

**RESPONSE OF MAIZE AND RICE TO APPLIED ZINC IN SOME
BENCHMARK SOILS OF MOROGORO RURAL DISTRICT**

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**A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE
(AGRICULTURE) OF SOKOINE UNIVERSITY OF AGRICULTURE**

1992

ABSTRACT

A study was undertaken to evaluate the response of maize and rice to applied Zn in benchmark soils of Morogoro District. Thirteen bulk soil samples were collected from the benchmark sites. Zinc from these soils was extracted with four commonly used Zn extractants namely 0.005M DTPA (pH 7.3), EDTA-(NH₄)₂CO₃ (pH 8.6), 0.1N HCl, and 0.05N HCl + 0.25N H₂SO₄.

Response of maize and rice in these soils was assessed in two glasshouse experiments. Three rates of Zn viz: 0, 2.5 or 5 mg/kg soil were applied. These treatments received recommended levels of N, P and K.

Field experiments were also conducted at eleven sites, two for rice and nine for maize. Zinc rates of 0, 5, 10 or 15 kg Zn/ha were applied together with recommended rates of N, P and K..

Zinc application significantly increased dry matter yield of plants. Of the four extractants tested, DTPA was found most suitable for assessing available Zn in the soils. The critical level for this extractant was 1.95 ppm. EDTA-(NH₄)₂CO₃ came second. The other two did not give significant correlations with plant uptake. Critical level of Zn for maize in these soils were established at 1.95, 1.3, 3.0 and 0.5 ppm by 0.005M DTPA, 1M EDTA - (NH₄)₂CO₃, 0.1 N HCl and 0.05 N HCl + 0.25 N H₂SO₄,

respectively. The critical Zn level in maize shoots was estimated to be 17 ppm.

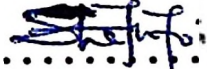
On the basis of the critical level established out of 43 samples analyses to gauge the Zn status 65% of these soils tested were deficient and 35% had adequate Zn levels.

Field experiments with rice confirmed the need for Zn application in Dakawa 2 where grain yield increased by 653% after Zn supplementation. A rate of 10 kg Zn/ha is tentatively recommended for use in this soil.

Field experiments with maize gave inconclusive results because of moisture stress which dominated prior to the tasselling stage. Therefore additional experiments are recommended.

DECLARATION

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

Signature..........

Bashiru Hassan Shelukindo

Date.....th
16 November 1992

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ACKNOWLEDGEMENTS

I am indebted to many individuals who contributed to the development and production of this dissertation. In particular, I wish to express my sincere thanks to my supervisors, Drs.J.M. Semoka and E. Semu for their constant, tireless guidance, constructive criticisms and encouragement during the course of the investigation and preparation of the dissertation.

I am extremely thankful to the staff of the Department of Renewable Resources, Macdonald College of McGill University (Canada) for all the efforts they made which enabled me to pursue the course work very successfully. I am also thankful to the members of Soil Science Department, Sokoine University of Agriculture for providing facilities and guidance during the research work.

Thanks are also due to Prof.A.F. Mackenzie, of McGill University, and Dr. P.N.S..Mnkeni (SUA) for the role they played during my study time. The fellowship offered to me by the Canadian International Development Agency (CIDA) under the Benchmark Soils Project and study leave granted to me by the Ministry of Agriculture (Tanzania), my employer, are gratefully acknowledged. The assistance rendered by the Management of the Soil Erosion Control/ Agroforestry Project (SECAP) in the Usambara mountains is highly appreciated.

Finally, but not least, special thanks go to my wife Aisha Shelukindo for her patience, understanding and inspiration during the course of this study.

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1. INTRODUCTION

1.1 General

Zinc (Zn) is one of the micronutrient essential in plant as well as animal nutrition. In Tanzania more research has been directed at fertilizers supplying the major elements (N, P, K), with much less attention to the micronutrients (Cu, Fe, Mn, Zn etc.). The assumption has been that micronutrients were adequate in most soils because they are generally needed by plants only in very small quantities (Tisdale and Nelson 1985). However, the increase in crop yields due to use of N, P, K fertilizers results in greater removal of the micronutrients, hence hastening development of deficiencies of micronutrients in such soils.

Deficiencies of Zn have been reported frequently to reduce crop yields. For example, Forno et al. (1975) and Yoshida et al. (1973) have reported Zn deficiency in rice from many rice growing countries. A survey of world literature to-date shows that Zn deficiency is most serious in the tropics, and is becoming as important as deficiencies of N, P, K, Ca, and Mg. The reason suggested was that tropical soils have been highly weathered and strongly leached. As a result, growth of crops is improved by applying N, P, K and lime and by using improved varieties of plants. Under these circumstances,

the risk that deficiencies of micronutrients will limit yields is becoming greater.

1.2 Problem analysis and statement of objectives

Maize and rice, like all other plants, require adequate amounts of the essential elements (De Datta 1981). The two crops are the staple foods in most tropical countries. In Tanzania, the demand for the two crops increases from year to year due to a high population growth rate and the current insufficient production. A number of factors, such as lack or minimum use of fertilizers, poor crop husbandry, etc., account for the low production.

In terms of importance maize ranks first. It is grown almost everywhere in this country with Rukwa, Iringa, Ruvuma, Mbeya, Arusha and Mara being the leading regions, with total annual production of 120,000-150,000 tons (Croon et al. 1984). However, the average yield per unit area is generally very low, usually less than 1 ton/ha (Bureau of statistics 1988).

Rice is next to maize in terms of importance in Tanzania. It is grown throughout the country though leading producing regions are Mbeya, Kilimanjaro, Coast, Morogoro and Mwanza. Yields under small farmers are generally very low due to low yielding varieties and decline in soil fertility since small farmers do not use

fertilizers. In parastatal farms e.g. Mbarali, Ruvu and Dakawa, yields were relatively higher, at first up to 7 tons/ha. But even on these farms yields have dropped to 4 tons/ha, or less, despite the use of N, and P fertilizers. It has been shown elsewhere that among the micronutrients, Zn is very important in crop production. It plays an important role in auxin formation and in enzyme systems such as dehydrogenases, proteinases and peptidases in plant tissues (Lindsay 1972; Kanwar and Youngdahl 1985). Simultaneous to its importance in crop production, soil Zn content has been reported to be low in some areas of the country. For example, Kamasho (1980) reported Zn deficient soils in Mbeya region. Soils from Igunga and Nzega districts (Tabora) were reported by Msolla (1991) to be Zn deficient. In Morogoro district, Zn deficiency was reported in Dakawa Rice Farm (Semoka 1990; personal communication; Nzabayanga and Mnkeni, 1984). The low levels of Zn indicate that Zn deficiency may account, at least partially, for the low and declining yields of maize and rice. This may be pronounced especially in the big farms where high yielding and thus more nutrient demanding varieties are used. Thus, there is a need to assess the status of Zn in some major soil types in which these crops are grown.

Therefore, the study reported here was conducted to evaluate the Zn nutrition of maize and rice grown in some soils of Morogoro district, with the following objectives:

- (a) to establish chemical criteria for predicting the need for Zn in some benchmark soils of Morogoro district.
- (b) to determine the status of Zn in some soils of Morogoro using the established criteria.
- (c) to assess the response of maize and rice to Zn application on the benchmark sites.

2.0 LITERATURE REVIEW

2.1 Zinc in soils

The source of soil zinc is the soil parent material. The most dominant form of zinc in soil solution is Zn^{2+} , though $\text{Zn}(\text{OH})^+$ may also form at high pH values (Udo et al. 1970; Xie and Mackenzie 1988). Zinc ions are released into soil solution during weathering of rocks. The inorganic zinc mineral controlling zinc solubility in soils is unknown (Lindsay 1972), but Kittrick (1976) indicated that sphalerite (ZnS) may be a factor controlling Zn levels in well aerated soils.

Another important practical aspect is that 60% of the Zn in soil solution has been reported to exist as organic complexes (Hodgson et al. 1966; Liang et al. 1989). Thus, the free ions and various hydrated forms as well as organic complex forms must be considered in the fractions of soluble Zn in soils. Soil zinc can be conveniently classified as total soil Zn content, zinc minerals in soil and available zinc.

2.1.1 Total zinc content

Total soil zinc is very variable depending on the nature of parent material, clay content and soil type (Mortvedt et al. 1972; Shukla and Lyngdoh 1990). Total zinc content of the lithosphere has been estimated to range from 10-300 ppm (Katyal et al. 1982). The average content of the lithosphere has been estimated as 80-89 ppm (Katyal et al. 1982).

A number of reports indicated that parent rocks influence total zinc content of soils to a significant extent. For instance, soils developed from limestones contained more Zn than soils derived from gneisses or quartzite (Mitchell 1964; Katyal et al. 1982). Soil type is another factor which influences soil zinc. For example, Sharma and Motiramani (1969) reported that total zinc was highest in fine-textured Vertisols and lowest in coarse-textured alluvial soils. Among the different soils analyzed by Lal et al. (1960) as quoted by Katyal et al. (1982), alkaline Vertisols had the highest total Zn levels (69-76 ppm), whereas the lowest values (24-30 ppm) were found in relatively coarse-textured Oxisols.

Total zinc content, however, does not reflect availability of Zn to plants. Singh and Abrol (1986) determined available and total Zn in soils from different climatic zones and found that in a tropical agroclimatic zone, available Zn was 0.35 ppm while the total Zn was 62

ppm. In the tropical semi-arid climatic zones, available Zn was 0.53 ppm while the total Zn was 253 ppm. Available Zn is discussed further in section 2.1.3. Hazra et al. (1987) while studying the distribution of different forms of Zn in 16 acid alluvial rice growing soils of West Bengal (India), showed that more than 84% of the total Zn occurred in relatively inactive lattice bound form. Thus, a large proportion of total soil zinc occurred in relatively inactive form.

