil and shaken for 30 minutes in a reciprocating shaker. The suspension was filtered and 10 ml of the filtrate were used for P determination.

For the Pi method, the filter paper strips were prepared as outlined by Menon *et al.* (1989a). One gram of air dried soil was put into 100 ml shaking bottle and 40 ml of 0.01M $CaCl_2$ were added. A paper strip was then placed in the bottle and the mixture was shaken for 16 hours at a speed of 180 r.p.m. Then the paper strips were removed and rinsed with distilled water and transferred into another plastic bottle. 40 ml of 0.2 N H_2SO_4 was added into the bottle and shaken for one hour and the resulting filtrate was used for P determination. Colour was developed in all the above cases by the phospho-molybdate blue method of Murphy and Riley (1962) and P was determined by spectrophotometer.

3.3.3 Zinc and iron

DTPA extractable micronutrients in all soils were determined using the procedure of Lindsay and Norvell (1978). The extractant contained 0.005M DTPA (diethylenetriamine pentaacetic acid), 0.01M $CaCl_2$ and 0.1M TEA (triethanolamine) adjusted to pH 7.3. 20 g of air dried soil were mixed with 40 ml of extracting solution and shaken for two hours and then filtered.

EDTA-$(NH_4)_2CO_3$ extractable micronutrients were performed using the procedures of Trieweiller and Lindsay (1969). The extractant contained 0.01M EDTA (ethylenediamine-tetraacetic acid) plus 1M $(NH_4)_2CO_3$ adjusted to pH 8.6 using NH_4OH. 20 g soil samples were shaken with 40 ml of the extracting solution for 30 minutes and then filtered.

The 0.1N HCl extractable micronutrients were determined following the procedure of Cox and Wear (1977). Two grams of soil were mixed with 50 ml of the extractant, shaken for 30 minutes and filtered. Micronutrients concentration in all the above extraction procedures was determined by atomic absorption spectrophotometry.

3.4 Pot experiment

3.4.1 Preparation of potted soils

Ten soils from selected rice growing areas of Morogoro, Mbeya and Coast regions were used in a pot experiment carried out at SUA. Four kilograms of each soil were weighed into a clean five litres plastic pot. The plastic pots had drainage holes at the bottom which were plugged with cotton wool to prevent soil loss. Appropriate quantities of all nutrients except N were thoroughly mixed with the soil samples before sowing. Six treatments designated as shown below were tested:

(i) $N_0P_0K_0Zn_0Fe_0$

(ii) $N_{200}P_0K_0Zn_0Fe_0$

(iii) $N_{200}P_{50}K_0Zn_0Fe_0$

(iv) $N_{200}P_{50}K_{50}Zn_0Fe_0$

(v) $N_{200}P_{50}K_{50}Zn_5Fe_0$

(vi) $N_{200}P_{50}K_{50}Zn_5Fe_{20}$

The subscript numbers on the nutrients indicate the rates of the different nutrients in mg/kg soil added to the soil. The treatments were replicated three times and arranged in a randomized complete block design in the glasshouse.

3.4.2 Cultural practises in the glasshouse

Pre-germinated seeds were transplanted at the rate of 10 seedlings/pot and thinned to 5 plants/pot fourteen days after planting (DAP). A bowl was placed under each plastic pot to collect excess solution flowing out of the pot. Water content was maintained at FC for the first 21 DAP after which the pots were flooded soon after the first N dose of 1904.76 mg sulphate of ammonia/pot was applied. Before flooding, the bowls retaining leachate were removed and replaced by 12 L plastic pots to enable flooding of the pots. The second N dose was applied 36 DAP.

Shoots were harvested 51 DAP by cutting at 1 cm above the soil surface. The shoots were washed in 0.5N HCl and rinsed twice in distilled water. The samples were then placed in paper bags and dried in the oven at 65°C for72 hrs. The samples were weighed to obtain DM yield and then chopped to pieces of about 1 cm and ground using a cyclone sample mill with stainless steel blades to a fineness of less than 1 mm.

3.5 Data analysis and interpretation

The DM response to application of N, P, K, Zn and Fe and the uptake of these nutrients by rice plants were

subjected to analysis of variance using the statigraphics programme and means were compared using Duncan Multiple Range Test. Percentage yield was calculated to estimate the response to N, P, K, Zn and Fe using the following formula defined by Sanchez (1976).

$$\% \text{ yield} = \frac{\text{DM yield of the treatment control}}{\text{DM yield with all nutrients}} \times 100$$

For the selection of suitable method for assessing the availability of N, P, Zn and Fe, simple correlation relationships were obtained using the statigraphics programme. The simple correlation relationship were calculated by using the DM yield of the controls and the extractable nutrients (N, P, Zn and Fe) by different methods. The graphical method of Cate and Nelson (Cate and Nelson, 1965) was used to estimate the critical levels of a particular nutrient using a particular method. This was done by drawing a scatter diagram of the relationship between extractable nutrient and percentage yield.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Physico - chemical properties of the soils

The physico - chemical properties of the soils used in the pot experiment are summarized in Table 2. The data indicate wide ranges in physical and chemical properties of the soils used in this study. The soil pH ranged from 4.9 to 6.7. The extreme pH values were obtained in Kilangali and Kapunga soils, respectively. This pH range is categorized by Landon (1984) as low to medium. The results also indicate that, nine of the soils have medium pH range of 5.0 to 7.0 and only one soil acidic. The pH range obtained in this study is within the pH range of 4.5 to 6.6 reported by van Breeman (1980) to be satisfactory for rice production.

The ranges of exchangeable bases were: Ca^{2+} 1.55 to 12.25 cmol (+)/kg, Mg^{2+} 0.53 to 9.55 cmol (+)/kg, Na^{+} 0.24 to 2.70 cmol (+)/kg and K^{+} 0.21 to 1.19 cmol (+)/kg (Table 2). The results from this study indicate that among the exchangeable bases, Ca^{2+} was the most abundant followed by Mg^{2+}, Na^{+} and lastly K^{+}. Similar findings were obtained by Msolla *et al.*, (1994), Bashiru (1992) and Ussiri (1992) in

Table 2. Some physico - chemical properties of the soils used in pot experiment

Location	pH	Exch.bases (cmol (+)/kg)				CEC (cmol/kg)	Soil separates (%)			
	(H_2O)	Ca	Mg	Na	K		sand	silt	clay	TC[1]
Kilangali	4.9	6.76	3.90	0.39	0.47	19.35	38.1	10.0	51.9	C
Mlali	5.9	8.67	6.12	0.56	0.37	19.43	30.6	35.7	33.7	CL
Mkindo	5.8	3.39	0.67	0.24	0.21	7.67	70.2	7.8	22.0	SCL
Mgomba	5.6	9.05	5.93	0.73	1.19	24.10	6.5	16.8	76.7	C
Kigongoni	5.5	12.25	9.55	2.70	0.60	40.63	1.6	13.1	85.3	C
Ruvu NAFCO	5.6	9.08	7.16	0.70	0.69	31.87	13.0	14.9	72.1	C
Ruvu sec. school	5.9	8.75	5.64	0.75	0.26	24.35	29.4	12.6	58.0	C
Majengo	5.7	6.55	1.96	0.44	1.07	15.89	35.2	29.2	35.6	CL
Malenga	5.5	1.55	0.69	0.43	0.35	8.23	35.0	24.3	40.7	C
Kapunga	6.7	5.37	0.53	2.03	1.05	9.53	16.1	16.5	67.4	C

1 = Textural Class, C = clay; CL = clay loam ; SCL = sand clay loam

production basing on their good water holding capacity and good nutrient supply (De Datta, 1981; Moorman and Veldkamp, 1978). This indicates that all the soils used in this study are suitable for rice production. However, Moorman and Veldkamp, (1978) ranked clayey soils as being the best for paddy production.

4.2 Nutrients availability indices

4.2.1 Nitrogen

Available N was evaluated using three indices namely organic carbon (OC), total N and alkaline $KMnO_4$. The first two indices are standard methods recommended for routine soil analysis in Tanzania, while alkaline $KMnO_4$ method has been found to work better in a number of soils. Soil test values for the three indices of N availability are given in Table 3.

Total N values ranged from 0.08 to 0.20% with a mean value of 0.13% (Table 3). Landon (1984) categorized soil total N as follows: very high (> 1.0), high (0.5 - 1.0), medium (0.2 - 0.5), low (0.1 - 0.2) and very low (< 0.1). The values of total N from this study indicate that three out of ten soils are very low in total N and seven soils are low in total N. The values of total N obtained in this study also indicate that seven soils have total N

Table 3. Nitrogen contents of the experimental soils as estimated by three indices

Location	Total N (%)	Organic C (%)	Alkaline $KMnO_4$ (mg/kg)
Kilangali	0.13	1.59	257.60
Mlali	0.19	2.49	257.60
Mkindo	0.08	1.49	128.80
Mgomba	0.18	2.04	257.60
Kigongoni	0.12	1.31	386.40
Ruvu NAFCO	0.11	1.12	193.20
Ruvu sec. school	0.08	1.18	257.60
Majengo	0.08	0.93	193.20
Malenga	0.10	0.99	193.20
Kapunga	0.20	1.89	322.00
Mean	0.13	1.50	244.72

below the critical level of 0.15% established by Singh *et al.* (1976) for maize in soils of Morogoro, Tanzania.

Organic carbon values ranged from 0.93 to 2.49% with a mean value of 1.50% (Table 3). Landon (1984) categorized organic carbon content as follows: very high (> 20), high (10 - 20), medium (4 -10), low (2 - 4) and very low (< 2). The results from this study show that all soils have low organic carbon which also indicates that they have low levels of organic matter content. Studies in rice soils of Tanzania by Msolla *et al.*, (1994) and Bashiru (1992) also gave low organic carbon content in soils of Tabora and Morogoro regions, respectively. These results also demostrate that three out of ten soils have organic carbon values greater than the critical level of 1.75% established by Singh *et al.* (1976) in soils of Morogoro.

Alkaline-$KMnO_4$ N values ranged from 128.8 to 322.0 mg/kg with a mean value of 244.72 mg/kg (Table 3). Results from this study indicate that only one soil (Mkindo) had Alkaline-$KMnO_4$ N below the critical level of 190 ppm established by Singh *et al.* (1976) for maize in soils of Morogoro.

4.2.2 Phosphorus

Three indices for P availability were evaluated in this study. These were Bray-1, Olsen and filter paper strip (Pi). The Bray-1 and Olsen methods were chosen based on their recommendation as standard methods for Tanzanian soils (Singh *et al.*, 1977; National Soil Service, 1990). The filter paper strip (Pi) method had recently been suggested as a good method for evaluating P availability in some rice soils in Tanzania (Semoka *et al.*, 1996).

The ranges for extractable P using the three indices are shown in Table 4. The Bray-1 extractable P ranged from 1.2 to 24.5 mg/kg (Table 4). Landon (1984) categorized extractable P in soils as: high (> 50), medium (15 - 50) and low (<15). The results of this study show that six soils are low in available P and four soils have medium P supply. Except for the Malenga and Ruvu secondary school, the rest of the soils have extractable P values above the critical levels of 4.35 and 3.51 mg/kg established by Mutagwaba (1986) and Ussiri (1992) for maize soils of Mbeya region and of Morogoro district, respectively. Nine of the 10 soils used in this study had extractable P values below the critical level of 25 and 20 mg/kg suggested by Singh *et al.* (1977) and Semoka *et al.* (1996) in some soils of Morogoro district, respectively. Mlali,

Table 4. Extractable phosphorus as determined by three extractants

Location	Bray -1	Olsen	Pi
	mg/kg		
Kilangali	6.4	66.1	15.4
Mlali	13.4	38.2	24.7
Mkindo	24.5	80.2	64.5
Mgomba	10.6	48.2	24.3
Kigongoni	5.2	15.9	8.2
Ruvu NAFCO	4.7	13.0	7.4
Ruvu sec. school	1.6	6.8	3.9
Majengo	15.0	50.5	28.4
Malenga	1.2	6.3	4.1
Kapunga	7.2	9.5	5.6
Mean	9.0	33.5	18.6

Mkindo, Mgomba and Majengo soils have extractable P above the critical value of 9 mg/kg established by Smyth and Gravo (1990) in Brazilian Amazon Oxisols.

The Olsen extractable P ranged from 6.3 to 80.2 mg/kg with a mean value of 33.5 mg/kg (Table 4). Basing on the categorization of extractable P by Landon (1984), the available P from Kilangali, Mkindo and Majengo are ranked as high; Mlali, Mgomba and Kigongoni as medium and the rest as low. All the soils used in this study had extraxtable P values greater than the critical value of 4.25 mg/kg reported by Jones *et al.* (1982) in soils of Punjab, India. Ruvu secondary shool, Malenga and Kapunga soils have extractable P values lower than the critical level of 10.5 mg/kg established by Ussiri (1992) for some soils of Morogoro district, Tanzania.

The Pi extractable P values ranged from 4.1 to 64.5 mg/kg with a mean value of 18.6 mg/kg (Table 4). These results differed from those of Menon *et al.* (1989a) who obtained higher extractable P using Pi method as compared to other methods which also included Bray-1 and Olsen methods. Only one soil (Mkindo) had extractable P value greater than the critical value of 35.0 mg/kg suggested by Semoka *et al.* (1996) in some soils of Morogoro district.

4.2:3 Zinc

The extractable Zn data extracted by 0.1N HCl, 0.005M DTPA and 0.01M EDTA-$(NH_4)_2CO_3$ are given on Table 5. The results demostrate that the ranges of extractable Zn in these soils were 5.3 to 10.3 mg/kg for 0.1N HCl, 0.8 to 3.3 mg/kg for DTPA and 1.8 to 4.8 for EDTA-$(NH_4)_2CO_3$. The average extractable Zn values were 6.4 mg/kg for 0.1N HCl, 2.3 mg/kg for DTPA and 3.0 mg/kg for EDTA-$(NH_4)_2CO_3$. The quantities of Zn extracted are ranked in the order: 0.1N HCl > 0.01M EDTA-$(NH_4)_2CO_3$ > 0.005M DTPA.

The values of 0.1N HCl extractable Zn from this study are higher than the critical values of 3.3 mg/kg reported in some soils of Morogoro district (Nzabayanya and Mnkeni, 1985), 0.28 mg/kg in soils of Iringa district (Mkangwa, 1992) and 0.88 mg/kg in soils of Igunga and Nzega districts in Tabora region (Msolla, 1991). Sims and Johnson (1991) reported a soil critical range of 1.0 to 5.0 mg/kg which also indicate that all soils used in this study had extractable Zn values above this critical range. Except Mlali and Ruvu NAFCO, the rest of the soils have extractable Zn values within the range of 1.0 to 7.5 mg/kg Zn for this extractant reported by Sanchez (1976) in tropical soils. The higher values of 0.1N HCl extractable Zn levels found in this study is probably due to higher

Table 5. Extractable zinc as determined by 0.1N HCl, 0.005M DTPA and 0.01M EDTA-$(NH_4)_2CO_3$

Location	0.1N HCl	0.005M DTPA	0.01M EDTA-$(NH_4)_2CO_3$
	mg/kg		
Kilangali	5.5	2.0	3.2
Mlali	10.3	2.4	2.7
Mkindo	5.3	3.2	3.1
Mgomba	5.8	2.1	2.3
Kigongoni	6.0	2.0	1.8
Ruvu NAFCO	8.0	3.3	3.2
Ruvu sec.school	6.0	3.2	4.8
Majengo	6.0	1.7	3.1
Malenga	5.3	2.3	3.3
Kapunga	5.8	0.8	2.5
Mean	6.4	2.3	3.0

clay content of the soil as postulated by Singh *et al.* (1987) and Meelu and Randhawa (1973).

The quantities of extractable Zn by DTPA from this study are lower than the critical level of 3.7 mg/kg established by Kamasho and Singh (1982) in volcanic soils of Mbeya but higher than the critical level of 0.5 mg/kg reported by Brown *et al.* (1971) in soils of Califonia, U.S.A.. Except Kapunga soils, the rest of the soils had extractable Zn values greater than the critical value of 1.18 mg/kg established by Sakal *et al.* (1984) in some rice soils of India. All the soils used in this study had extactable Zn values greater than the critical value of 0.85 mg/kg reported by Nzabayanya and Mnkeni (1985) in some soils of Morogoro and, Tanzania.

The EDTA-$(NH_4)_2CO_3$ extractable Zn values are higher than the reported critical values of 1.4 mg/kg (Trieweiller and Lindsay, 1969), 1.0 mg/kg (Singh and Takkar, 1981), 1.5 ppm (Randhawa *et al.*, 1978), 0.6 mg/kg (Bashiru, 1992) and 0.86 mg/kg (Msolla, 1991). Mlali, Mgomba, Kigongoni and Kapunga had extractable Zn values below the critical level of 2.8 mg/kg tentatively suggested by Semoka *et al.* (1996) in some rice soils of Morogoro district.

4.2.4 Iron

Three extractants were evaluated for available Fe in soils viz: 0.1N HCl, 0.005M DTPA and 0.01M EDTA-$(NH_4)_2CO_3$. Data on available Fe for these extractants are shown on Table 6. The data showed a range of 172.5 to 2227.5 mg/kg for 0.1N HCl, 57.4 to 678.8 mg/kg for 0.005M DTPA and 6.6 to 1034.8 mg/kg for EDTA -$(NH_4)_2CO_3$. Their respective mean values are 1099.5, 227.0 and 221.1 mg/kg. These indicate that 0.1N HCl extracted the highest amount of Fe followed by DTPA and lastly EDTA-$(NH_4)_2CO_3$ in that order. The higher extractable Fe by 0.1N HCl in these soils could be due to the acidifying nature of the extractant which tends to acidify the soil thereby solubilizing more Fe from Fe containing compounds like Fe_2O_3 (Hematite), $Fe(OH)_3.nH_2O$ (amorphous hydroxide) and $Fe_3(OH)_8$ (ferrosoferric hydroxide).

The values of DTPA extractable Fe from this study are higher than the critical range of 2.5 to 5.0 mg/kg reported by Randhawa *et al.* (1978) and Sims and Johnson (1991).

Table 6. Extractable Fe as determined by 0.1N HCl, DTPA and 0.01M EDTA $(NH_4)_2CO_3$

Location	0.1N HCl	0.05M DTPA	0.01M EDTA-$(NH_4)_2CO_3$
	mg/kg		
Kilangali	2025.0	490.4	260.0
Mlali	1087.5	127.8	49.0
Mkindo	2227.5	678.8	1034.8
Mgomba	1035.0	162.0	42.6
Kigongoni	555.0	107.2	11.8
Ruvu NAFCO	917.5	160.4	34.4
Ruvu sec. school	172.5	57.4	6.6
Majengo	1127.5	216.8	110.8
Malenga	1302.5	191.6	570.4
Kapunga	545.0	77.8	90.2
Mean	1099.5	227.0	221.1

4.3 Rice response to different nutrients

4.3.1 Performance of rice plants

Visual observations for nutrients disorders on rice plants were made starting from 14 days after planting (DAP). Yellowish green colour of leaves was observed in all pots before the application of the first N dose. At 21 DAP, the leaves of plants from the absolute control pots were all yellowish green which is a characteristic symptom of N deficiency and the plants were also stunted. Generally plants grown on soils from Ruvu secondary school, Ruvu NAFCO, Malenga and Kapunga soils were more stunted and the yellowish green colour of leaves was observed in almost all pots indicating that probably N deficiency was very severe in these soils.

Phosphorus deficiency became clear 28 DAP. Few tillers were observed in almost all pots that were not treated with P (absolute control and N treated pots) as compared with those treated with P. Another deficiency symptom for P observed was the drying of older leaves. This was noted in all pots before flooding of the pots and disappeared thereafter suggesting that P availability might have increased after flooding. Flooding is known to increase P availability in the wetland rice culture (Chang, 1976). Mkindo soil was exceptional in that there was no clear

difference in plant performance between treatments with P and those without P. This was possibly due to high levels of extractable P in this soil (Table 4).

No vivid deficiency symptoms were observed for other nutrients i.e. K, Zn and Fe. In some soils (Mgomba, Kilangali and Mlali), intervenal chlorosis was observed but this could not be attributed to any particular element.

4.3.2 Dry matter (DM) yield and percent yield (PY)

Tables 7 and 8 give the response of rice to N, P, K, Zn and Fe application in terms of DM yield and PY, respectively. On average, application of all nutrients together gave the highest response over the control. The mean value for DM of the control was 3.3 mg/pot while that of all nutrients was 22.1 mg/pot.

Plants in all the soils tested gave significant responses to N application indicating that N was a limiting nutrient in these soils. Higher response were obtained in Kilangali, Mkindo, Mgomba and Majengo soils. The higher responses in these soils were expected because of their relatively lower values of organic matter and relatively higher amounts of extractable P. Similar responses to N

Table 7. Rice response to nitrogen (N), phosphorus (P), potasium (K), zinc (Zn) and iron (Fe) applied to soils from different rice growing areas of Tanzania

Location	Treatments					
	Control	N	NP	NPK	NPKZn	NPKZnFe
	g/pot					
Kilangali	5.5[b]	23.6[a]	25.0[a]	27.0[a]	27.3[a]	25.8[a]
Mlali	5.9[c]	18.5[b]	22.9[a]	21.7[ab]	24.3[a]	24.2[a]
Mkindo	3.9[b]	19.6[a]	19.4[a]	21.5[a]	19.8[a]	20.8[a]
Mgomba	4.1[b]	25.7[a]	31.2[a]	28.0[a]	28.2[a]	29.0[a]
Kigongoni	2.2[d]	13.5[c]	21.0[b]	24.0[a]	23.9[a]	23.1[a]
Ruvu NAFCO	2.7[b]	8.4[b]	19.6[a]	16.3[a]	19.3[a]	20.1[a]
Ruvu sec. school	1.5[c]	3.3[b]	16.2[a]	16.5[a]	17.3[a]	17.3[a]
Majengo	2.8[b]	23.8[a]	23.8[a]	25.0[a]	23.4[a]	24.5[a]
Malenga	1.9[c]	5.3[b]	14.4[a]	14.2[a]	14.4[a]	15.8[a]
Kapunga	2.5[c]	8.0[b]	20.9[a]	20.4[a]	20.6[a]	20.7[a]
Mean	3.3	15.0	21.5	21.5	21.8	22.1

Mean in the same row followed by the same letter are not significantly different ($P < 0.05$) using Duncan multiple range test.