2.1.2 Zinc minerals in soils

The common minerals that contain zinc are sphalerite (ZnS), smithsonite (ZnCO_3) and hemimorphite ($\text{Zn}(\text{OH})_2\text{SiO}_3 \cdot \text{H}_2\text{O}$). Zincite (ZnO) may also form but it is too soluble to persist in soils (Krauskopf 1972). Zinc appears to be scattered throughout the mineral fraction of soils. It is associated with the Mg/Fe^{2+} octahedral sites of the relatively unstable ferromagnesian minerals concentrated in mafic igneous rocks. It is probably held in crystal lattices by isomorphous substitution and as occluded ions (Krauskopf 1972).

Lindsay (1972) reported that among igneous rocks, basalts contain, on the average, 100 ppm Zn while granite contains only 40 ppm Zn. Sedimentary rocks and shale contain 95 ppm Zn while limestone and sandstones contain 20 and 16 ppm Zn, respectively. Krauskopf (1972) pointed

out that zinc in igneous rocks tends to concentrate in mafic as compared to felsic rocks because Zn^{2+} can substitute in silicates for Mg^{2+} and because Zn can occur as small grains of sphalerite in the mafic rocks. The largest Zn concentrations in sedimentary rocks are found in the shale where it is held as adsorbed Zn and in the lattice structure of clay minerals (Lindsay 1972).

2.1.3 Available zinc

This is the zinc fraction that is available to plants. It is the fraction which can be correlated with plant uptake. It generally makes up only a small fraction of total soil Zn. The amount of available Zn may vary with soil type, pH and climate (Cottenie et al. 1980; Kanwar and Youngdahl 1985). Katyal and Agarwala (1982), using DTPA, found available Zn to account for no more than 1% of the total zinc in some Indian soils. Using 0.1N HCl on 20 ferralitic soils from Vietnam, Glinski and Thai (1971) extracted between 0.20% and 10.60% of the total zinc. However, these two workers found available zinc to be well correlated with total zinc ($r=0.76$). Soepartini et al. (1980) found the correlation between total and available zinc to be low ($r=0.55$) for Indonesian soils; and they reported even lower correlation coefficients using EDTA and dithizone as extractants.

Generally, available zinc is minimum in highly leached sandy soils, muck soils and soils that have high pH levels (Randhawa and Nayyar 1982). Light-textured soils appear more vulnerable to zinc deficiency than other soils.

Chavan et al. (1980) reported that low pH Oxisols contained more available zinc than did neutral to alkaline Alfisols and Vertisols. Various correlation studies (Rajagopa et al. 1977; Halдар and Mandal 1979) have confirmed the decline of available Zn with a rise in soil pH.

Climate influences Zn availability in soils. It affects soil pH and the level of organic matter in the soil. Katyal et al. (1982) considered low organic matter as a cause for generally low DTPA-extractable Zn in arid and semi-arid soils. Halдар and Mandal (1979) demonstrated the favourable effect of organic matter on Zn availability. However, Rajagopal et al. (1974), working with high organic matter soils from Nilgris Hills, Tamil Nadu, India, reported a reduction in Zn availability when soils contained more than 5.0% organic matter.

There are three Zn pools that are important in supplying the nutrient for the plant during the growing season, viz: exchangeable form, organically complexed fraction and the water soluble fraction (Viets 1962); Prasad et al. 1990).

These three pools are thought to be in equilibrium and a change in one of them will result in a change of the other two. However, the different pools differ in solubility and thus in availability to plants (Mandal et al. . 1986).

Hazra et al. (1987), found that the water soluble plus exchangeable forms of Zn, which was assessed by extraction with DTPA was comparatively low, ranging from 0.90-1.90 ppm with a mean of 1.5 ppm. These two fractions are thought to be the readily available sources of Zn (Prasad et al. (1990). Mandal et al. (1986) and Murthy (1982) pointed out that the organically complexed Zn, which is known to play a significant role in the Zn nutrition of lowland rice, varied from 1.90 to 2.70 ppm with a mean of 2.3 ppm. Mandal et al. (1986) reported that only small fractions viz; 0.26, 0.74, 1.58 and 0.71% of the total Zn occurred as water soluble, exchangeable organic complexed, amorphous sesquioxides, and crystalline sesquioxides forms, and these forms accounted for most of the Zn available to plants.

2.1.4 Factors affecting Zn availability

There are many factors which have been found to affect Zn availability, namely soil pH, type of clay minerals, high phosphate levels, organic matter, nitrogen, soil type, crop management and yield levels, climate and toxic substances (Randhawa and Nayyar 1982; Tiller et al.

1984). In this review only soil pH, soil type, phosphate level, nitrogen and climate will be dealt with in some detail.

2.1.4.1 Soil pH

Soil pH is a major factor regulating Zn availability in soils (Saeed and Fox 1979; Barrow 1987), and it is generally accepted that soil pH is negatively correlated with extractable Zn (Bandyopadhyaya and Adhikari 1968; Jahiruddin et al. 1985; Xie and Mackenzie 1988). The above relationship holds because at high pH values, Zn forms insoluble compounds such as $\text{Zn}(\text{OH})_2$ and ZnCO_3 , which reduce the availability of Zn^{2+} (Lindsay and Norvell 1969; Sims 1986).

Adsorption of Zn^{2+} by soil constituents, including clay minerals and various oxides of aluminium, iron and manganese, is pH dependent, with the amount adsorbed markedly increasing with increasing pH (Tiller et al. 1984). Most pH induced Zn deficiencies occur within the range of 6.0-8.0, and calcareous soils are particularly prone to this nutritional problem (Singh and Abrol 1986); Soper et al. (1989). Thus, overliming of acid soils or presence of large amounts of calcium carbonates in soils frequently induce Zn-deficiency (Udo et al. 1970; Papadopoulos and Rowell 1989).

Adsorption of Zn^{2+} by soil organic matter is also influenced by pH. For example, the amount of Zn^{2+} complexed by humic acids increases with rising pH (Stevenson and Ardakani 1972; Follet et al. 1981). Also, with increasing pH, stabilities of Zn-organic complexes increase up to a point after which the complexes break up and hydroxides, which are relatively insoluble form (Udo et al. 1970; Xie and Mackenzie 1989).

On the other hand a decrease in soil pH is accompanied by high levels of Zn concentration in the soil solution and increased stability of Zn compounds in soils (Chapman 1968; Saeed and Fox 1977; Pulford 1986). This may lead to increased uptake of Zn by crops and the uptake may attain toxic levels in plants causing negative effects (Corey et al. 1973 as cited by Kamasho 1980). Thus, Zn uptake by plants is highly pH dependent. For example, Viets et al. (1957) observed that Zn uptake by plants decreased to about one half when the soil pH was increased from 5 to 7.

2.1.4.2 High phosphate levels in the soils

Prolonged use or heavy dosage of P-fertilizers have been reported to reduce Zn uptake and even induce deficiency on various crops on many soils (Chapman 1968; Barrow 1987; Xie and Mackenzie 1989). The effect of P on Zn uptake by crops varies with soils and crops, Zn and P

levels and other factors. It was suggested that P limits Zn availability by a Zn-P interaction in the plant rather than in the soils (Barrow 1987). For example, excess P-fertilization has been reported to inhibit Zn metabolism in various plants by reducing the absorption rate of Zn by roots, hence inducing Zn deficiency (Barrow 1987).

Stanton and Burger (1970) and Bollard et al. (1977) argued in favour of a bridge effect in which Zn was sorbed on phosphated hydrous oxides through the medium polyvalent bond between the oxide and Zn^{2+} . Increased negative charge or cation exchange capacity with sorbed P has been found by other workers e.g. Mekaru et al. (1972); Gillman and Fox (1980).

Loneragan et al. (1979) suggested that one of the reasons for P induced Zn deficiency in plants could be P-enhanced Zn adsorption by sesquioxides, especially in acid soils, and consequent decrease in Zn concentration in the soil solution. Several workers have shown that application of P especially in excess amounts, can lead to development of Zn-deficiency or reduced Zn content in plant tissues (Terman et al. 1966).

Generally, P-induced deficiency is more severe in calcareous soils and under heavy P-fertilization (Xie and Mackenzie 1988). Thus, the management practices that use high levels of P fertilizers may lead to a decrease in Zn uptake or, more likely, reduced transport in plants, hence induce Zn deficiency (Mengel and Kirkby 1987).

2.1.4.3 Effect of nitrogen

The effect of various nitrogen sources on Zn availability has been investigated by several researchers, and it was found that pH changes accompanying the use of N-fertilizers with an acidifying effect had the greatest effect on Zn uptake and growth of plants (Viets et al. 1957). According to Lindsay (1972), comparisons between various nitrogen carriers [ammonium sulphate $\{(\text{NH}_4)_2\text{SO}_4\}$, ammonium nitrate (NH_4NO_3) and calcium nitrate $\{\text{Ca}(\text{NO}_3)_2\}$] were made. It was found that pH changes accompanying the use of carriers exerted the greatest effect on Zn-uptake. The N-sources that reduced soil pH, for example $(\text{NH}_4)_2\text{SO}_4$, increased Zn availability, and this was attributed to the increased solubility of Zn compounds with increase in soil acidity. It was also reported that N-fertilizers sometimes increased the uptake of Zn by plants by increasing the exchange capacity of roots, hence increasing the withdrawal of Zn from the soils (Lindsay 1972; Kumar et al. 1985).

Kumar et al. (1985) reported that N-produced a synergistic effect on Zn concentration of leaves and stems and antagonistic effect on the roots, whereas Zn had an antagonistic relationship on N-concentration in the roots and leaves. Thus, whenever there is Zn deficiency, N-should also be considered as a factor.

2.1.4.4 Soil type

The distribution of soil Zn varies with soil types. Very often, sandy soils are deficient in available Zn. The reason is that quartz is generally low in Zn content, hence soils developed from it are inherently low in total Zn content; often ranging from 10-30 ppm only (Lindsay 1972; Katyal et al. 1982).

Lucas and Knezek (1972) reported that peats and mucks (Histosols) are also deficient in Zn, because the surface layer where plant roots feed becomes isolated from the mineral forms of zinc in the soil below.

Total Zn is lower in soils having a basic reaction than in acidic or neutral soils. Sharma and Motiramani (1969) reported that in high rainfall areas, where acid conditions prevail, weathered minerals release Zn that is soon removed by leaching. Thus, Zn deficiencies in acid soils are generally associated with low soil Zn content.