Table 8. Percent yield (PY) data for response of rice to application of nitrogen (N), phosphorus (P), potasium (K), zinc (Zn) and iron (Fe) to different soils

Location	PY for N	PY for NP	PY for NPK	PY for NPKZn	PY for NPKZnFe
Kilangali	23.4	94.5	92.7	98.6	106.1
Mlali	32.1	80.6	105.4	89.6	100.1
Mkindo	19.6	101.0	90.5	108.5	95.2
Mgomba	16.0	82.5	111.1	99.3	97.4
Kigongoni	16.3	64.2	87.2	100.6	103.3
Ruvu NAFCO	32.2	42.6	120.6	84.4	95.8
Ruvu sec. school	44.3	20.4	98.6	95.2	99.9
Majengo	11.7	100.0	95.3	106.6	95.6
Malenga	36.5	36.5	101.5	98.5	91.4
Kapunga	31.8	38.2	102.4	98.9	99.3

were reported by Temu (1985) in soils of Mbarali (Mbeya region), Semoka and Shenkalwa (1985) and Semoka *et al.* (1996) in soils of Morogoro district both from Tanzania. In India, Singh and Kumar (1996) found good responses to N application when N rates were increased from 0 to 200 kg N/ha under field conditions. They found the mean grain yield for the control to be 3.7 tonnes/ha and 8.0 tonnes/ha when 200 kg N/ha was applied.

The data from this study (Table 7) also show that plants grown in six soils out of ten responded to P application indicating that P is also a limiting nutrient in these soils. In the soil from Ruvu secondary school, P was more limiting than N while in Malenga, Kapunga and Ruvu NAFCO, P was comparable to N in increasing rice yield. Thus P application in these soils increased DM yield by two times or more. The significant increase in DM yield due to the application of N and P together had also been obtained by Semoka and Shenkalwa (1985) and Semoka *et al.*(1996) in rice soils of Morogoro district. Response to P in this study ranged from -1.0% in Mkindo to 79.6% in Ruvu secondary school (Table 8). This range is above that obtained by Lian (1989) in rice soils of Taiwan which ranged from 5.4 to 6.7%. No significant response to P was obtained in Kilangali, Mkindo, Mgomba and Majengo soils. Lack of response to P application in these soils was

probably due to their relatively high contents of extractable P (Table 4).

Except in Kigongoni soil, potassium application did not significantly affect DM yield in other soils. In five of the soils, K slightly increased DM yield while in the other five K caused slight decreases in yield. These results suggested that K was not limiting in nine of the soils tested. The results of exchangeable K from this study (Table 2) also show that nine soils had exchangeable K values greater than the critical level of 0.26 cmol (+)/kg reported by Jones *et al.* (1982). Semoka and Shenkalwa (1985) on the other hand obtained response to K application when K was applied in combination with 200 kg N/ha and 60 kg P/ha in a pot experiment when the exchangeable K values were 0.52 and 0.32 cmol (+)/kg in the top and sub-soils, respectively. Despite the higher amounts of exchangeable K contained in the soils used in this study (Table 2), lack of significant response to K application may among other things, be attributed to enhanced K release following flooding as reported by IITA (1984).

In general, Zn application did not increase DM yield significantly although in Ruvu NAFCO and Mlali soils increases of 15.5% and 10.4%, respectively were observed.

The lack of a significant response to Zn in Kapunga soil was not expected since the extractable Zn values by DTPA and EDTA were below critical values established by Msolla (1991) in soils of Tabora region, Bashiru (1992) in Benchmark soils of Morogoro and Singh and Takkar (1981) in soils of India. In addition, Ruvu secondary school with EDTA extractable Zn of 4.8 mg/kg gave a response of 4.8% due to Zn application (Table 8) while Kigongoni with 1.8 mg/kg extractable Zn gave a negative response to Zn application. These contradictory results suggests that either the extractants were not reliable predictors of Zn availability in these soils or that there were other factors that were responsible for Zn uptake and which were not evaluated in this study.

There was no significant increase in DM yield from all soils due to Fe application (Table 7) indicating that Fe is also not a problem in the study area. This was expected since all the soils studied had very high extractable Fe values far above the critical level of 2.0 ppm found to be adequate for healthy growth of rice plants (Agarwal and Sharma, 1979).

4.4 Evaluation of nutrient availability indices

4.4.1 Nitrogen

The correlation coefficients between soil test values for N and the DM yield of the control treatments are shown on Table 9. The results show a significant correlation ($r = 0.73$, $p < 0.05$) between DM yield of the control and organic carbon indicating that this index was a good predictor of N supplying capacities of soils. These results are in agreement with the findings of Singh and Tripathi (1970) and Singh *et al.* (1976) who concluded that OC could serve as an alternative test for assessing N supplying capacities of soils of India and Morogoro, Tanzania, respectively. The results however contradict earlier findings that organic carbon was a poor indicator of N supplying capacities of soils (Semoka *et al.*, 1996). Total N and alkaline-$KMnO_4$ N showed poor and non significant correlations with DM yield. This differed from results by Singh and Tripathi (1970) and Singh *et al.* (1976) who reported higher and significant correlation between alkaline-$KMnO_4$ N and percentage yield of crops and recommended it for use in assessing N supplying capacities of soils.

Since plants in all the soils used in this study responded appreciably to N application (response > 50%), it was not

Table 9. Correlation coefficients (r) for relationships between N determined by three methods and the DM yield of the control treatments

Method	(r)
Total N	0.46^{ns}
Organic carbon	0.73^{*}
Alkaline $KMnO_4$	-0.11^{ns}

ns = non significant

Table 10. Correlation coefficients (r) for relationship between extractable P and DM yield of the control treatments

Method	(r)	critical level (mg/kg)
Bray-1	0.61^{ns}	10.0
Olsen	0.85^{**}	20.0
Pi	0.61^{ns}	26.0

ns = non significant, ** significant at 1%

possible to establish a critical level for N.

4.4.2 Phosphorus

Table 10 gives the correlation coefficients for the relationship between extractable P by different extractants and the DM yield of the control treatments. Among the extractants tested, the Olsen method gave the highest and significant correlation coefficient ($r = 0.85$, $p < 0.01$). Bray-1 and Pi methods gave the same r values which was non significant ($r = 0.61$) and lower than that of the Olsen method. Walmsley and Cornforth (1973) also found that extractable P by the Olsen method correlated better ($r = 0.37$) with percentage yield of maize in pot experiment, and they recommended it for use in West Indian soils on the basis that it is less sensitive to changes with soil properties. Similar findings were also obtained by Mutagwaba (1986) and Ussiri (1992) in soils of Mbeya and Morogoro districts, Tanzania, respectively. The results from this study differed from those of Menon *et al.* (1989b) who obtained better correlation coefficients ($r = 0.837$) between DM yield of maize and Pi extractable P which was significantly higher than that of Bray-1 and Olsen. Menon *et al.* (1992) on the other hand revealed that P extracted by Pi and Olsen correlated equally with DM yield of maize grown in soils fertilized with single super

phosphate or acidulated phosphate rock in a glass house experiment. Similarly, the report by Semoka *et al.* (1996) showed different results from this study. In their study they obtained a higher and significant correlation coefficient (r = 0.60) for the Pi method followed by Olsen and Bray-1 both of which were non significant. The close correlation between Bray-1 and Pi from this study suggests that probably both extractants extract P from the same source.

Figures 1 (a to c) shows the scatter plots for the relationship between P extracted by the three extractants and the percentage yield of the control. Like the correlation relations, the Olsen method showed a better distribution of points than the other methods. Bray-1 and Pi methods had the same distribution pattern. The results show that the critical levels for the extractants are 10.0, 20.0 and 26.0 mg/kg for Bray-1, Olsen and Pi, respectively. The critical levels for Bray-1 extractable P from this study is comparable to that of 9 mg/kg reported by Smyth and Gravo (1990) for Brazilian Amazon Oxisols. However the Bray-1 and Pi P critical levels from this study differed from those of Semoka *et al.* (1996) who obtained critical values of 20.0 mg/kg for Bray-1 and 35.0 mg/kg for Pi. This difference can be attributed to differences in the physical and chemical Figure 1.

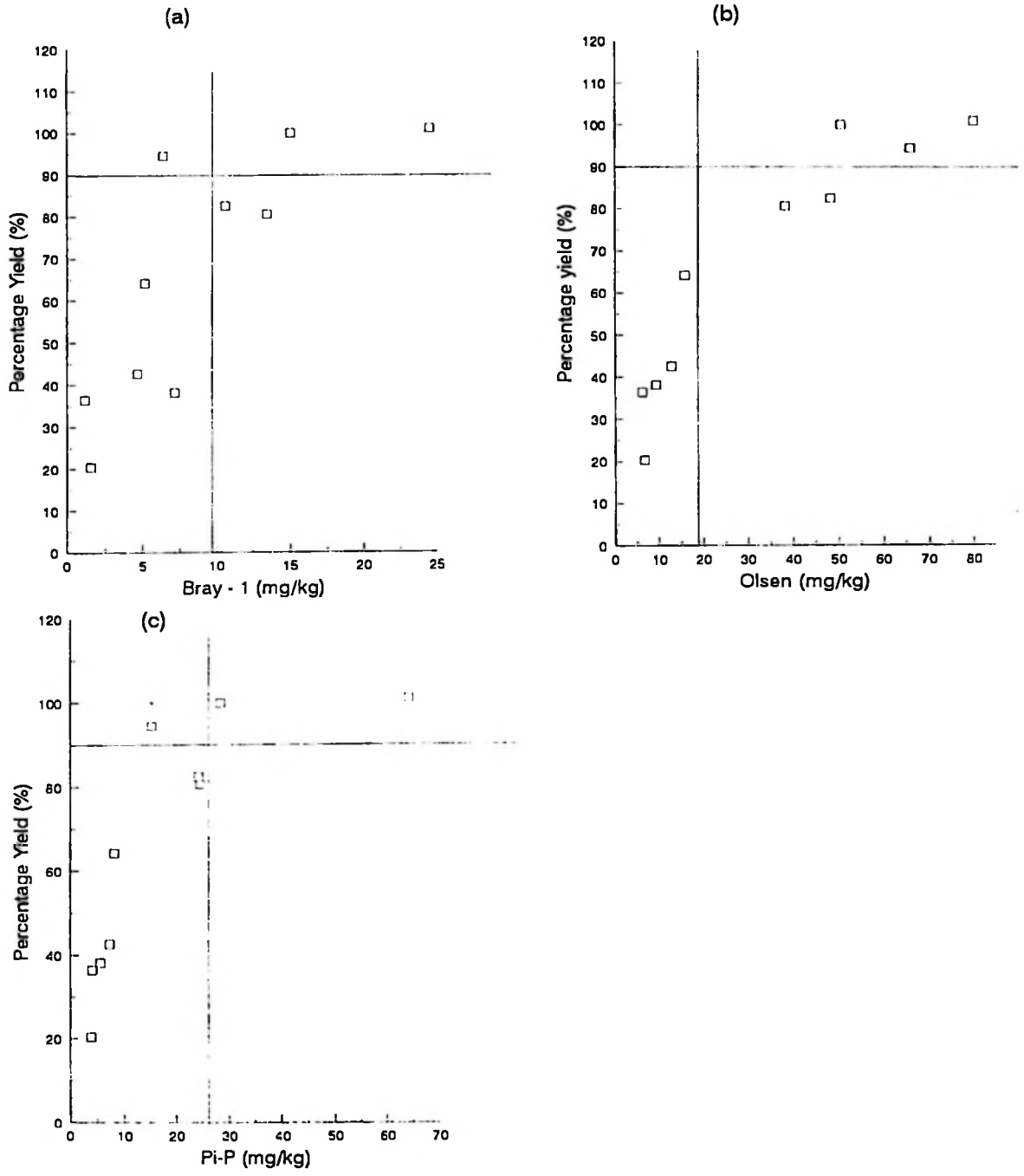

Figure 1. Relationship between P extracted by Bray-1, Olsen and Pi and percentage yield of rice

properties of the soils used in this study. For example, Semoka *et al.* (1996) used soils with pH range of 6.3 to 7.9 while the pH of the soils used in this study ranged from 4.9 to 6.7 (Table 2).