In Hawaii, Kanehiro and Sherman (1967) observed that the soils from volcanic ash had higher amounts of Zn than highly weathered oxisols and ultisols. Jalali et al. (1989) reported that soils rich in montmorillonitic clays may contain more total Zn than others due to strong bonding of Zn on the exchange complex. Thus, soil type dictates the amount of Zn available to plants.

2.1.4.5 Climate

The two main components of climate affecting micronutrient availability are temperature and moisture. The effects of these factors have been studied most extensively in temperate regions; little work on the effect on tropical conditions has been reported. Nevertheless, some general conclusions are still possible. Sharma and Motiramani (1969) reported that the response of rice to Zn application decreased with an increase in soil temperature.

Martin et al. (1965) found that applying high levels of P in soils of low available Zn induced Zn deficiency in cool weather but not during hot weather. Randhawa and Nayyar (1982) observed that in India, micronutrient deficiencies are most severe in cold weather and absent in warm weather on marginally deficient soils. Thus, cool soil temperatures enhance Zn deficiency.

Soil moisture also affects micronutrients availability. Continuous submergence induces Zn deficiency in rice regardless of soil pH (Castro 1970; Takkar and Randhawa 1979). Gangwar and Mann (1972) and Brar and Sekhon (1976) reported greater responses to Zn applications in rice under flooded conditions than under drained conditions.

2.2 Functions of Zn in plants

Zinc, as an essential micronutrient for plant growth and yield, serves a number of functions. Katyal and Sharma (1979) indicated that Zn serves both some structural and some regulatory roles in enzyme activity in plant tissues. For example, Clarkson and Hanson (1980) showed that Zn is an important component for the stability of cytoplasmic ribosomes. Lindsay (1972) and Mengel and Kirkby (1987) pointed out that Zn catalyses the process of oxidation in plant cells and is vital for the transformation of carbohydrates; viz: it regulates the consumption of sugar, increases the source of energy for the production of chlorophyll, aids in formation of auxins, and promotes the absorption of water and in so doing prevents stunting.

Prince et al. (1972) summarized that Zn is recognized as an essential component in several dehydrogenases, proteinases, and peptidases. In plants these include carbonic anhydrase, alcohol dehydrogenase, glutamic dehydrogenase, L-lactic dehydrogenase, aldolase, malic dehydrogenase, D-lactic cytochrome C reductase and D-glyceraldehyde-3-phosphate dehydrogenase. For example, the enzyme carbonic anhydrase catalyses the decomposition of carbonic acid to carbon dioxide and water in the formation of the amino acid tryptophan. Zinc is also believed to induce resistance to bacterial and fungal

diseases in plants (Katyal and Sharma 1979). Thus, without Zn plant growth becomes severely restricted.

2.3 Diagnosing Zn deficiencies

In the past, methods used to detect Zn deficiencies were visual observations of deficiency symptoms in response to foliar applications of Zn (Lindsay 1972; Bell et al. 1990). The deficiency of Zn is often associated with decreased internode length, restricted development of new leaves, brownish appearance, often small, distorted and necrotic leaves (Bell et al. 1990).

At present, soil tests and plant analysis for Zn are becoming more widely used, where atomic absorption spectrophotometry and direct reading emission spectroscopy have greatly simplified the analytical procedure (Bell et al. 1990). Critical levels have been established to forecast Zn concentration in soils and vegetative parts during early growth in the field, which would indicate the likelihood of Zn deficiency that would limit crop growth and yields.

2.3.1 Zinc deficiency symptoms on maize and rice

Generally, Zn is not translocated from old to new tissues, and consequently, it exhibits various

combinations of interveinal chlorosis, dieback and rosetting in young growth.

Deficiency of Zn in maize generally reduces plant growth and causes chlorotic bands on both sides of the leaf midrib (Banda and Singh 1989). Kang and Osiname (1985) reported that Zn deficiency in maize shows up in early stages of growth, as yellow streaks in the leaves with a white to yellowish top. White spots may appear in the leaves or along the edges, a portion of the marginal area of leaves may die and the entire plant may be stunted due to shortening of the internodes.

In rice, Zn deficiency is characterized by stunted growth (though tillering may continue), reddish brown blotches in the lower leaves, delayed maturity, and low yield in severe cases (Katyal and Ponamperuma 1974; Van Breemen and Castro 1980). Yoshida et al. (1973) and Soepard et al. (1977) reported that Zn deficiency in rice causes chlorotic brown blotches in the midribs of the younger leaves, especially at the base, and streaks develop in lower leaves, accompanied with a decrease in the size of the blade, and uneven growth, and delayed maturity of rice.

2.3.2 Plant analysis for Zn

Plant tissue analysis is a useful tool in diagnosing nutrient deficiencies in soils. It should reflect the

ability of the soil to supply a nutrient element under conditions of plant growth (Kanwar and Youngdahl 1985). Brar et al. (1980) pointed out that plant analysis holds a theoretical advantage over soil analysis in that the nutrient fraction found in plants has indeed been in the soil in forms available to plants. However in practice, a combination of soil and plant analysis offers better means of estimating the nutrient status of soils than either analysis alone.

Small and Ohlronge (1973) emphasized that plant analysis must be accompanied with proper collection and handling of plant samples. When using plant analysis for making diagnosis of a certain nutrient, a part of the plant is usually preferred. Some workers have suggested the use of recently matured leaves at appropriate stages of growth (Walsh and Beaton 1973) whereas others recommended specific leaves e.g earleaf in maize (Melsted et al. 1969) and 'Y' leaf in rice (Yoshida et al. (1973). Viets et al. (1954) proposed the use of upper mature leaves of the plant.

The Zn content of healthy plants usually ranges from 20-100 ppm. This range varies with plant species. Some plants seem to have greater ability than others to extract Zn from the soil (Brar et al. 1980). A Zn concentration of 20-70 ppm in the ear leaf at silking stage is considered as an adequate level for maize (Barber and Olsen 1968).

Various plants and parts differ considerably in the levels of Zn that accompany Zn deficiencies. Viets et al. (1954) reported that there is no general agreement as to a critical level of Zn in plants below which Zn deficiency occurs and above which it does not occur. Melsted et al. (1969) proposed a critical level of 15 ppm for maize in recently matured leaves (sixth leaf from the base or second leaf from the nodes below the upper ear node). Coffman and Miller (1973) found that the level of Zn in maize above which no further significant increase in dry matter yield occurred was 12 ppm. Bell et al. (1990) recommended Zn concentration of 20 mg/kg in upper stems of leaves and 25 mg/kg in recently matured leaves at early pegging to be the critical level for rice. Harlin and Soltanpour (1981) found that soils testing below 0.7 ppm DTPA- $(\text{NH}_4)_2\text{CO}_3$ extractable-Zn produced Zn deficiency symptoms in maize. However, it is difficult to establish precisely, the critical Zn value for deficiency because of possible analytical errors, variations among sampled plants, interactions between Zn and other elements, various stages of sampled plants, and contaminations (Sakal et al. 1984).

2.3.3 Soil test for Zn

Soil testing is a well developed technique to provide information on nutrient status of soils and to estimate

fertilizer needs (Singh and Takkar 1981). The lower the soil test value for a nutrient, the greater would be the expected response of a crop to its application. Gangwar and Chandra (1975) pointed out that the ideal soil test should identify as nearly as possible the critical level of an extractable nutrient below which plants will be deficient and above which no deficiency occurs. Soil tests should also provide some guide as to how much fertilizer is needed to correct a given deficiency. In addition, they should help to detect toxic levels of any nutrient that might occur. Soil testing for micronutrient is particularly difficult because plant requirements for these elements are relatively low and even slight contamination of a sample or modification of a procedure may seriously affect soil test results (Lindsay and Cox 1985).

Ideally, a soil test should extract nutrients from the same pool of nutrients as the plant does. The amount extracted must be meaningfully related to the amount taken by the plant (Lindsay and Cox 1985). In recent years, a large number of methods have been employed to assess the status of plant available Zn in soils. Most of the methods are based on the amount of soil Zn extracted by water, neutral salt solutions, inorganic acids, and chelating agents buffered to various pH levels.

For the purpose of this dissertation, only inorganic acids and chelating agent extractants will be reviewed in

detail. It is important to note that different extractants differ in the amount of Zn that they can extract from the soil. This is because different extractants differ in chemical structures and, therefore, extracting power. Also, Zn in soil is present in different forms (Lindsay 1972; Lindsay and Cox 1985). For example, Coffman and Miller (1973) compared three extractants, viz: 0.05N HCl+0.25N H₂SO₄, 0.1N HCl, and EDTA-(NH₄)₂CO₃, for extracting available Zn. The quantities of Zn extracted by these three extractants suggested that 0.05N HCl+0.25N H₂SO₄ extracted about 70% as much Zn from the soils as 0.1N HCl and about 25% more than that extracted by EDTA-(NH₄)₂CO₃. Thus, it appears that the double acid and 0.1N HCl may have extracted Zn from the same pool.

2.3.3.1 Extraction of Zn by inorganic acids

Extraction of Zn by dilute and strong acids such as hydrochloric acid (HCl), nitric acid (HNO₃), sulphuric acid (H₂SO₄) have been used by several workers e.g. Trierweiller and Lindsay (1969) and Singh and Takkar (1981). These acids are thought to extract water soluble Zn, exchangeable Zn, Zn from acid soluble compounds and occluded Zn. Part of the latter two fractions may not be available to plants. Thus, strong acid extractants are objectionable especially in calcareous soils because of

the abundance of otherwise unavailable acid soluble carbonates which decompose and contribute to the available Zn fraction. Viets and Lindsay (1973) overcame this problem by using 'titratable alkalinity' as an estimate of the extractable fraction that was not part of the available fraction.

Another shortcoming of acid extractants in assessing the Zn status of calcareous soils is that, a single acid extraction may be partially or totally neutralized and its effectiveness decreased.

Extraction with 0.1N HCl

The 0.1N HCl solution has been used extensively. Kanehiro and Sherman (1967) observed that Hawaiian soils had an average of 4.5 ppm 0.1N HCl-extractable Zn and that the critical level was between 1 and 2 ppm. Viets and Lindsay (1973) found that more Zn was removed by the 0.1N HCl extractant than by either 2N $MgCl_2$ and NH_4OAC -dithizone. The NH_4OAC -dithizone and 1N $MgCl_2$ extracted about half and one sixth, respectively, of the amount extracted by 0.1N HCl. These observations were expected in view of the greater solvent action of acidic extractants. Kamasho (1980) reported that soils in southern Tanzania had more than 30 ppm 2M HCl-extractable Zn. Saeed and Fox (1979) reported that 0.1N HCl-extractable Zn was more closely related to the labile Zn

pool than was DTPA-extractable Zn in some Hawaiian acid soils.

Osiname et al. (1973a) reported that the best prediction of Zn uptake was provided by a combination of 0.1N HCl-extractable Zn, pH, organic matter and the silt plus clay fraction in a multiple regression analysis. With all the four extractants evaluated, the uptake of Zn was predicted better on soils of pH less than 6 than those of pH greater than 6.

Dolar and Keeney (1971) found that 0.1N HCl extracted more of the organically complexed form of the element than other forms such as hydroxides, oxides or phosphates. Singh et al. (1987) noted that Zn associated with CaCO_3 showed positive significant correlation with 0.1N HCl fractions of Zn. They attributed this observation to the ability of 0.1N HCl to extract some of the CaCO_3 bound Zn. Kanehiro and Sherman (1967) found high correlation between total and 0.1N HCl extractable Zn but found none between soil pH and 0.1N HCl extractable Zn.

Wear and Evans (1968) correlated Zn uptake by maize with soil test values viz: 0.1N HCl, 0.05N HCl + 0.025N H_2SO_4 and 0.05N EDTA at pH 7. The correlation coefficients for the respective extractants were 0.89, 0.82, and 0.62. Thus, Zn uptake by maize correlated best with 0.1N HCl-extractable Zn. Coffman and Miller (1973) compared three extractants viz: 0.05N HCl + 0.25N H_2SO_4 , 0.1N HCl and 0.1M EDTA- $(\text{NH}_4)_2\text{CO}_3$, for extracting available soil Zn. The

correlation coefficients (significant at $P \geq 0.01$) were 0.83, 0.85, and 0.79, respectively. The quantities of Zn extracted by the three extractants suggested that 0.05N HCl + 0.25N H_2SO_4 extracted about 70 percent as much Zn from the soils as 0.1N HCl and about 25 percent more than that extracted by $EDTA-(NH_4)_2CO_3$. Thus, it appears that 0.1N HCl and 0.05N HCl + 0.25N H_2SO_4 extractants extract Zn from the same pool.

Generally 0.1N HCl has been found to be a satisfactory predictor of Zn uptake by plants especially when the correlation is made on soils of very limited genetic variations (Martens and Chesters 1967). The disadvantage of 0.1N HCl is that the amount of Zn extracted is pH dependent.

Double acid (0.05N HCl+0.25N H_2SO_4) extractant

The double acid extractant is most useful in soils where CEC is less than 10 meq/100g (pH 7.0) and have relatively low organic matter. Wear and Evans (1968) obtained the best correlation between extractable Zn and Zn uptake by corn (" r " = 0.89) with the double acid extractant in acid soils with coarse to medium texture. Mnkeni and Nzabayanga (1989) recommended the use of double acid extractant for maize in soils of Morogoro district in Tanzania. They proposed a critical level of 3.8 ppm Zn to separate Zn-deficient soils from non-deficient soils.

However, other workers have found the double acid extractant to be inferior to other extractants e.g. 0.1N HCl, DTPA and EDTA-(NH₄)₂CO₃ (Singh et al. 1987).

2.3.3.2 Extraction by chelating agents

Chelating agents e.g. DTPA and EDTA-(NH₄)CO₃ have been reported to be superior to other extracting agents (Lindsay 1972; Singh and Takkar 1981; Singh et al. 1987). The reason suggested was that chelating agents react with free metal ions in solution, forming soluble complexes and thus simulating the absorbing action of roots. In addition chelates have advantage over strong acid-extractants because the pH of the extracting media can be carefully selected and maintained (Lindsay 1972).

Extraction with DTPA

This extractant consists of 0.005M DTPA, 0.01M CaCl₂ and 0.1M TEA buffered at pH 7.3. Selection of pH 7.3 and 0.01M CaCl₂ enables the extractant to attain equilibrium with CaCO₃. This prevents the dissolution of CaCO₃ from calcareous soils (Singh and Takkar 1981).

Kamasho and Singh (1982) compared DTPA, EDTA and 0.1N HCl for Zn extraction in soils of Mbeya district. They found DTPA Zn to be better correlated with Zn uptake by

wheat and suggested a critical value of 3.7 ppm Zn. Singh and Takkar (1981), found DTPA to be the best method for estimating Zn for rice in salt affected soils of India and recommended a critical level of 0.86 ppm.

Banda and Singh (1989) recommended the use of DTPA for assessing Zn extractability by maize plants in high rainfall areas of Zambia. They established a critical level of 0.7 ppm. Brown et al. (1971) compared several extractants for determining available Zn using 92 neutral-calcareous Californian soils. Their predictive values for DTPA, dithizone, 0.1N HCl and EDTA were 83, 79, 73 and 72%, respectively. They recommended a critical level of 0.5 ppm DTPA-extractable Zn as a separator for deficient and non-deficient soils.

However, contrary to the good results cited above Dolar and Keeney (1971) obtained poorer results with DTPA buffered at pH 10.9 instead of 7.3 compared to 0.1N HCl and EDTA buffered at pH 7.0

Different critical levels for rice have been reported by various workers with this extractant. For example, Lindsay and Norvell (1978) found a critical level of 0.80 ppm while Singh and Takkar (1981) reported a critical level of 0.86 ppm. Singh et al. (1971) reported a critical level of 1.4 ppm. Zn in 30 calcareous soils in India.

Extraction with EDTA-(NH₄)₂CO₃

The chelating agent EDTA at concentration ranging 0.007M to 0.05M and buffered at neutral pH has been used as an extractant for copper, manganese and zinc (Viets and Lindsay 1973). This extractant is a more effective extracting agent for the adsorbed ions than NH₄OAC and it gives a good recovery of cations e.g. copper, zinc, etc. as well as certain anions such as PO₄⁼ (Viro 1955). However, the EDTA method is disadvantageous in calcareous soils because it dissolves water soluble carbonates that are not part of the exchange complex (Viro 1955).

Trierweiller and Lindsay (1969) developed an EDTA-(NH₄)₂CO₃ extractant for assessing available Zn in high pH soils. This extractant is advantageous in that it suppresses the dissolution of carbonates and oxides, and thereby avoids extraction of occluded Zn. The method was evaluated on 42 Colorado soils for maize. The extractant was superior to 0.1N HCl but was equal to dithizone in suitability for Zn extraction. A critical level of 1.4 ppm Zn separated Zn-deficient from non-deficient soils. Singh and Takkar (1981) established a soil critical level of 1.0 ppm. Msolla (1991) established a critical level of 0.86 ppm for soils of Igunga and Nzega districts, Tanzania. The shortcomings of this method are that, soil organic matter is soluble at the pH level employed (Trierweiller and Lindsay (1969) and it tends to clog the

atomizer of the atomic absorption spectrophotometer. Some workers e.g Singh and Takkar (1981) and Msolla (1991) have reported that $\text{EDTA}-(\text{NH}_4)_2\text{CO}_3$ and DTPA extractants extract Zn from the same pool as the plants.

2.4 Correction of Zn deficiencies

The widespread occurrence of zinc deficiency could make it a serious nutritional problem. Fortunately, zinc deficiencies are relatively easy to correct, either with sprays or with soil application of Zn fertilizers. Numerous field and greenhouse trials have been conducted to evaluate the most effective method for correcting Zn deficiencies (Murphy and Walsh 1972; Kanwar and Youngdahl 1985).

2.4.1 Foliar application

Solutions containing one or more micronutrient are widely used as foliar sprays to correct deficiency. Foliar application are sometimes advantageous compared to soil application because application rates are much lower than for soil application, uniform distribution is obtained, response to the applied nutrient is almost immediate, and suspected deficiencies can be more easily diagnosed with spray trials. However, there may also be some disadvantages, viz: Leaf burn may result if salt

concentrations are excessive, and there is little residual effect (Kanwar and Youngdahl 1985).

Typical recommendations for foliar Zn sprays are 0.9-4.5 kg of $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ per 378 litres of H_2O . For maize a typical treatment consists of 920 litres of 0.5% $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ applied at the 3-leaf stage and again at the 5-leaf stage of growth (Mortvedt and Cox 1984). The exact concentration and application rates vary from crop to crop.

Mikkelsen and Kuo (1977) reported that foliar application of Zn as $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ to rice has been effective in correcting Zn deficiencies in rice. Zinc chelates have also been used as foliar sprays.

Foliar applications are, however, not a substitute for soil application because the application must be after the crop has developed (Mortvedt and Cox 1984). Thus a subsequent crop will still need its own application.

2.4.2 Soil applications

Soil application has been recommended as the most effective way of correcting Zn deficiency of most crops such as maize and rice. The commonest ways of soil application are broadcasting Zn prior to tillage and band application at planting (Mikkelsen and Kuo 1977). Broadcast applications allow a greater proportion of the soil in the root zone to be affected by the fertilizer.

Amer et al. (1980) pointed out that soil application of ZnSO_4 and ZnSO_4 -urea mixed with soil at 5 kgZn/ha gave comparable yields. They further compared two Zn sources viz: ZnO and ZnSO_4 , and showed that ZnO was more effective than ZnSO_4 when both are incorporated into the soil. However, surface applications of Zn are particularly effective in water sown rice.

2.4.3 Zinc sources.

The effectiveness of various Zn sources in supplying Zn to plants depend on their chemical reactions and solubility relationships. The two main Zn sources used are inorganic and chelate sources.