4.4.3 Zinc

Table 11 shows the correlation coefficients (r) between extractable Zn by three extractants and the DM yields of the control treatments. The results show that none of the correlation coefficients were significant, indicating poor relationships between the two variables. This further showed that none of these extractants was adequate in assessing Zn availability in the soils.

Since none of the soils tested responded to Zn application, it was not possible to establish a critical Zn level for these soils. However, the results indicated that Zn was not limiting in any of the soils tested. Thus, although Zn deficiency is known to be a problem in some areas of Tanzania, e.g. Igunga and Nzega districts and parts of Morogoro districts, it does not appear to be a widely spread problem in all rice growing areas.

Table 11. Correlation coefficients (r) for relationship between extractable Zn and dry matter yield of the control treatment

Extractant	(r)
0.1N HCl	-0.12^{ns}
0.005M DTPA (pH 7.3)	-0.42^{ns}
0.01M EDTA-$(NH_4)_2CO_3$ (pH 8.6)	-0.53^{ns}

ns= non significant

Table 12. Correlation coefficients (r) for relationship between extractable Fe and dry matter yield of the control treatment

Extractant	(r)
0.1N HCl	0.20^{ns}
0.005M DTPA (pH 7.3)	0.12^{ns}
0.01M EDTA-$(NH_4)_2CO_3$ (pH 8.6)	-0.35^{ns}

ns = non significant

4.4.4 Iron

The correlation relationship between extractable Fe and the DM yield of the control treatments are shown in Table 12. The results indicate that none of the correlation coefficients were significant, suggesting that none of the extractants was adequate in assessing Fe availability in the soils used in this study.

4.5 Nutrients concentration in rice shoots and uptake

4.5.1 Nitrogen

Data for N concentration in rice shoots and uptake are shown on Table 13 and Appendix 2a, respectively. Nitrogen concentration in the control treatment ranged from 0.86% in Malenga to 1.44% in Mlali with a mean value of 1.05% (Table 13). These values are below the optimum N concentration of 1.8 to 2.5% reported by Wallihan *et al.* (1974) confirming that all the soils tested could not supply sufficient N to rice. Nitrogen concentration increased significantly over the control after N application in all soils. Nitrogen concentration in plants from N treated soils ranged from 2.27 to 3.24% with a mean value of 2.74%. This range is within the optimum range reported by Wallihan *et al.* (1974) and above the critical level of 2.37% reported by Temu (1985) in soils of Mbarali

Table 13. Effects of N, P, K, Zn and Fe application on N concentration in rice shoots

Location	N Concentration (%)					
	Control	N	NP	NPK	NPKZn	NPKZnFe
Kilangali	1.03^{b}	2.55^{a}	2.45^{a}	2.51^{a}	2.45^{a}	2.73^{a}
Mlali	1.44^{d}	3.16^{b}	2.97^{bc}	3.46^{a}	2.72^{c}	2.84^{b}
Mkindo	1.13^{b}	3.24^{a}	3.11^{a}	2.91^{a}	3.18^{a}	2.98^{a}
Mgomba	0.95^{b}	2.27^{a}	2.13^{a}	2.20^{a}	2.23^{a}	2.24^{a}
Kigongoni	1.02^{c}	2.70^{a}	2.48^{ab}	2.10^{b}	2.45^{ab}	2.54^{a}
Ruvu NAFCO	0.97^{b}	2.64^{a}	2.49^{a}	2.48^{a}	2.34^{a}	2.40^{a}
Ruvu sec. school	1.13^{b}	2.83^{a}	2.64^{a}	2.80^{a}	2.70^{a}	2.79^{a}
Majengo	0.97^{c}	2.35^{ab}	2.65^{a}	2.60^{a}	2.51^{a}	1.98^{b}
Malenga	0.86^{b}	3.00^{a}	3.19^{a}	3.33^{a}	3.27^{a}	3.26^{a}
Kapunga	1.05^{b}	2.88^{a}	2.84^{a}	2.79^{a}	2.91^{a}	2.88^{a}
Mean	1.05^{b}	2.74^{a}	2.69^{a}	2.72^{a}	2.68^{a}	2.66^{a}

Values in the same row followed by the same letter are not significantly different at 5% using Duncan multiple range test

rice farm, in Tanzania. Thus the application of N at 200 mg/kg soil corrected N deficiency in all soils. The application of Zn and Fe to the soil from Mlali decreased nitrogen concentration significantly while in Kigongoni a significant decrease in N concentration was due to K application. In general, when the means over all the soils are compared, application of nutrients other than N did not significantly affect N concentration in rice shoots.

The data on N uptake (Appendix 2a) also indicate that N application significantly increase N uptake from all soils over the control. Mean N uptake in the control was 34.92 mg/pot which is significantly lower than the uptake from treatments which received N, P, K, Zn and Fe. Kigongoni, Ruvu NAFCO, Ruvu secondary school, Malenga and Kapunga had significantly higher N uptake when N and P were applied together than when N was applied alone. This observation also agrees with the results of Semoka and Shenkalwa (1985) who obtained a positive interaction of N and P on N uptake in soils of Morogoro district, Tanzania.

4.5.2 Phosphorus

Data for P concentration in rice shoots and uptake are shown on Table 14 and Appendix 2b, respectively. Phosphorus concentration in the P control treatment ranged

Table 14. Effects of N, P, K, Zn and Fe application on P concentration in rice shoots

Location	P Concentration (%)					
	Control	N	NP	NPK	NPKZn	NPKZnFe
Kilangali	0.29^{b}	0.24^{b}	0.26^{b}	0.30^{b}	0.52^{a}	0.27^{b}
Mlali	0.30^{ab}	0.23^{c}	0.26^{b}	0.32^{ab}	0.34^{a}	0.27^{bc}
Mkindo	0.30^{b}	0.35^{ab}	0.34^{ab}	0.43^{a}	0.36^{ab}	0.42^{a}
Mgomba	0.23^{ab}	0.16^{b}	0.18^{ab}	0.21^{ab}	0.25^{a}	0.23^{ab}
Kigongoni	0.18^{a}	0.13^{a}	0.15^{a}	0.15^{a}	0.19^{a}	0.16^{a}
Ruvu NAFCO	0.31^{a}	0.14^{b}	0.18^{b}	0.18^{b}	0.18^{b}	0.19^{b}
Ruvu sec. school	0.24^{a}	0.18^{ab}	0.21^{a}	0.12^{b}	0.16^{ab}	0.2^{ab}
Majengo	0.28^{a}	0.26^{a}	0.23^{a}	0.25^{a}	0.30^{a}	0.30^{a}
Malenga	0.20^{a}	0.11^{a}	0.13^{a}	0.15^{a}	0.16^{a}	0.16^{a}
Kapunga	0.18^{a}	0.14^{ab}	0.08^{b}	0.15^{a}	0.17^{a}	0.17^{a}
Mean	0.25^{a}	0.19^{a}	0.20^{a}	0.23^{a}	0.26^{a}	0.24^{a}

Values in the same row followed by the same letter are not significantly different at 5% using Duncan multiple range test

from 0.11 to 0.35% (Table 14). Malenga, Kigongoni, Ruvu NAFCO and Kapunga had the lowest P concentration. The P concentration values in these soils are higher than the critical value of 0.1% established by Tanaka and Yoshida (1970). Phosphorus application had no significant influence in shoot P concentration except in Mlali. The range of P concentration in the treatment with P application was 0.08 to 0.34%. The lowest P concentration of 0.08% was noted in Kapunga and the highest concentration of 0.34% was recorded in Mkindo. Low P concentration in Kapunga and high P concentration in Mkindo was attributed to the extractable P content in these soils (Table 4). The results from this study indicate that the value of 0.08% is below the critical value of 0.1% reported by Tanaka and Yoshida (1970) which also indicate that the rest of the soils had P concentration above this critical level. Semoka and Shenkalwa (1985) also obtained relatively low P concentration values of 0.09 to 0.19% using three levels of P, i.e. 0, 30 and 60 kg/ha in soils of Morogoro district. Temu (1985) on the other hand obtained slightly higher values ranging from 0.20 to 0.25% at flowering stage under field conditions.

Phosphorus uptake varied considerably between soils (Appendix 2b). In P control treatment (treatment with N

application), P uptake ranged from 5.79 mg/pot in Malenga to 67.79 mg/pot in Mkindo. The results also show that, P application increased P uptake significantly in Mlali, Ruvu NAFCO, Ruvu secondary school and Malenga soils. In Ruvu secondary school and Malenga, P application increased P uptake more than threefold. These soils were severely deficient in P as demostrated by their low extractable P contents (Table 4) and thus P application caused a dramatic increase in DM yields and P uptake. The overall results in P uptake also show wide variation when different nutrients were applied. The results show that more P uptake was obtained when N, P, K and Zn were applied together. These unexpected results contradict earlier findings that P and Zn have antagonistic effects (Lindsay, 1972).

4.5.3 Potassium

The results of K concentration in rice shoots and uptake are shown on Table 15 and Appendix 2c, respectively. Potassium concentration ranged from 1.00% in plants grown in Malenga soil to 2.57% in Majengo soil for the K control (treatment with N and P but no K). When K was applied, K concentration changed from 1.45 to 2.41%. Application of N alone and N plus P significantly decreased K concentration in rice shoots in Mlali, Mkindo and Malenga

Table 15. Effects of N, P, K, Zn and Fe application on K concentration in rice shoots

Location	K Concentration (%)					
	Control	N	NP	NPK	NPKZn	NPKZnFe
Kilangali	2.09^{a}	2.03^{a}	1.92^{a}	2.41^{a}	1.97^{a}	1.81^{a}
Mlali	2.04^{a}	1.12^{c}	1.37^{bc}	1.45^{b}	1.48^{b}	1.52^{b}
Mkindo	1.95^{ab}	1.44^{c}	1.45^{c}	1.66^{bc}	2.12^{a}	1.77^{bc}
Mgomba	1.96^{a}	2.40^{a}	2.33^{a}	2.34^{a}	2.50^{a}	2.54^{a}
Kigongoni	1.82^{c}	2.07^{abc}	1.94^{bc}	1.85^{c}	2.16^{ab}	2.27^{a}
Ruvu NAFCO	1.76^{b}	2.14^{a}	2.35^{a}	2.38^{a}	2.34^{a}	2.37^{a}
Ruvu sec. school	1.99^{a}	1.69^{a}	1.94^{a}	1.82^{a}	1.75^{a}	2.30^{a}
Majengo	1.77^{b}	2.25^{ab}	2.57^{a}	2.22^{ab}	2.14^{ab}	2.18^{ab}
Malenga	1.77^{a}	1.45^{b}	1.00^{c}	1.54^{ab}	1.56^{ab}	1.58^{ab}
Kapunga	1.61^{cd}	1.60^{d}	1.82^{ab}	1.75^{bc}	1.92^{a}	1.89^{ab}
Mean	1.88^{a}	1.82^{a}	1.87^{a}	1.94^{a}	1.99^{a}	2.02^{a}

Values in the same row followed by the same letter are not significantly different at 5% using Duncan multiple range test

soils. These soils had exchangeable K levels of less than 0.4 cmol (+)/kg which are close to the soil critical level 0f 0.26 cmol (+)/kg reported by Jones *et al.* (1982). The results indicated that plants in all soils had K concentration above the critical level of 1.00% established by Tanaka and Yoshida (1970). This accounts for the lack of response to K application in all soils (Table 7) since all soils supplied sufficient amounts of K to plants. However, the three soils where K concentration decreased when N and P were applied suggested that the K supply in these soils was marginal and this needs to be considered in the management of these soils.