2.4.3.1 Inorganic Zn sources

There are many Zn salts which can be used as Zn fertilizers e.g. $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ containing 35% Zn, ZnO containing 78% Zn, $\text{Zn}(\text{OH})_2$ containing 55% Zn, and ZnCO_3 containing 52% Zn (Kalabasi et al. 1976). Other inorganic Zn sources such as ZnCl_2 , $\text{Zn}(\text{NO}_3)_2$ and $\text{Zn}(\text{PO}_4)_2$ are also occasionally used for rice and have about the same characteristics as $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ (Mikkelsen and Kuo 1977).

Zinc sulphate is the most commonly used inorganic source because of its high water solubility and ease of handling for soil application or use in fertilizer

mixtures (Mikkelsen and Kuo 1977). However, Amer et al. (1980) found that ZnO was more effective than $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ for flooded rice when incorporated into a calcareous soil in Egypt. The greater effectiveness of ZnO was due to its slower solubility compared to ZnSO_4 . Whereas $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ dissolved immediately after application, and hence caused a sharp increase in solution Zn followed by a rapid decline. The ZnO on the other hand, dissolved more slowly and maintained soluble Zn at intermediate levels for at least 9 weeks.

Zinc oxide powder was twice as effective as a granular ZnSO_4 based by product for wheat in South Africa (Banda and Singh 1989). The physical accessibility of the fertilizer by plant roots is essential. When Zn compounds of intermediate solubility are granulated or banded, they remain localized so that a small fraction of the total soil volume is affected (Brown and Krantz 1966). Mixing these Zn sources with as little as one sixteenth of the total soil volume was adequate to correct Zn deficiency.

The effect of granulation in restricting Zn movement is most pronounced at high pH because most of the common inorganic Zn compounds used as fertilizers decrease in solubility with increase in pH (Kalabasi et al. 1976). Use of ZnSO_4 frequently shows slightly greater availability than similar applications of granular ZnO or ZnCO_3 , particularly in high pH soils. In acid soils the difference between ZnSO_4 , ZnO and ZnCO_3 is very slight

because ZnO and ZnCO_3 are also highly soluble under such conditions.

The recommended amount of Zn to apply depends on the type of crop, Zn source, method of application and severity of Zn deficiency (Gupta 1989). Usually a modest application of 4-10 kgZn/ha is adequate for several years. Sedberry et al. 1971 cited by Mikkelsen and Kuo (1977) recommended the use of 10 kgZn/ha prior to or at seeding time, to effectively control Zn deficiency in Louisiana.

2.4.3.2 Zinc chelates

Zinc chelates are formed by combining a chelating agent with a Zn atom through coordinate bonds (Young 1969). The most commonly used chelating agents are EDTA, DTPA, EDDHA, HEDTA and NTA. These are available in liquid forms. Numerous studies have been made to compare the effectiveness of Zn chelates with inorganic zinc fertilizers (Brown and Krantz 1966; Kalabasi et al. 1976). Generally, Zn chelates are more available than inorganic sources per unit of Zn (Giordano and Mortvedt 1966).

Brown and Krantz (1966) showed that the effectiveness of chelates decreased at low pH. The reason was that at low pH Zn^{2+} ions from the chelate are displaced by Fe^{3+} . Thus the use of chelates is more favoured in calcareous soils.

Lindsay and Norvell (1969) predicted stability diagrams for ZnEDTA and ZnDTPA in soils and observed that at low pH, Fe^{3+} displaced Zn^{2+} ions from these chelates whereas at high pH, Ca^{2+} displaced it. ZnEDTA has a maximum stability at pH 6.5 where approximately 70% of the EDTA ligand is chelated with Zn^{2+} . ZnDTPA on the other hand, has a maximum stability at pH 7.3. Kalabasi et al. (1976) pointed out that in the presence of CaCO_3 , increasing CO_2 forms CO_3^{2-} which depresses Ca^{2+} ions and allows more Zn^{2+} to be held by chelating agent. Udo et al. (1970) recommended that Zn chelates that are not readily dissociated in soils are most useful where fertilizers are either granulated or applied in bands, especially in high pH soils.

Generally the rate of chelated Zn ranges from 0.56 to 2.24 kgZn/ha (Tisdale and Nelson 1985). Sedberry et al. (1971) as cited by Mikkelsen and Kuo (1977) found that 0.31 KgZn/ha applied as Zn chelate to the soil prior to, or at the time of seeding effectively controlled Zn deficiency in Louisiana, USA. Well et al. (1973) cited by Follet et al. (1981) used 1 kgZn/ha as Zn chelate.

2.4.4 Response to Zn application

Brown and Krantz (1966) and Reuter et al. (1982) classified zinc deficient soils as those that gave a response to application of Zn. Generally, Zn uptake was

found to increase with increasing rates of Zn applied. Numerous workers have reported response of crops to Zn application. For example, Sanzo et al. (1984) and Raju et al. (1986) found that paddy yields of 3.36 tons/ha in rice given 100 kgN/ha were increased to 3.9 tons/ha by applying 18.2 kgZn/ha. Khamparia et al. (1977) found that the yield of rainfed rice was almost doubled when ZnSO_4 was applied. Krishnamoorthy et al. (1971) obtained an increase in rice grain yield of 1.8 tones/ha on a calcareous Alfisol (pH=7.6) in Andra Pradesh, India, by applying 10 kgZn/ha.

Maize has also shown considerable responses to Zn application. Agboola et al. (1970) reported an increase in maize yield of 33% with Zn application. Coffman and Miller (1973) obtained an increase in dry matter yield of maize of 100% by applying 1.25 ppm Zn. Osiname et al. (1973) obtained large maize grain yield increase with the application low rates of Zn. They pointed out that significant Zn responses were limited to soils with extractable Zn values of less than 1 ppm. Zinc application markedly increased the yield of maize on Vertisols (Ramakrishnan and Kaliapa 1976). Wheat, Lucerne and maize grown on some soils of Mbeya, Tanzania, responded to application of 10 kgZn/ha as ZnSO_4 (Uyole Agricultural Centre, Annual Report 1973/1974, cited by Kamasho, 1980).

Kanwar and Randhawa (1974), Takkar and Randhawa (1979) and Osiname et al. (1973) summarized thousands of experiments assessing response of crops to Zn application in farmers, fields. They all showed that in about 60% of the sites the crops responded to Zn application.

2.4.4 Residual effects

The magnitude of response by a succeeding crop to a given micronutrient applied to a preceding crop is defined as its residual effectiveness. Zinc fertilizers have a significant residual effectiveness that persists for several years depending on the crop, soil, and zinc rate applied (Takkar and Randhawa 1979). Brown et al. (1960) reported that approximately 35% of 18 kgZn/ha application was still extractable with 0.1N HCl from the upper 20 cm of a fine sandy loam after four cropping seasons.

Brown et al. (1964) found that 2.5 ppm Zn as ZnSO_4 was adequate for 10 successive crops grown in the greenhouse on a previously Zn-deficient soil without Zn deficiency recurring. Giordano and Mortvedt (1972) reported that application of 3 kgZn/ha as $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ was still adequate for maize after four croppings in Cerrado soils in Brazil. Varma et al. (1977) reported that broadcasted ZnSO_4 or ZnO suspension on roots of rice transplants supplied Zn to a succeeding wheat crop on calcareous soils in India. Sakal et al. (1984) found that application of 5 kgZn/ha as ZnSO_4 ,

especially when combined with 10 tons compost/ha, to a calcareous silt loam soil significantly increased Zn uptake and paddy yield, and subsequent crops of barley and rice still benefitted from it.

3.0 MATERIALS AND METHODS

3.1 Materials

3.1.1. Soils

The soils used in this study were collected from thirteen reference (benchmark) sites representing the important agricultural areas of the district. The sites were Mvomero, Wami-Vijana, Dakawa 1, located at the Cholima Agriculture Experimental Station Farm. Others were Dakawa 2 and Dakawa 3 located at field 22, (plot 16) and field 24, (plot 20), respectively, of Dakawa Rice Farm; Mkundi, Pangawe, Kingolwira, SUA gate and Magadu areas of SUA farm, Melela, Mlali and Mindu. These sites are marked on a map of Morogoro district given in Appendix 1.

3.1.2 Test crops

Maize (Zea mays L.) (Tanzania maize variety 1) and rice (Oryza sativa L.) variety sabarmati were used as test crops.

3.1.3 Fertilizers

Fertilizers used were: (i) zinc oxide (78% Zn) as a source of Zn, (ii) ammonium sulphate (21% N) as a source of N, (iii) potassium sulphate (48% K_2O) as a source of K and triple superphosphate (46% P_2O_5) as a source of P.

3.2 METHODOLOGY

3.2.1 Soil classification

Soil profiles representing the different Benchmark sites were dug, described, sampled and characterized following standard procedures (FAO 1977; FAO-UNESCO 1989 and Soil Survey Staff 1990). The soils were classified down to subgroup level according to the US Soil Taxonomy system and down to level-2 of the FAO-UNESCO soil classification system (Msanya and Kaaya 1992, Unpublished work). According to the two international systems of soil classification the soils were classified as shown below:

Soil	FAO-UNESCO (1989) Classification	US Soil Taxonomy (1990) Classification
(1) SUA gate	Rhodic Ferralsol	Rhodic Haplustox
(2) Magadu	Haplic Acrisol	Paleustult
(3) Pangawe	Gleyic Cambisol	Vertic Tropaquept
(4) Kingolwira	Rhodic Ferralsol	Rhodic Haplustox
(5) Mlali	Haplic Acrisol	Ustic Haplohumult
(6) Melela	Eutric Vertisol	Paleustollic Pellustert
(7) Mvomero	Mollic Fluvisol	Fluvaquertic haplaquoll
(8) Wami-Vijana	Eutric Fluvisol	Vertic Tropaquept
(9) Mkundi	Dystric Regosol	Tropaquent
(10) Dakawa 1	Gleyic Cambisol	Vertic Tropaquept
(11) Dakawa 2	Calcic Vertisol	Typic Pellustert
(12) Dakawa 3	not classified	not classified
(13) Mindu	not classified	not classified.

3.2.2 Soil sampling and sample preparation

Composite surface (0-20cm) soil samples from the above mentioned sites were collected. The soil samples were composited, air dried and ground to pass through 8 mm sieve for the glasshouse pot experiment and 2mm sieve for physico-chemical analysis. The same sites were used later for field experiments.

3.2.3 Soil analysis

Soil pH was measured electrometrically in water using 1:2.5 soil:water ratio (Peech 1965). Particle size distribution was determined by the Bouyoucus hydrometer method as described by Day (1965) while the textural classes were obtained using the USDA textural class triangle. Extractable phosphorus was determined following the Bray 1 procedure (Bray and Kurtz 1945) and P in the extract measured by the ascorbic acid-molybdate blue method as described by Watanabe and Olsen 1965. Cation exchange capacity (CEC) was determined by the ammonium acetate saturation method (Chapman 1965). The amounts of Ca, Mg, K, and Na in the ammonium acetate extract were determined by atomic absorption spectrophotometry. Organic carbon was determined by the wet digestion method of Walkley and Black (Allison 1965). Total nitrogen was obtained by the micro-Kjeldahl digestion-distillation method (Bremner 1965). Exchangeable acidity was determined by the barium chloride-triethanolamine method of Peech (1965). Micronutrients e.g. Fe, Cu and Mn were determined using the DTPA (diethylene triamine pentaacetic acid) method of Lindsay and Norvell (1978).

Soil water content at field capacity (FC) was determined following the procedure employed by Savage (1979). The formula used was:

$$\%H_2O \text{ at FC} = \frac{\text{Wt of } H_2O \text{ added}}{\text{Wt of soil wetted}} \times 100$$

The (FC) results are presented in appendix 2.

3.3 Zinc determination

Available Zn was determined using different extractants. These were: 0.005M DTPA adjusted to pH 7.3 (Lindsay and Norvell 1978); 0.1M EDTA-(NH₄)₂ CO₃ at pH 8.6 (Trierweiler and Lindsay 1969); 0.1N HCl (Cox and Wear 1977) and the double acid (0.05N HCl in 0.25N H₂SO₄ method (Baker and Amacher 1982). Following is a summary showing the salient aspects of the procedures:

Summary of the salient aspects of the procedures:

Extractant	Soil:solution ratio	Shaking time	Reference
0.005M DTPA - TEA pH 7.3	1:2	2 hours	Lindsay & Norvell (1978)
0.05M EDTA -(NH ₄) ₂ CO ₃	1:2	2 hours	Trierweiler and Lindsay (1969)
0.1N HCl	1:10	30 minutes	Cox & Wear (1977)
0.05N HCl in 0.25N H ₂ SO ₄	1:5	15 minutes	Baker and Amacher (1982)

3.4 Glasshouse experiment

3.4.1 Preparation of potted soils

Four kilogrammes portions of air dry soil, passed through 8 mm sieve from each site were weighed into 6-litre plastic pots with drainage holes at the bottom. The holes were plugged loosely with cotton wool to prevent loss of soil but allow excess water to drain out. The soils were thoroughly mixed with phosphorus (P), potassium (K) and zinc (Zn) according to the treatments as follows:

- (i) Absolute control ($P_0K_0Zn_0$)
- (ii) Zinc control (20 mgP/kg soil, 20 mgK/kg soil and 0 mgZn/Kg soil.
- (iii) First Zn level " "
and 2.5 mgZn/kg soil.
- (iv) Second Zn level " "
and 5 mgZn/kg soil.

The treatments were replicated three times and arranged in a randomized complete block design in the glasshouse. The soils were moistened to field capacity and allowed to equilibrate for two days before sowing.

3.4.2 Maize experiment

Maize seeds were sown into the moist soil in pots. Ten soils were used for the maize trial. Four maize seeds were drilled in each pot and thinned to two plants per pot one week after emergence. A dose of 30 mgN/kg soil, as sulphate of ammonia, was applied two weeks after germination and the pots were maintained at approximately field capacity throughout the growing period.

3.4.3 Rice experiment

Rice seeds, variety sabarmati, were pregerminated by moistening with distilled water for 48 hours, in the dark. Ten seedlings were transplanted in each pot and the seedlings were thinned to six seedlings one week after germination. The water content of the soils was maintained at field capacity for the first two weeks. After this period, the soils were flooded for the remainder of the experimental period. Nitrogen was applied as ammonium sulphate in two splits at a rate of 22.5 mgN/kg soil per split. The first split was applied two weeks after planting and the second split at five weeks after planting.

3.5 Harvesting

3.5.1 Maize

After five weeks of growth, the plants were harvested by cutting the above ground portions at the soil level. The harvested plants were washed twice with distilled water to remove any adhering soil and other contaminants. The plants were then dried at 70°C to constant weight. Dry matter yields were determined. The plant samples were then ground and screened through a 1 mm sieve after which Zn concentration was determined following the HNO_3 - HClO_4 digestion method of Baker and Amacher (1982).

3.5.2 Rice

In the eighth week, the plant shoots above the soil surface were cut. This was followed by washing the plants in detergent solution and rinsed with distilled water twice. They were then put in labelled paper bags and handled as the maize samples in section 3.5.1 above.

3.5.3 Zinc availability indices

The relative yield as defined by Cate and Nelson (1965, 1971) was obtained as follows:

$$\text{Relative yield} = \frac{\text{Yield for treatment including all nutrients but Zn}}{\text{Yield for treatments including all nutrients}} \times 100$$

The soil test values obtained by the four extraction methods mentioned in section 3.3 and the maize relative yield data were used to evaluate the suitability of the extractants for assessing Zn availability to maize using the graphic and discontinuous linear model of Cate and Nelson (1971). The latter method involves the calculations of a series of coefficients of determination (R^2). The R^2 values are then plotted against the average soil test data. The average soil test value corresponding to the maximum (R^2) value for each extractant was considered as the critical level below which maize or rice would likely respond to Zn fertilization.

3.6 Zinc status of soils in Morogoro district

Thirty soil samples were collected from different locations in the district and analyzed for extractable Zn using the DTPA method to gauge the Zn fertility status within the district, based on the critical values established from the glasshouse experiment.

3.7 Field experiment

3.7.1 General

Land preparation was done by disc ploughing followed by disc harrowing. Plots of 5 m x 4 m dimensions were demarcated with 0.5 m paths between plots and 1.5 m paths between blocks. Borders were made around each plot to restrict water movement from one plot to another. The treatments were arranged in a randomized block design with four replications.

Zinc oxide was applied at four Zn rates namely 0, 5.0, 10.0 and 15.0 kgZn/ha. The fertilizer was broadcasted on the soil surface and incorporated into the soil prior to sowing rice or maize. Phosphorus and potassium were applied in all plots at a rate of 40 kgP or K/ha using the same sources as the glasshouse experiment. Nitrogen was applied later at a rate of 60 kgN/ha and 90 kgN/ha for maize and rice, respectively.

3.7.2 Maize

Nine soils out of the ten used in the glasshouse were used for maize field trials. The purpose of these trials was to validate the glasshouse results. Four Zn treatments viz: 0, 5, 10, and 15 KgZn/ha were tested in a randomized complete block design with four replications.

Phosphorus and potassium were applied at optimum levels i.e. 40 kg/ha each. Two maize seeds were sown per hole at a spacing of 75 cm between rows and 30 cm within rows. The plants were thinned to one plant per hole two weeks after emergence. Nitrogen (60 kgN/ha) was applied 4 weeks after germination.

Seedlings were sampled for the determination of dry matter yield, Zn concentration and uptake at the fifth leaf stage. Plants were then allowed to grow to maturity and grain yields for each treatment were recorded after harvesting.

3.7.3 Rice

Two of the four sites whose soils were used in the glasshouse studies were used for rice field trials. Rice seeds were drilled at a spacing of 20 cm x 20 cm after treatments (P, K and Zn) were applied as in the maize trial (section 3.7.2). Nitrogen was applied in two splits at a rate of 90 kgN/ha as ammonium sulphate. The first split was applied two weeks after sowing and the second split at panicle initiation (50 days) after drilling. The field trials were under irrigation so moisture was not a limiting factor. Optimal water level in the fields was maintained until maturity. Three weeks before harvesting, water was drained to enhance drying. Grain yields were measured after eliminating border effects. The net

harvested area was 3.6 m x 4.6 m. The weight measurements were taken at 14% moisture content.

3.8 Statistical analysis

The data obtained from the above experiments were subjected to analysis of variance based on the following model:

$$Y_{ij} = U + t_i + B_j + E_{ij}$$

where: Y_{ij} = Yield

U = General effect

t_i = Treatment effect

B_j = Block effect

E_{ij} = Random error

Means were separated using Duncan's New Multiple Range test and simple correlation coefficients between extractable zinc and dry matter yield for each extractant were also calculated (Montgomery 1984).

4.0 RESULTS AND DISCUSSION

4.1 Properties of the experimental soils

Data on selected physical and chemical properties of the experimental soils are given in Table 1. The data show marked differences in physico-chemical properties. From the textural classes (Table 1) the soils can be grouped into two textural groups viz: medium texture (7 out of 13 soils) and heavy texture (6 out of 13 soils). Soil texture greatly affects the productivity and usability of a soil. For example, heavy textured soils (e.g. clays) may hold water and nutrients so tightly that their availability to plants is reduced. These soils are also difficult to till. Light textured soils (e.g. sands) cannot hold sufficient water and nutrients due to big pores between the particles but are excellent in gaseous exchange. Medium textured soils (e.g. sandy clay loam) are good in nutrient release, gaseous exchange and water retention because of their medium pore spaces. Medium textured soils give few agricultural problems.

Rice production requires soils of medium to heavy texture whereas maize requires soils of medium texture.