Generally, application of N and K significantly increased K uptake while application of the other nutrients did not increase K uptake significantly (Appendix 2c). This also implies that K supply was adequate in almost all soils at least for the immediate cropping.

4.5.4 Zinc

The results of Zn concentration in rice shoots and uptake are shown on Table 16 and Appendix 2d, respectively. The results from this study indicated no significant increase in Zn concentration over Zn control treatment (Table 16).

Table 16. Effects of N, P, K, Zn and Fe application on Zn concentration in rice shoots

Location	Zn Concentration (ppm)					
	Control	N	NP	NPK	NPKZn	NPKZnFe
Kilangali	33.3^{a}	40.0^{a}	43.0^{a}	43.3^{a}	38.9^{a}	25.6^{a}
Mlali	35.6^{b}	48.9^{a}	46.7^{a}	54.4^{a}	56.7^{a}	53.3^{a}
Mkindo	22.2^{b}	41.1^{a}	40.0^{a}	38.9^{a}	48.9^{a}	40.0^{a}
Mgomba	26.7^{ab}	21.1^{bc}	13.3^{c}	22.2^{bc}	34.4^{a}	31.1^{ab}
Kigongoni	34.4^{b}	35.6^{ab}	30.0^{b}	28.9^{b}	42.2^{ab}	47.8^{a}
Ruvu NAFCO	84.4^{a}	90.0^{a}	65.6^{a}	54.4^{a}	63.3^{a}	62.2^{a}
Ruvu sec. school	22.2^{c}	33.3^{bc}	32.2^{bc}	50.0^{a}	44.4^{ab}	47.8^{ab}
Majengo	48.9^{a}	71.1^{a}	106.7^{a}	101.1^{a}	75.5^{a}	105.6^{a}
Malenga	45.6^{c}	44.4^{c}	48.9^{bc}	51.1^{bc}	65.6^{ab}	70.0^{a}
Kapunga	52.2^{a}	73.3^{a}	47.8^{a}	48.9^{a}	34.4^{a}	47.8^{a}
Mean	40.5^{a}	49.9^{a}	47.4^{a}	49.3^{a}	50.4^{a}	53.1^{a}

Values in the same row followed by the same letter are not significantly different at 5% using Duncan multiple range test

However, Zn concentration in Mlali and Mkindo increased significantly after N application. Kumar *et al.* (1985) also reported that N application produced a synergistic effects on Zn concentration in leaves and stems. In general all the concentration values are above the critical concentration of 15 mg/kg reported by Katyal and Ponnamperuma (1974) suggesting that all soils supplied sufficient amounts of Zn to plants.

Zinc uptake differed considerably between soils (Appendix 2d). This difference can be accounted for by the difference in physico - chemical properties of the soils (Table 2) and the extractable Zn (Table 5). Plants grown in all soils except Mgomba and Ruvu secondary school showed a significant Zn uptake after N application. This was attributed to the higher DM produced in response to N application. Zinc uptake from Kigongoni and Malenga soils showed a significant increase over the Zn control (treatment with NPK). Results on Appendix 2d also show that application of P significantly increased Zn uptake in Ruvu secondary school contrary to the earlier findings that P depresses Zn availability (Giordano and Mortvedt, 1974). The results from this study also agree with those reported by Giordano and Mortvedt (1974) who, among other things found no consistency of high P rates on the depressing Zn uptake. Since more Zn uptake was observed

even in soils with relatively low extractable Zn, the phenomenon can be related to plant characteristics like root distribution and morphology rather than to the soil.

4.5.5 Iron

Results for Fe concentration and uptake are shown on Table 17 and Appendix 2e, respectively. Iron concentration in rice shoots ranged from 232.2 mg/kg in the Fe control treatment to 480.9 mg/kg in the treatment where Fe was applied (Table 17). Values of Fe concentration in the absolute control are however higher than in treatments with N, P, K, Zn and Fe. The overall mean of Fe concentration also showed a significant increase in Fe concentration in absolute control as compared to other treatments. The values from this study are higher than the critical value of 70 mg/kg reported by Tanaka and Yoshida (1970). They also reported that concentration of 300 mg Fe/kg at tillering stage is likely to cause Fe toxicity. The values from this study are higher than those obtained by van Vorm and van Diest (1979). In their study, they found the Fe concentration to be 161 mg/kg when the plants were harvested at 41 DAP in flooded soil with medium pH. Higher values of Fe concentration were also obtained by Moore and Patrick (1989) who reported leaf Fe concentration values ranging from 25 to 1205 mg/kg. They

Table 17. Effects of N, P, K, Zn and Fe application on Fe concentration in rice shoots

Location	Fe Concentration (ppm)					
	Control	N	NP	NPK	NPKZn	NPKZnFe
Kilangali	448.9^{a}	465.6^{a}	494.4^{a}	412.2^{ab}	370.0^{ab}	206.6^{b}
Mlali	312.2^{a}	294.4^{a}	322.3^{a}	368.9^{a}	316.7^{a}	287.8^{a}
Mkindo	372.2^{a}	530.0^{a}	425.6^{a}	408.9^{a}	405.6^{a}	376.7^{a}
Mgomba	662.2^{a}	323.4^{b}	276.7^{b}	300.0^{b}	375.6^{b}	411.1^{b}
Kigongoni	396.7^{ab}	227.8^{c}	234.4^{c}	270.0^{c}	452.2^{a}	315.6^{bc}
Ruvu NAFCO	478.9^{a}	374.4^{a}	498.9^{a}	562.2^{a}	522.2^{a}	448.9^{a}
Ruvu sec. school	386.7^{a}	294.5^{ab}	288.2^{ab}	272.2^{b}	232.2^{b}	255.6^{b}
Majengo	388.9^{a}	294.5^{a}	367.8^{a}	276.7^{a}	250.0^{a}	216.7^{a}
Malenga	594.4^{a}	262.2^{b}	274.5^{b}	313.3^{b}	267.8^{b}	297.8^{b}
Kapunga	375.6^{a}	366.7^{a}	295.5^{a}	403.3^{a}	246.6^{a}	307.8^{a}
Mean	441.7^{a}	343.3^{b}	347.8^{b}	358.8^{ab}	343.9^{b}	312.5^{b}

Values in the same row followed by the same letter are not significantly different at 5% using Duncan multiple range test

however observed bronzing, a symptom of Fe toxicity in rice in samples with high Fe contents. Since no Fe toxicity was observed in this study, it is possible that the variety used was tolerant to Fe toxicity or that the high Fe concentration in plants may be partly due to contamination during sample preparation.

Data on plant Fe uptake (Appendix 2e) also showed the same trend as in Fe concentration. Since no Fe toxicity was observed despite the high values of extractable Fe, it was suspected that other factors were responsible for Fe uptake by rice plants. Moore and Patrick (1989) suggested ion competition as being the most important factor in determining Fe uptake by rice plants.

6.0 REFERENCES

Agarwal, S.C. and Sharma, C.P. (1979) *Recognising micronutrients disorders of crop plants on the basis of visible symptoms and plant analysis*. Botany Department, Lucknow University, Lucknow, India.

Ahmad, N., Cornforth, I.S. and Walmsley, D. (1973) Methods of measuring available nutrients in West Indian soils. III. Potassium. *Plant and Soil* 39,635-647.

All India Coordinated Rice Improvement Project (AICRIP), (1977) Annual report for 1976. AICRIP, New Delhi, India. pp 267.

Allias, B.H., Bachiki, A.T.B. and Cadlwell, A.G. (1986) Plant response to potassium related to soil tests for potassium fractions in 30 soils from Lousiana. *Plant and Soil* 96,57-67.

Allison, L.E. (1965) Organic Carbon. *In: Methods of soil analysis*. Part 2. (Edited by Black, C.A, Evans, D.D, Ensiminger, L.E, Clark, F.E. and White, J. ...) American Society of Agronomy. Madison, Wisconsin, pp 1367 - 1378.

Bajaj, J.C., Gulati, M.L. and Tamhane, R.V. (1967) Correlation studies of soil tests for available N with N uptake and response of paddy and wheat. *Indian Society of Soil Science Journal* 15,29-33.

Bashiru, H.S. (1992) Response of maize and rice to zinc application on some benchmark soils of Morogoro rural district. M.Sc dissertation, Sokoine University of Agriculture, Morogoro.

Beringer, H. (1985) Adequacy of soil testing for predicting fertilizer requirements. *Plant and Soil* 83,21-37.

Brady, N.C. (1984) *The nature and properties of soils*. 9thed. MacMillan Publishing Co, Inc. New York. pp 750.

Brar, M.S., Singh, B. and Sekhon, G.S. (1980) Leaf analysis for monitoring the fertilizer requirements of peanut. *Communication in Soil Science and Plant Nutrition* 11,335-346.

Bray, R.H. and Kurtz, L.T. (1945) Determination of total carbon and available forms of phosphorus in soils. *Soil Science* 59,39-45.

Bremmer, J.M. (1965) Magnesium oxide Devarda alloy method of soils *In: Methods of soil analysis.* (Edited by Black, C.A., Evans, D.D., Ensiminger, L.E., Clark, F.E. and White, J.L.). American Society of Agronomy, Madison, Wiscosin. pp 1149 - 1179.

Bremner, J.M. and Mulvaney, C.S. (1982) Nitrogen-Total. *In: Methods of soil analysis.* Part 2. 2nd ed. (Edited by Page, A.L., Muller, R.H. and Keeney, D.R.). American Society of Agronomy and Soil Science of America, Inc., Madison, Wisconsin. pp 595 - 624.

Brown, A.J., James, Q. and Eddings, J.L. (1971) A comparison of analytical methods for soil zinc. *Soil Science Society of America Proceedings* 35,105-107.

Bureau of statistics. (1992) Statistics abstract. Ministry of Agriculture Livestock development and Cooperative, Dar es salaam, Tanzania.

Bureau of Statistics. (1993) Statistics Abstract. Ministry of Agriculture, Livestock development and Cooperative. Dar es salaam, Tanzania.

Buresh, R.J. and De Datta, S.K. (1991) Nitrogen dynamics and management in rice - legume cropping

systems. *Advance in Agronomy* 45,1-59.

Cabrera, M.L. and Kissel, D.E. (1988) Evaluation of methods to predict N mineralized from soil organic matter under field conditions. *Soil Science Society of America Journal 52,1027-1031.*

Cate, Jr.R.B. and Nelson, L.A. (1965) A rapid method for correlation of soil tests analysis with plant responses data. Technical bulletin no.1. ISTP Series, North Carolina State University, Raleigh. N.C. pp 50.

Chandler, R.F. (1979) *Rice in the tropics.* A guide to the development of national programmes. Westview Press, Inc. Colorado. pp 256.

Chang, C.S. (1976) Phosphorus in submerged soils and fertilization for rice. *In: The fertility of paddy soils and fertilizer application for rice.* Food and fertilizer technology centre, ASPAC, Taiwan. pp 93-116.

Chang, K.L. and Bray, R.H. (1953) Two specific methods of determining Cu in soils and plant material. *Analytical Chemistry* 25,655-659.

Chapman, H.D. (1965) Cation exchange capacity. *In: methods of soil analysis*. (Edited by Black, C.A., Evans, D.D., Ensiminger, L.E., Clark, F.E. and White, J.L.). American Society of Agronomy, Madison, Wisconsin. pp 891-901.