Table 1. Some physico-chemical properties of the soils used

Site	PH in water	Organic C (%)	Total N (%)	Avai- lable P(µg/g)	Exchangeable cations CEC me/100g					Particle size			Textural class	
					Ca ²⁺	Mg ²⁺	K ⁺	Na ⁺	Al ³⁺	Clay (%)	Silt (%)	Sand (%)		
SUA-Gate	5.1	1.53	0.12	2.11	2.80	1.00	0.95	0.22	1.70	16.00	59	5	36	C
Magadu	4.5	1.17	0.11	21.05	2.25	1.00	1.46	0.34	2.40	15.10	51	3	46	SC
Pangawe	5.8	1.66	0.13	2.11	8.00	5.50	0.77	0.26	-	17.20	39	5	56	SC
Kingolwira	5.5	1.82	0.18	3.86	5.25	5.00	0.87	0.30	-	14.40	57	9	34	C
Mlali	5.8	1.17	0.15	14.40	2.38	1.21	0.69	2.69	-	11.40	41	3	56	SC
Melela	7.7	1.50	0.09	7.72	22.50	5.66	0.67	1.48	-	33.21	31	11	58	Sci
Hvomero	7.0	1.41	0.23	50.00	7.50	1.50	0.97	0.26	-	18.95	17	5	78	Sl
Wani-Vijana	6.0	1.57	0.15	20.00	11.00	4.80	1.79	0.26	-	20.05	53	11	36	C
Mkundi	5.8	0.82	0.13	2.81	3.63	0.83	0.59	0.34	-	25.10	61	15	24	C
Dakawa1	5.9	1.25	0.07	2.81	10.00	5.75	0.56	0.44	-	26.10	55	20	25	C
Dakawa2	7.9	1.65	0.07	9.65	16.00	7.08	1.49	1.04	-	25.52	38	7	55	SC
Dakawa3	8.1	1.68	0.06	8.77	13.50	10.80	0.64	1.48	-	27.70	36	10	54	SC
Hindu	7.0	1.27	0.16	21.05	13.00	5.75	1.22	1.26	-	29.60	43	14	43	C

Legend: C = Clay
 SC = Sandy clay
 SC1 = Sandy clay loam
 Sl = Sandy loam

Thus, most of the soils studied herein are suitable for the production of rice and maize.

Clay content ranged from 10% to 61% with 11 out of 13 soils having 31% clay and more. Thus, most of the soils are composed of a clay component which is important in water holding and nutrient supply to the plants.

The pH of the soils ranged from acidic (4.5) to alkaline (8.1) with most of the soils (8 out of 13 soils) being moderately acid to slightly acid, with pH values less than 7.0. The rest of the soils (5 out of 13 soils) had pH values of 7.0 and above. Landon (1984) categorized pH values as follows:- very high (>8.5); high (7.0-8.5); medium (5.5-7.0) and low (<5.5). Rice production does best at pH values of 5.0 to 6.5 whereas maize requires pH values of 5.5 to 7.5. The pH values obtained from the experimental soils accommodate both crops. The low pH values of Magadu and SUA-gate is caused by the exchangeable aluminium in these soils (Table 1).

Total N ranged from 0.06% to 0.23%. Metson (1961) cited by 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). Except for Mvomero soil which fell under medium category of total N, the rest of the soils planted with maize fell under the low N category. The soils planted with rice recorded low and very low total N levels. The very low level of total N observed in rice soils of Dakawa is probably due the

practice of grass burning prior to cultivation used by the farm management. This practice probably causes N volatilization. Thus, for high and sustained crop production N should be applied in all the soils, with larger amounts in rice soils.

The Bray 1 extractable P ranged from 21 to 50 ppm. Landon (1984) categorized extractable P in soils as follows:- high (>50); medium (15-50) and low (<15). The distribution of the studied soils were: low (9 soils) and medium (4 soils). Thus, high crop production requires P application on those soils which recorded low levels of P. The organic carbon (OC) ranged from 0.82 to 1.82%. Metson (1961) cited by Landon (1984) categorized percent OC as follows:- very high (>20); high (10-20); medium (4-10); low (2-4) and very low (<2). From the results obtained, all the soils fall under very low category. This indicates that the level of soil organic matter is low in these soils.

Among the exchangeable bases, Ca^{2+} was the most abundant followed by Mg^{2+} , K^+ and lastly Na^+ , in that order. Maff (1967) cited by Landon (1984) categorized soil exchangeable bases in me/100g soil as follows:-

Ca^{2+} : high (>10); medium (4-10) and low (<4)

Mg^{2+} : high (>0.5); medium (0.2-0.5) and low (<0.2)

K^+ : high (>0.6) and low (<0.6)

Na^+ : high (>1) and low (<1).

From the results, Dakawa 1, Dakawa 2, Dakawa 3, Mindu, Melela and Wami-Vijana soils had high levels of Ca^{2+} whereas Pangawe, Kingolwira and Mvomero had medium levels of Ca^{2+} . SUA-gate, Magadu, Mlali and Mkundi recorded low levels of Ca^{2+} . Thus Calcium application may be beneficial in soils testing low. All the soils had high levels of Mg^{2+} , some even more than enough. All the soils had enough levels of K^+ except Dakawa 1, and Mkundi. Mlali, Dakawa 2, Dakawa 3, Melela and Mindu had high levels of Na^+ . The rest of the soils had low levels of Na^+ .

The cation exchange capacity (CEC) ranged from 11.95 to 33.21 me/100g soil. According to Landon (1984), CEC can be categorized as: very high (>40); high (25-40); medium (15-25); low (5-15) and very low (<5). From the results (Table 1) most of the experimental soils ranged from medium to high CEC values and are satisfactory for agricultural production. Kingolwira and Mlali soils recorded low CEC values. Sustainable production on these two soils needs nutrient supplementation. The variations in soils properties as presented in Table 1 conform to the findings of Nzabayanga and Mnkeni (1984) and Mawenya (1986) using the soils from the same locations. The variations in physico-chemical properties indicate that the initial fertility and productivity status of these soils are markedly different. Such variations may be attributed to the nature of the parent material, extent of weathering and mode of soil formation.

4.2 Extractable Zn levels by different soil tests

The extractable zinc levels of the experimental soils are presented in Table 2. The amounts of available Zn extracted by 0.1N HCl ranged from 0.1 to 9.0 ppm; that by 0.05N HCl in 0.25N H₂SO₄ ranged from 0.1 to 5.75 ppm; that by EDTA-(NH₄)₂CO₃ ranged from 1.1 to 3.2 ppm and from 0.6 to 2.7 ppm for DTPA.

Based on the quantities of Zn extracted, the extractants were ranked in the order: 0.1N HCl > 0.05N HCl in 0.25N H₂SO₄ > EDTA-(NH₄)₂CO₃ > DTPA. These results are not very different from those reported by Alley *et al.* (1972) for some USA soils. They found the amounts of Zn extracted by the same extractants decreased in the order: 0.05N HCl + 0.25N H₂SO₄ > 0.1N HCl > EDTA > DTPA. Singh and Takkar (1981) found that the order of the extractants decreased as 0.005M EDTA > 0.01M EDTA-(NH₄)₂CO₃ > 0.005M DTPA > 0.05N HCl + 0.25N H₂SO₄. Banda and Singh (1989) found extractable Zn to decrease in the order: 0.1N HCl > 1N NH₄OAC > EDTA > DTPA for soils of high rainfall areas of Zambia. Thus, leaving out 0.05N HCl in 0.25N H₂SO₄ and other extractants not evaluated in this study, the trend reported by other workers is similar to the results reported here.

The variations in the trends of the amounts of extractable Zn by the extractants could be due to the

Table 2. Extractable zinc contents (ppm) of the experimental soils.

Location	E x t r a c t a n t s			
	0.1N HCl	Double acid	DTPA	EDTA-(NH ₄) ₂ CO ₃
SUA-gate	3.5	2.00	1.05	1.30
Magadu	3.0	5.75	1.85	2.40
Pangawe	4.5	2.50	1.95	2.00
Kingolwira	3.5	1.50	2.70	1.60
Mlali	4.5	1.25	1.30	1.60
Melela	1.0	0.25	1.15	1.30
Mvomero	9.0	5.25	2.70	3.20
Wami-Vijana	3.5	4.00	2.40	2.00
Mkundi	2.5	0.50	1.20	1.30
Dakawa 1	6.0	1.50	1.20	1.10
Dakawa 2	1.0	1.50	0.60	1.20
Dakawa 3	0.1	0.10	0.70	1.20
Mindu	6.0	5.75	1.50	2.30
Mean.	3.7	2.45	1.56	1.70

differences in soil pH, OC and CaCO_3 , as reported by Lindsay and Norvell (1972). With the exception of Dakawa 2, Dakawa 3 and Melela which recorded lower values of extractable Zn, relatively higher values were obtained with acid extractants compared to chelating extractants. The reason might be that acid extractants destroy acid-soluble fractions of the soil such as carbonates and oxides of iron and aluminium thus exaggerating the amount of Zn in solution. The three soils above i.e. Dakawa 2, Dakawa 3 and Melela are exceptional because they are calcareous and had little Zn associated with the solid phase of the soil. The acid-solubilization of carbonates and oxides of iron and aluminium in this case released much less Zn into solution. The chelate extractants (DTPA and $\text{EDTA}-(\text{NH}_4)_2\text{CO}_3$) recorded relatively lower values because these extractants avoid the dissolution of the carbonates and oxides into soil solution.

The amounts of 0.1N HCl extractable Zn obtained in this study (0.1-9.0 ppm) are lower than those reported by Kamasho (1980) who obtained a range of 15.5 to 151 ppm in soils of Mbeya, Tanzania. Nzabayanga and Mnkeni (1984) obtained somewhat comparable range of 2.0 to 9.6 ppm in soils of Morogoro. Banda and Singh (1989) obtained lower values (0.32-1.76 ppm) than those obtained in this study.

The amounts of Zn extracted by double acid extractant (0.1-5.7 ppm) were higher than those reported by Coffman and Miller (1973) who obtained a range of 0.3-1.5 ppm Zn.

Nzabayanga and Mnkeni (1984) obtained higher values (1.0-12.0 ppm) than those obtained in this study from the same sites.