Chatterjee, B.N. and Maiti, S. (1985) Principles and practises of rice growing. 2nd ed. Oxford & IBH Publishing Co.PVT Ltd. New-Delh, India. pp 419.

Coffman, C.B. and Miller, J.R. (1973) Response of corn in the greenhouse to soil applied zinc and comparisons of three chemical extractants for determining available zinc. *Soil Science Society of America Proceedings* 37,721-724.

Cox, F.R. and Wear, J.I. (1977) Diagnosis and correction of Zn problems in corn and rice production. Southern Coop. Ser. Bull.222. North Carolina State University.

Dahnke, W.C. and Johnson, C.U. (1990) Testing soil for available N. *In: Soil testing and plant analysis*. No. 3. (Edited by Westerman, R.L.). Soil Science Society America, Inc. Madison, Wisconsin. pp 128-137.

Day, P.R. (1965) Particle fraction and particle size analysis. *In: Methods of soil analysis.*(Edited by Black, C.A., Evans, D.D., Ensiminger, L.E., Clark, F.E. and White, J.L.). American Society of Agronomy. Madison, Wisconsin. pp 545-567.

De Datta, S.K.(Ed). (1981) *Principles and practises of rice production.* John Wiley and Sons, New York. pp 618.

De Datta, S.K. (1987) Nitrogen transformation processes in relation to improved culture practises for lowland rice. *Plant and Soil* 100,47-69.

De Datta, S.K. and Cruswell, E.T. (1982) Nitrogen fertility and fertilizer management in wetland soils. *In: Rice Research Strategies for the future.* International Rice research Institute. Los Banos, Philippines.

Dei, Y. and Yamasaki, S. (1979) Effect of water and crop management on N supplying capacity of paddy soils. *In: Nitrogen and rice.* International Rice Research Institute, Los Banos, Philippines. pp 451-463.

Dzowela, B.H. (1974) Fertilizer trials in Malawi. *In: Proceedings of the 5th Eastern African Cereals Research Conference held in Malawi*. March 10 - 15, 1974.

Fageria, N.K. (1976) Effect of P, Ca and Mg concentration in solution culture on growth and uptake of these ions by rice. *Agronomy Journal* 68(5),726:732.

Giordano, P.M and Mortvedt, J.J. (1974) Response of several rice cultivars to Zn. *Agronomy Journal* 66,220-223.

Goswami, N.N. and Banerjee, N.K. (1978) Phosphorus, Potassium and other macronutrients. *In: Soils and Rice.* International Rice Research Institute. Los Banos. Philippines. pp 581-604.

Haby, V.A., Russelle, M.P. and Skogley, E.O. (1990) Testing soil for K, Ca and Mg. *In: Soil testing and plant analysis.* (Edited by Westerman, R.L.). Soil Science Society of America, Madison, Wisconsin, pp 184-221.

Haq, A.U.; Miller, M.H. (1972) Predicting available zinc, copper and manganese using chemical extractants. *Agronomy Journal* 64,779-782.

Hari, O.M., Katyal, S.K. and Dhiman, S.D. (1996) Response of rice hybrid PMS2A/IR31802 to seedling vigor and nitrogen levels in Haryana, India. *In: International Rice Research Notes*. International Rice Research Institute, Los Banos, Philippines. pp 47-48.

International Rice Research Institute (IRRI). (1973) Annual Report for 1972. IRRI, Los Banos, Philippines.

International Rice Research Institute (IRRI). (1974) Annual Report for 1973. IRRI, Los Banos, Philippines.

International Rice Research Institute (IRRI). (1992) Progress Report. IRRI, Los Banos, Philippines.

International Rice Research Institute (IRRI). (1993) Progress Report. IRRI, Los Banos, Philippines.

International Institute for Tropical Agriculture (IITA). (1984) Rice production training manual. IITA, Ibadan, Nigeria.

Jensen, H.L. and Lamm, G.G. (1961) On zinc content of Danish soils. *Acta Agronomy* 11,63-81.

Jones, U.S., Katyal, J.C., Mamaril, C.P. and Park, C.S. (1982) Wetland nutrients deficiencies other than nitrogen. *In: Rice research strategies for the future*. International Rice Research Institute. Los Banos, Philippines. pp 327-378.

Jones, U.S. 1982. *Fertilizers and soil fertility*. 2nd ed. Prentice - Hall of India Private Ltd.New Delh. pp 421.

Jones, J.B.Jr and Case, V.W. (1990) Sampling, handling and analysing plant tissue samples. *In: Soil testing and plant analysis*. (Edited by Westerman, R.L.). No.3. Soil Science Society of America, Inc., Madison, Wisconsin. pp 389-427.

Jones, J.B. Jr and Vernon, W.C. (1990) Sampling, handling, and analysing plant tissue samples. *In: Soil testing and plant analysis*. (Edited by Westerman, R.L., Baird, J.V., Christesten, N.W., Fixen, P.E. and Whitney, D.A.). 3rd edition. No. 3. Soil Science Society of America, Inc. Madison, Wisconsin. pp 390-420.

Jones, J.B.Jr., Eck, H.V. and Voss, R. (1973) Plant analysis as an aid in fertilizing corn and grain sorghum. *In: Soil testing and plant analysis*. (Edited by Westerman, R.L., Baird, J.V., Cristensen, N.W., Fixen, P.E. and Whitney, D.A.). No. 3. Soil Science Society of America, Inc. Madison, Wisconsin, pp 523-541.

Kabata-Pendias, A. and Pendias, H. (1985) *Trace elements in soil and plants*. CRC Press, Inc. Florida, U.S.A. pp 315.

Kamasho, J.A. and Singh, B.R. (1982) Availability of copper and zinc status of some Tanzanian volcanic soils. A case study. *Pedology* II 2,209-224.

Katya, J.C. and Ponnamperuma, F.N. (1974) 14th Annual Report of the ICAR's All Indian Coordinated Scheme of Micronutrient in Soils and Plants for the year 1980/81.

Keeny, D.R. and Bremner, J.M. (1966) Comparison and evaluation of laboratory methods of obtaining an index of soil Nitrogen availability. *Agronomy Journal* 58,498 - 503.

Keeney, D.R. and Bremner, J.M. (1971) Comparison and evaluation of laboratory methods of obtaining an index for soil nitrogen availability. *Agronomy Journal* 58,498-503.

Kemmler, G. (1980) Potassium deficiency in soils of tropics as a constraints to food production. *In: Priorities for alleviating soil related constraints to food production in the tropics*. International Rice Research Institute and New York State College of Agriculture and life Sciences, Cornell University pp 253-277.

Kosaki, T. and Juo, A.S.R. (1986) Iron toxicity of rice in inland valleys: A case from Nigeria. In: *The wetlands and rice in Subsaharan Africa*. (Eds) Juo, A.S.R. and Lowe, J. International Institute for Tropical Agriculture. Ibadan, Nigeria. pp 167-174.

Kumar, V., Ahlawat, V.S., Antil, R.S. (1985) Interaction of N and Zn in pearmillet. 1. Effect of N and Zn levels on dry matter yield and concentration and uptake of N and Zn in pear millet. *Soil Science* 139(4),351-356.

Knudsen, D., Peterson, G.A. and Pratt, P.F. (1982) Lithium, Sodium and Potassium. pg 228-235. *In: Methods of soil analysis*. Part 2. 2nd ed. (Edited by Page, A.L., Miller, R.H. and Keeney, D.R.). American Society of Agronomy and Soil Science Society of America, Inc., Madison, Wisconsin. pp 225-245.

Landon, J.R. (1984) *Booker Tropical soil manual*. A handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Longman, New York. pp 450.

Lian, S. (1989) Fertility management of rice soils in R.O.C. on Taiwan. *In: Food and Fertilizer Technology*. ASPAC extension bulletin No. 293.

Lindsay, W.L. (1972) Zinc in soils and plant nutrition. *Advances in Agronomy*.24,147-186.

Lindsay, W.L. and Norvell, W.A. (1969) Development of DTPA micronutrient soil test. *Agronomy Abstract*.pp 84.

Lindsay, W.L. and Norvell, W.A. (1978) Development of DTPA soil test for Zn,Fe and Cu. *Soil Science Society America Journal* 42,421-428.

Lopes, A.S. (1980) Micronutrients in soils of the tropics as a constraints to food production. *In: Priorities for alleviating soil related constraints to food production in the tropics.* International Rice Research Institute and New York State college of Agriculture and Life Sciences, Cornell University pp 277-298.

Mandal, L.N. (1961) Transformation of iron and manganese in waterlogged rice soils. *Soil Science* 91,121-126.

Mandal, L.N. and Mandal, B. (1986) Zinc fractions in soil in relation to zinc nutrition of lowland rice. *Soil Science* 142,141-148.

Marshner, H. (1990) *Mineral nutrition of higher plants*. Academic press. London, UK. pp 674.

Martens, D.S., Lindsay, W.L. (1990) Testing for copper, zinc, iron and manganese. *In: Soil testing and plant analysis*. (Edited by Westerman, R.L.). Soil Science Society of America, Inc., Madison, Wisconsin, pp 229-264.

Meelu, O.P. and Bhanduri, A.L. (1981) Fertilizer management of paddy in Northen India. *Soils and Fertilizer* 44,684.

Menon, R.G., Hammond, L.L. and Sissingh, H.A. (1989a) Determination of plant available P by iron hydroxide impregnated filter paper strip (Pi) soil test. *Soil Science Society of America Journal* 53(1),110-115.

Menon, R.G., Chien, S.H. and Hammond, L.L. (1989b) Comparison of Bray-1 and Pi tests for evaluating plant-available P from soils treated with different partially acidulated phosphate rocks. *Plant and Soil* 114,211-216.

Menon, R.G., Chien, S.H. and Gadalla, A.E. (1992) Comparison of Olsen and Pi soil tests for evaluating P bioavailability in a calcareous soil treated with single super phosphate and partially acidulated phosphate rock. *Soils and Fertilizer* 55(2),172.

Mkangwa, C.Z. (1992) Assessment of copper and zinc status of some soils of Iringa district. M.Sc Dissertation. Sokoine University of Agriculture.Morogoro-Tanzania.

Moore, P.A.Jr. and Patrick, W.H.Jr. (1989) Iron availability and uptake by rice in acid sulphate soils. *Soil Science Society of America Journal* 53 (2), 471-476.

Moorman, F.R. and Veldcamp, W.J. (1978) Land and rice in Africa: Constraints and Potentials. *In: Rice in Africa*. Proceedings of a conference held at IITA, Nigeria, from 7 - 11 March 1977. (Edited by Buddenhagen, I.W. and Persley, G.J.). International Institute for Tropical Agriculture, Ibadan, Nigeria. pp 29 - 43.

Mowo, J.G., Floor, J., Kaihura, F.B.S. and Magogo, J.P. (1993) Fertilizer recommendation in Tanzania. Part 1, Revised fertilizer recommendation for Tanzania. A.R.I. Ministry of Agriculture, Tanzania.

Msolla, M.M. (1991) Evaluation of zinc status of rice growing areas of Igunga and Nzega districts, Tabora region, Tanzania. M.Sc. dissertation, Sokoine University of Agriculture, Morogoro, Tanzania.

Msolla, M.M., Semoka, J.M.R. and Singh, B.R. (1994) Assessment of available zinc for rice soils of the Tabora region, Tanzania. *Norwegian Journal of*

Agriculture Science 8,1-2.

Murphy, J. and Riley, J.P. (1962) A modified single solution for determination of phosphate in natural waters. *Anal. Chim.Acta* 27,31-36.

Mutagwaba, S.K.L. (1986) Evaluation of soil test methods for estimation of available phosphorus in some soils of Mbeya region (Tanzania). M.Sc. dissertation, Sokoine University of Agriculture, Morogoro, Tanzania.

National Soil Service. (1990) Laboratory procedures for routine analysis. (3rd eds). Miscellaneous report No. 13. Ministry of Agriculture and livestock development, Tanzania.

Nelson, D.W. and Sommers, L.E. (1982) Total carbon, organic carbon and organic matter. *In: Methods of soil analysis*. Part 2. Chemical and microbiological properties. (Edited by Page, A.L., Miller, R.H. and Keeney, D.R.). American Society of Agronomy, Inc., Soil Science Society of America, Inc., Madison, Wisconsin. pp 539-577.

Neue, H.U. (1989) Rice growing soils: Constrains, Utilization and Research Needs. Food & Fertilizer Technology Centre. Extension Bulletin No. 292.

Neue, H.U. and Bloom, P.R. (1989) Nutrient kinetics and availability in flooded rice soils. *In: Progress in irrigated rice research*. International Rice Research Institute. Los Banos, Philippines. pp 173-190.

Nzabayanya, S.I.M. and Mnkeni, P.N.S. (1985) Maize response to zinc application and comparison of Zn availability indices for some Morogoro soils. *In: Proceedings for the 7th annual general meeting of Soil Science Society of East Africa*. (Edited by Msumali, G.P., Semoka, J.M.R. and Sharma. A.K.). 16-19th Dec. 1985, Arusha, Tanzania, pp 160 - 173.

Olsen, R.A., Watanabe, F.S., Cosper, H.R., Larson, W.E. and Nelson, L.B. (1954) Residual phosphorus availability in long-time rotations on calcareous soils. *Soil Science* 78,141-151.

Olsen, S.R. and Sommers, L.E. (1982) Phosphorus. *In: Methods of soil analysis*. Part 2. 2nd ed. (Edited by Page, A.1., Miller, R.H. and Keeny, D.R.). American Society of Agrnomy, and Soil Science Society of

America, Inc., Madison, Wisconsin. pp 403-427.

Okajima, H., Mannikar, N.D. and Rao, M.J. (1970) Iron chlorosis of rice seedling in calcareous soil under upland conditions. *Soil Science and Plant Nutrition* 16,128-132

Okalebo, J.R., Gathua, K.W. and Woomer, P.L. (1993) Laboratory methods of soil and plant analysis. A working manual. KARI and Rost. Nairobi, Kenya.

Patnaik, S. (1978) Natural sources of nutrients in rice soils. *In: Rice and soils*. International Rice Research Institute. Los Banos. Philippines. pp 501-520.

Peech, M. (1965) Hydrogen ion activity. *In: Methods of soil analysis*. Chemical and microbiological properties. (Edited by Black, C.A., Evans, D.D., Ensiminger, L.E., Clark, F.E. and White, J.L.). American Society of Agronomy, Madison, Wisconsin, pp 914-926.

Prasad, R. and De Datta, S.K. (1979) Increasing fertilizer nitrogen efficiency in Wetland rice soils. *In: Nitrogen and rice*. International Rice Research

Institute. Los Banos, Philippines, pp 465 - 484.

Ponnamperuma, F.N. (1965) Dynamic aspects of flooded soils and nutrition of rice plants. *In: Proceedings of the Symposium in Mineral Nutrition of Rice Plants.* Los Banos, Philippines. Febr. 1964. John Hopkings Press, Baltimore.

Ponnamperuma, F.N. 1974. Micronutrients limitations in acid tropical rice soils. *In: Soil management in tropical America.* (Edited by Bornemisza, E. and Alvarado, A.). Soil Science department, North Carolina State University, Raleigh, USA, pp 330-347.

Ponnamperuma, F.N. (1978) Electrochemical changes in submerged soils and the growth of rice. *In: Soils and rice.* International Rice Research Institute, Los Banos, Philippines, pp 421-441.

Raju, R.A., Reddy, G.V. and Reddy, M.N. (1986) Studies on response of rice to P, K and Zn. *Indian Journal of Agronomy* 31(2),193-194.

Randal, G.W. and Grava, J. (1971) Effect of soil: Bray No 1 ratio on the amount of phosphorus extracted from calcareous Minnesota soils. *Soil Science Society of*

America Proceedings 35,112-114.

Randhawa, N.S., Sinha, M.K., Takkar, P.N. (1978) Micronutrients. pgs 581-603. *In: Soils and Rice.* International Rice Research Institute. Los Banos, Philippines, pp 605-622.

Rhoades, J.D. (1982) Cation exchange capacity. *In: Methods of soil analysis*. Part 2. (Edited by Page, A.L., Miller, R.H. and Keeney, D.R.). American Society of Agronomy, and Soil Science Society of America, Inc., Madison, Wisconsin, pp 149-157.

Sahrawat, K.L. (1983) Nitrogen availability indices for submerged rice soils. *Advance in Agronomy* 36,415-451.

Sakal, R., Singh, A.B., Singh, B.R. and Sinia, R.B. (1984) Assessment of some extractants for available zinc in relation to response of rice to applied zinc in Sub-Himalayan hill forest soils. *Plant and Soil* 79(3),417-428.

Sanchez, P.A. (1976) *Properties and management of soils in the tropics*. John Willey and Sons. New York, USA. pp 618.

Sedberry, J.E., Miller, B.J. and Said, M.B. (1979) An evaluation of chemical methods for extracting zinc from soils. *Communication in Soil Science and Plant Analysis* 10,689-701

Semoka, J.M.R. and Shenkalwa, E.M. (1985) Effect of N, and P and K fertilizers on the growth and yield of rice grown in a soil from Dakawa rice farm. *In: Proceedings of 7th Annual General meeting of the soil science society of East Africa*. (Edited by Msumali, G.P., Semoka, J.M.R. and Sharma, A.K.). Dec.16-19,1985 Arusha, Tanzania, pp 209-219.

Semoka, J.M.R., Shekiffu, C.Y. and Mende, D. (1996) Nutrient constraints in selected rice growing areas of Morogoro region. *In: Meeting farmers needs through Agricultural research*. Proceedings of the First Facult of Agriculture Annual Research Conference. (Edited by Matee, A.Z., K.P. Sibuga, J.M.R. Semoka and M. Tsunoda).28 - 30th August 1995. Sokoine University of Agriculture, Morogoro pp 200 - 216.

Shekiffu, C.Y. (1995) Assessment of Phosphorus status of rice growing areas in Morogoro region using different extractants. A Special Project Report for B.Sc.(Agric.), Sokoine University of Agriculture,

Morogoro.

Sims, J.T. and Johnson, G.V. (1991) Micronutrients soil tests. *In: Micronutrients in agriculture*. 2nd eds. (Edited by Mortvedt, J.J., Cox, F.R., Shuman, L.M. and Welch, R.M.). Soil Science Society of America, Madison, Wisconsin, pp 427-476.

Singh, R.M. and Tripathi, B.R. (1970) Correlation studies of soil tests for available nitrogen and response of paddy on certain soils of Uttar Pradesh. *Journal of the Indian Society of Soil Science* 18,313-318

Singh, B.R., Uriyo, A.P. and Mnkeni, P.N.S. (1976) Evaluation of the indices of plant nutrients availability in soils of Morogoro region. I. Nitrogen. A paper presented at the 2nd Annual General Meeting of Soil Science Society of East Africa held at Arusha from 6 - 8th Sept., 1976.

Singh, B.R., Uriyo, A.P., Mnkeni, P.N.S. and Msaky, J.J.T. (1977) Evaluation of indices of N and P availability for soils of Morogoro, Tanzania. Proceedings of Clamatop.

Singh, H.G. and Takkar, P.N. (1981) Evaluation of efficient soil test methods for zinc and their critical values in salt affected soils for rice. *Communication in Soil Science and Plant Analysis* 12,383-406.

Singh, B., Singh, M. and Dang, Y.P. (1987) Distribution of forms of zinc in some soils of Haryana. *Journal of Indian Society of Soil Science* 35,217-224.

Singh, H.G., Thakur, S. and Singh, S.K. (1995) Response of rice to Nitrogen and Zinc application in a calcareous situation. *In: International Rice Research Notes*. International Rice Research Institute. Los Banos, Philippines.

Singh, A.K. and Kumar, A. (1996) Response of promising rice genotypes to nitrogen levels in irrigated lowlands. *In: International Rice Research Notes*. International Rice Research Institute. Los Banos, Philippines, pp 46-47.

Smyth, T.J. and Gravo, M.S. (1990) Critical P levels for corn and cowpeas in a Brazilian Amazon Oxisols. *Agronomy Journal* 82,309-312.

Sterwart, T.A. and Berger, K.C. (1965) Estimation of available soil zinc using $MgCl_2$ as extractant. *Soil Science* 100,244-250.

Stanford, G. (1978) Evaluation of ammonia release by alkaline permanganate extraction as an index of soil N availability. *Soil Science* 126,244-253.

Subbiah, B.V. and Asija, G.L. (1956) A rapid method for the estimation of available nitrogen in soils. *Current Science* 25,259-260.

Subramanyan, A.V. and Mehta, B.V. (1974) Effect of zinc and iron application on the yield and chemical composition of rice. *Indian Journal of Agriculture Science* 44,602-607.

Tanaka, A and Yoshida, S. (1970) Nutrition disorders of the rice plants in Asia. IRRI *Technical Bulletin* 10, 35-40.

Tanaka, A., Yamaguchi, J., Miura, S. and Tamaru, H. (1984) Comparison of fertilizer nitrogen efficiency among field crops. *Soil Science and Plant Nutrition* 30(2),199-208.

Temu, A.B. (1985) Nitrogen and phosphorus effects on growth, yield and nitrogen and phosphorus content of lowland rice growth on alluvial soils at Mbarali rice farm, Mbeya. M.Sc dissertation at Sokoine University of Agriculture, Morogoro - Tanzania.

Thomas, G.W. and Peaslee, E.D. (1973) Soil testing for phosphorus. *In: Soil testing and plant analysis*. (Edited by Walsh, L.M. and Beaton, J.D.). Soil Science Society of America, Madison, Wisconsin, USA.

Trieweiler, J.F. and Lindsay, W.L. (1969) EDTA$(NH_4)_2CO_3$ soil test for zinc. *Soil Science Society America Proceedings*. 33,49-54.

Turker, T.C. and Krutz, L.T. (1956) A comparison of several chemical methods with bioassay procedure for extracting zinc from soils. *Soil Science Society of America Proceedings* 19,477-481.

United States Department of Agriculture (USDA). (1975) Soil Taxonomy. A basic system of soil classification for making and interpreting soil surveys. Soil survey staff. Soil Conservation Services. Washington, D.C.

Uriyo, A.P., Mongi, H.O., Chowdhury, M.S. and Semoka, J.M.R. (1976) Introductory soil science. Tanzania Publishing House, Dar es salaam, Tanzania. pp 232.

Ussiri, D.A.N. (1992) Phosphorus status and availability in some Benchmark soils of Morogoro district. M.Sc dissertation submitted to Sokoine University of Agriculture, Morogoro-Tanzania.

van Breeman, N. (1980) Acidity of wetland soils, including Histosols as a constraint to food production. *In: Priorities for alleviating soil related constraints to food production in the tropics*. International Rice Research Institute and New York State college of Agriculture and Life Sciences, Cornell University, pp 189-202.

van Vorm, P.D.J. and van Diest, A. (1979) Aspects of the iron and manganese nutrition of rice plants. *Plant and Soil* 51,233-246.

Viets, F.G. and Lindsay, W.L. (1973) Testing soils for zinc, copper, manganese and iron. *In: Soil testing and plant analysis*. (Edited by Walsh, L.M. and Beaton, J.D.). Soil Science Society of America, Inc., Madison, Wisconsin, pp 153-172.

Viro, P.J. (1955) Use of ethylenediamine tetraacetic acid in soil analysis. I. Experimental *Soil Science* 79,459-465.

Wallace, A., Muller, R.T., Lunt, O.R., Ashroft, R.T. and Shannon, L.M. (1955) Comparison of five chelating agents in soils,in nutrients solutions and in plant responses. *Soil Science* 80,101-108.

Walmsley, D. and Cornforth, I.S. (1973) Methods of measuring available nutrients in West Indian soils. II. Phosphorus. *Plant and Soil* 39,93-101.

Watanabe, I. and Inubushi, J. (1986) Dynamics of available nitrogen during rice cultivation and origin of N. *Soil Science and Plant Nutrition* 32(1),37=50.

Walihan, E.F., Mooman, J.C. and De Datta, S.K. (1974) Variable optimum concentration of nitrogen in rice plants. *Soil Science* 118,263-266.

Wear, J.I.and Sommer, A.I. (1948) Acid extractable zinc of soil in relation to occurrence of zinc deficiency symptoms of corn. *Soil Science Society of America Proceedings* 32,143-144.

Wear, J.I.and Evans, C.E. (1968) Relationship between zinc uptake by corn and sorghum to soil zinc measured by three extractants. *Soil Science Society of America Proceedings* 32,543-546.

Yoshida, S., Ahn, J.S. and Forno, D.A. (1973) Occurrence, diagnosis and correction of zinc deficiency of lowland rice. *Soil Science and Plant Nutrition* 25,121-134.

7.0 APPENDICES

Appendix 1. Extractable Mn and Cu (mg/kg) extracted by different extractants from the experimental soils.

Location	0.1N HCl		0.005M DTPA		EDTA-$(NH_4)_2CO_3$	
	Mn	Cu	Mn	Cu	Mn	Cu
Kilangali	95.0	10.2	39.8	5.9	70.4	6.8
Mlali	345.0	8.7	64.4	3.6	60.0	5.4
Mkindo	227.5	5.0	108.4	2.3	179.2	3.1
Mgomba	345.0	6.7	100.8	4.2	130.4	5.9
Kigongoni	312.5	7.7	93.6	3.9	81.8	6.0
Ruvu NAFCO	190.0	7.5	57.6	4.2	47.2	5.5
Ruvu sec. school	102.5	3.5	29.2	1.7	12.6	2.7
Majengo	215.0	2.0	139.6	1.0	122.4	1.8
Malenga	190.0	7.7	99.2	3.5	135.0	9.8
Kapunga	192.5	3.5	41.4	1.1	63.8	2.3

Appedix 2. Effect of N, P, K, Zn and Fe application on nutrients uptake by rice plants

Appendix 2a. Effect on N uptake

Location	N uptake (mg/pot)					
	Control	N	NP	NPK	NPKZn	NPKZnFe
Kilangali	56.69^{b}	599.29^{a}	604.23^{a}	674.80^{a}	670.81^{a}	702.73^{a}
Mlali	75.10^{c}	583.49^{b}	679.35^{ab}	752.52^{a}	655.94^{ab}	689.64^{ab}
Mkindo	43.63^{b}	636.81^{a}	609.32^{a}	621.25^{a}	633.57^{a}	611.54^{a}
Mgomba	38.81^{b}	586.10^{a}	662.42^{a}	601.14^{a}	630.58^{a}	647.13^{a}
Kigongoni	22.45^{c}	361.57^{b}	518.59^{a}	506.89^{a}	586.40^{a}	584.29^{a}
Ruvu NAFCO	25.87^{c}	222.51^{bc}	498.93^{a}	393.06^{ab}	451.12^{a}	527.05^{a}
Ruvu sec. school	16.46^{c}	93.38^{b}	427 95^{a}	461.62^{a}	467.67^{a}	485.41^{a}
Majengo	27.07^{d}	555.50^{b}	628.59^{ab}	644.98^{ab}	668.45^{a}	427.99^{c}
Malenga	16.59^{c}	159.74^{b}	458.87^{a}	475.02^{a}	468.24^{a}	514.84^{a}
Kapunga	26.51^{c}	229.67^{b}	592.40^{a}	569.43^{a}	598.65^{a}	601.03^{a}
Mean	34.92^{c}	402.79^{b}	568.06^{a}	570.07^{a}	583.14^{a}	579.16^{a}

Values in the same row followed by the same letter are not significantly different at 5% using Duncan multiple range test

Appendix 2b. Effect on P uptake

Location	P uptake (mg/pot)					
	Control	N	NP	NPK	NPKZn	NPKZnFe
Kilangali	16.11^{c}	56.77^{b}	66.86^{b}	79.26^{b}	148.89^{a}	71.47^{a}
Mlali	17.86^{d}	42.18^{c}	60.37^{ab}	69.63^{a}	70.72^{a}	55.97^{b}
Mkindo	11.51^{c}	67.79^{ab}	44.56^{b}	91.44^{a}	72.34^{ab}	87.96^{a}
Mgomba	9.45^{c}	41.92^{b}	57.03^{ab}	59.12^{ab}	71.36^{a}	64.83^{a}
Kigongoni	3.99^{c}	16.77^{bc}	30.52^{ab}	36.44^{a}	44.38^{a}	36.99^{a}
Ruvu NAFCO	8.42^{b}	11.21^{b}	35.06^{a}	28.25^{a}	35.38^{a}	41.56^{a}
Ruvu sec. school	3.48^{c}	5.88^{c}	33.02^{a}	19.52^{b}	27.76^{ab}	34.81^{a}
Majengo	7.87^{b}	63.20^{a}	54.65^{a}	62.30^{a}	69.49^{a}	73.53^{a}
Malenga	3.78^{b}	5.79^{b}	18.61^{a}	21.56^{a}	18.22^{a}	24.86^{a}
Kapunga	4.63^{c}	10.99^{c}	17.42^{bc}	29.93^{ab}	35.06^{a}	35.27^{a}
Mean	8.71^{c}	32.25^{b}	41.81^{ab}	49.74^{ab}	59.36^{a}	52.72^{ab}

Values in the same row followed by the same letter are not significantly different at 5% using Duncan multiple range test

Appendix 2c. Effect on K uptake

Location	K uptake (mg/pot)					
	Control	N	NP	NPK	NPKZn	NPKZnFe
Kilangali	115.48^{b}	477.45^{a}	475.66^{a}	650.74^{a}	540.73^{a}	481.30^{a}
Mlali	120.26^{c}	206.26^{b}	312.77^{a}	316.04^{a}	357.28^{a}	368.91^{a}
Mkindo	75.47^{c}	282.30^{b}	283.21^{b}	354.59^{ab}	418.08^{a}	363.11^{a}
Mgomba	80.61^{b}	620.56^{a}	717.48^{a}	657.69^{a}	707.07^{a}	732.49^{a}
Kigongoni	40.01^{e}	277.89^{d}	404.68^{c}	446.50^{bc}	515.51^{ab}	526.00^{a}
Ruvu NAFCO	46.50^{b}	180.08^{b}	467.11^{a}	385.97^{a}	450.17^{a}	512.48^{a}
Ruvu sec. school	29.06^{b}	55.41^{b}	264.68^{a}	300.62^{a}	302.35^{a}	391.00^{a}
Majengo	49.69^{b}	539.84^{a}	527.99^{a}	555.91^{a}	500.46^{a}	535.19^{a}
Malenga	34.24^{c}	76.46^{c}	144.79^{b}	221.29^{a}	222.29^{a}	250.52^{a}
Kapunga	40.56^{c}	127.38^{b}	378.31^{a}	356.64^{a}	396.23^{a}	393.15^{a}
Mean	63.19^{c}	284.36^{b}	397.67^{ab}	424.60^{a}	441.02^{a}	455.41^{a}

Values in the same row followed by the same letter are not significantly different at 5% using Duncan multiple range test

Appendix 2d. Effect on Zn uptake

Location	Zn uptake (mg/pot)					
	Control	N	NP	NPK	NPKZn	NPKZnFe
Kilangali	0.18^{b}	0.94^{a}	1.10^{a}	1.16^{a}	1.09^{a}	0.69^{ab}
Mlali	0.16^{d}	0.89^{c}	1.07^{bc}	1.18^{ab}	1.36^{a}	1.29^{ab}
Mkindo	0.08^{b}	0.80^{a}	0.79^{a}	0.82^{a}	0.97^{a}	0.83^{a}
Mgomba	0.11^{c}	0.40^{b}c	0.39^{bc}	0.62^{ab}	0.97^{a}	0.91^{a}
Kigongoni	0.07^{c}	0.47^{b}	0.62^{b}	0.69^{b}	1.01^{a}	1.11^{a}
Ruvu NAFCO	0.21^{b}	0.80^{a}	1.28^{a}	0.89^{a}	1.22^{a}	1.35^{a}
Ruvu sec. school	0.03^{c}	0.11^{c}	0.52^{b}	0.83^{a}	0.77^{a}	0.83^{a}
Majengo	0.13^{b}	1.65^{a}	2.58^{a}	2.53^{a}	1.77^{a}	2.62^{a}
Malenga	0.09^{e}	0.24^{d}	0.70^{c}	0.72^{c}	0.94^{b}	1.11^{a}
Kapunga	0.13^{b}	0.55^{ab}	0.99^{a}	1.00^{a}	0.71^{a}	1.00^{a}
Mean	0.12^{c}	0.68^{b}	1.00^{ab}	1.04^{ab}	1.08^{ab}	1.17^{a}

Values in the same row followed by the same letter are not significantly different at 5% using Duncan multiple range test

Appedix 2e. Effect on Fe uptake

Location	Fe uptake (mg/pot)					
	Control	N	NP	NPK	NPKZn	NPKZnFe
Kilangali	2.47^{c}	11.12^{b}	12.35^{a}	11.02^{ab}	10.48^{ab}	5.54^{bc}
Mlali	1.86^{c}	5.40^{b}	7.37^{a}	8.03^{a}	7.61^{a}	6.99^{ab}
Mkindo	1.43^{b}	10.54^{a}	8.30^{a}	9.32^{a}	7.94^{a}	7.89^{a}
Mgomba	2.76^{b}	8.32^{ab}	8.38^{ab}	8.50^{ab}	10.74^{a}	12.04^{a}
Kigongoni	0.86^{e}	3.02^{de}	4.86^{cd}	6.13^{bc}	10.76^{a}	7.31^{b}
Ruvu NAFCO	1.24^{c}	2.96^{bc}	9.67^{ab}	9.34^{ab}	9.89^{ab}	10.37^{a}
Ruvu sec. school	0.57^{b}	0.96^{b}	4.74^{a}	4.50^{a}	4.12^{a}	4.43^{a}
Majengo	1.08^{b}	6.91^{ab}	9.14^{a}	6.90^{ab}	5.87^{ab}	5.07^{ab}
Malenga	1.15^{b}	1.42^{b}	3.93^{a}	4.49^{a}	3.87^{a}	4.70^{a}
Kapunga	0.96^{c}	2.82^{bc}	6.16^{ab}	8.35^{a}	5.07^{ab}	6.55^{ab}
Mean	1.44^{b}	5.35^{a}	7.49^{a}	7.66^{a}	7.63^{a}	7.09^{a}

Values in the same row followed by the same letter are not significantly different at 5% using Duncan multiple range test