The amounts of Zn extracted by $\text{EDTA}-(\text{NH}_4)_2\text{CO}_3$ in this study (1.1-2.4 ppm) were not very far from those reported by Cox and Kamprath (1972) who obtained a range of 1.4-3.0 ppm Zn. Singh and Takkar (1981) however, reported a relatively lower range of 0.37 to 1.82 ppm Zn. Of the four extractants tested DTPA extracted the least amount of Zn (0.6-2.70 ppm). However, the amounts of Zn extracted by DTPA in this study were higher than those reported by Keisling and Mullinix (1979) and Nelson and Anderson (1977) both cited by Harlin and Soltanpour (1981) who reported ranges of 0.2-0.48 ppm and 0.21-0.44 ppm DTPA extractable Zn, respectively. The amounts of DTPA extractable Zn obtained in this study were lower than those reported by Kamasho (1980) who found a range of 1.1-6.9 ppm from soils of Mbeya, Tanzania. The results of this study are more or less similar to those found by Nzabayanga and Mnkeni (1984) who obtained a range of 0.7-3.5 ppm DTPA-extractable Zn from similar soils of Morogoro district. The differences observed from the above discussion could be attributed to differences in soils physico-chemical properties such as soil pH, OC and texture. Differences in amounts extracted by different extractants might also be associated with differences of extractants in extracting power. The extractants are

expected to dissolve different forms of Zn in soil differently.

4.3 Glasshouse experiment

4.3.1 Maize plant performance

Zinc deficiency symptoms were observed in many pots where Zn was not applied. Plant growth in these pots was generally slower than in pots with added Zn, and leaves developed interveinal chlorosis on both sides of the midrib. The plants grown in soils from SUA-gate, Melela, Mlali, Mkundi, Magadu and Pangawe were markedly stunted, with little violet red points on the leaves. The dry matter yields from the Zn-control treatments in each of these soils were also relatively low compared to the rest of the treatments. Similar observations have been made by other workers. For example, Banda and Singh (1989) and Kang and Osiname (1985).

4.3.2 Response of maize to Zn application

Results for dry matter yields (DMY) of maize are presented in Table 3 whereas the Zn concentrations and Zn uptake by maize are presented in Table 4. Data in Table 3 show that application of N, P and K alone increased DMY significantly in all soils. This indicated that N, P and

K either singly or in combination were very limiting in these soils.

Application of Zn, in addition to N, P and K also significantly increased DMY of maize (Table 3). The DMY of the Zn control pots ranged from 6.77 to 12.95 g/pot as compared with 6.60 to 13.48 g/pot in the pots which received 2.5 mgZn/kg. The dry matter response in percent at 2.5 mgZn/kg ranged from -5.4% to 58.6% whereas percent response in Zn uptake (Table 4) ranged from -1.6 to 90.3%. The response of maize to added Zn varied from soil to soil and, as a result, the data will be discussed in groups of soils which behaved similarly.

Non-significant negative responses to Zn application were observed in soils high in DTPA-extractable Zn whereas those with low Zn levels showed positive responses to Zn addition. Non-significant negative responses to Zn addition were observed in Wami-Vijana, Mvomero and Kingolwira soils (Tables 3). Application of 2.5 mgZn/kg to these soils resulted in DMY decreases of 5.4, 0.3 and 2.5%, respectively. The Zn uptake from these soils was -1.6, 3.6 and 8.3%, respectively. Application of 5 mgZn/kg resulted in even greater reductions in DMY of 13.2, 6.32 and 7.0%. The Zn uptake (Table 4) changed by -9.73, 10.0 and 13.6%, respectively.

Table 3. Effect of Zn application on dry matter yield of maize in the glasshouse study

Site	Dry matter yields g/pot			Mean over Zn	Percent response between Zn levels		
	Absolute control	Zinc levels (ppm)			0 and 2.5, 0 and 5		
		0	2.5	5			
SUA	6.63 ^b	7.28 ^a	7.88 ^a	7.98 ^a	7.71	8.2	9.6
Melela	5.64 ^b	11.19 ^a	12.29 ^a	12.39 ^a	11.95	9.8	10.7
Mkundi	5.73 ^b	8.50 ^b	13.48 ^a	12.16 ^a	11.38	58.6	3.1
Dakawa 1	5.99 ^b	11.68 ^a	12.66 ^a	10.10 ^a	11.48	8.4	-13.5
Mlali	5.93 ^b	10.15 ^a	11.41 ^a	10.53 ^a	10.70	12.4	3.7
Magadu	2.48 ^c	9.00 ^b	11.05 ^a	10.37 ^a	10.37	22.8	22.7
Pangawe	4.77 ^c	9.41 ^b	11.61 ^a	12.20 ^a	11.07	23.4	29.6
Wami-vijana	5.39 ^c	12.95 ^a	12.25 ^{ab}	11.24 ^b	12.15	-5.4	-13.2
Mvomero	5.09 ^b	10.28 ^a	10.32 ^a	9.63 ^a	10.08	0.3	-6.32
Kingolwira	1.93 ^b	6.77 ^a	6.60 ^a	6.29 ^a	6.55	-2.5	-7.0
Mean	4.96	9.70	10.96	10.4	-	-	-

Means in the same row followed by the same letter are not statistically different (P<0.05) using Duncan's Multiple Range Test.

Table 4. Effect of Zn application on Zn concentration and uptake by maize in the glasshouse study

Site	Zinc concentration in plants (ppm)				Zinc uptake (µg/pot) at			Increase in Zn uptake (%) between	
	Absolute Control	Zn levels			0	2.5	5 ppm	0 and 2.5	0 and 5
		0	2.5	5					
SUA	10	13	17	20	94.64	133.96	159.60	41.5	68.6
Melela	14	22	22	21	246.18	270.38	260.16	9.8	5.7
Mkundi	14	15	18	22	127.50	242.64	267.52	90.3	109.8
Dakawa	18	18	20	22	210.24	253.20	220.20	20.4	4.7
Malaji	14	19	22	21	192.85	251.02	211.13	30.2	9.5
Magadu	15	16	18	18	144.00	198.90	186.66	38.1	29.6
Pangani	16	18	22	20	169.38	255.42	244.00	50.8	44.0
Wamji-Vijano	19	25	26	26	323.75	318.50	292.24	-1.6	-9.7
Evomeco	22	25	24	24	257.00	247.68	231.12	3.6	10.0
Kingolwira	21	18	20	22	121.86	132.00	138.38	8.3	13.6

These results indicated that the soils had adequate initial amount of Zn and that further additions of Zn was detrimental to the crop. Kingolwira and Wami-Vijana soils were acidic with pH values of 5.6 and 6.0, respectively. At such pH values, Zn solubility and availability may have been so high to the extent that further additions of the element caused a decrease in DMY. The neutral Mvomero soil was expected to respond to Zn application, however the slight negative responses to Zn additions could be attributed to the probability that native Zn may have been more than enough.

Lack of response to Zn application of some soils has been reported by others. Nzabayanga and Mnkeni (1984) reported similar results in some soils of Morogoro district. Kamasho (1980) found that most of the major soil types of Mbeya district did not respond to Zn application.

Positive responses to Zn application were shown by the rest of the soils planted with maize, viz: SUA-gate, Melela, Mkundi, Mlali, Magadu and Pangawe. Addition of 2.5 mgZn/kg increased DMY by 8.2, 9.8, 58.6, 8.4, 22.8 and 23.4% on SUA-gate, Melela, Mkundi, Mlali, Magadu and Pangawe soils, respectively. Increasing the rate of Zn to 5 mgZn/kg caused small reductions in DMY on Mkundi and Mlali soils whereas no net change occurred on SUA-Gate. These results indicated that the three soils could benefit from supplemental Zn rates less than 5 mgZn/kg.

Substantial increases in DMY at this rate were observed on Melela, Magadu and Pangawe soils (Table 3). Since all of the above soils except Melela have pH values less than 7.0, the increased demand for Zn might be attributed to other soil properties such as soil texture (clay content), presence of Ca^{2+} and Mg^{2+} ions.

Among the ten soils studied, SUA-gate had the lowest DTPA-extractable Zn (1.05 ppm) followed by Melela (1.15 ppm). These values were low relative to others and could partly explain the observed positive response of maize to Zn application. In the case of Melela soil, the Zn deficiency could have been contributed largely by its high pH (7.7) (Table 1) and presence of high level of Ca^{2+} ions (22.00 me/100 g). The Zn solubility under such conditions is very low (Udo et al. 1970). However, the responses to Zn addition on Melela soil was very low as expected. The reason might be that the soil has very high CEC (33.21 me/100 g) and probably some other nutrients became limiting e.g. nitrogen and this limited response to Zn. The results obtained herein are in agreement with those reported by other workers such as Kanwar and Youngdahl (1985), Katyal and Agrawal (1982) and Lindsay (1972).

4.3.3 Selection of suitable extractants

The relationship between soil test values (Table 2) and the relative yield data (Table 5) for the four

extractants using the discontinuous linear regression model of Cate and Nelson (1971), are given on Figures 1, 2, 3 and 4. Figure 1 shows the scatter diagram and R^2 -plot for DTPA extractable-Zn. The figure shows that the critical Zn level for DTPA below which maize is likely respond to Zn fertilization is 1.95 ppm. Thus, soils with less than 1.95 ppm DTPA-extractable Zn are likely respond to Zn application whereas those which are above this critical level are not likely to respond.

The maximum R^2 value associated with this critical value was 0.67, significant at $P \geq 0.01$. The Zn critical value obtained by this method is higher than those obtained by other workers such as Singh and Takkar (1981); Sakal et al. (1984) and Banda and Singh (1989). However, Kamasho (1980) obtained a critical value of 3.7 ppm Zn for soils of Mbeya district, Tanzania.

Figure 2 shows a scatter diagram and R^2 -plot for EDTA- $(\text{NH}_4)_2\text{CO}_3$ extractable-Zn vs percentage yield. The critical soil Zn using this extractant was 1.30 ppm. Thus, soils containing EDTA- $(\text{NH}_4)_2\text{CO}_3$ extractable-Zn values less than this critical level are likely respond to Zn application whereas those with values higher than this critical level are not expected to respond. The critical Zn value

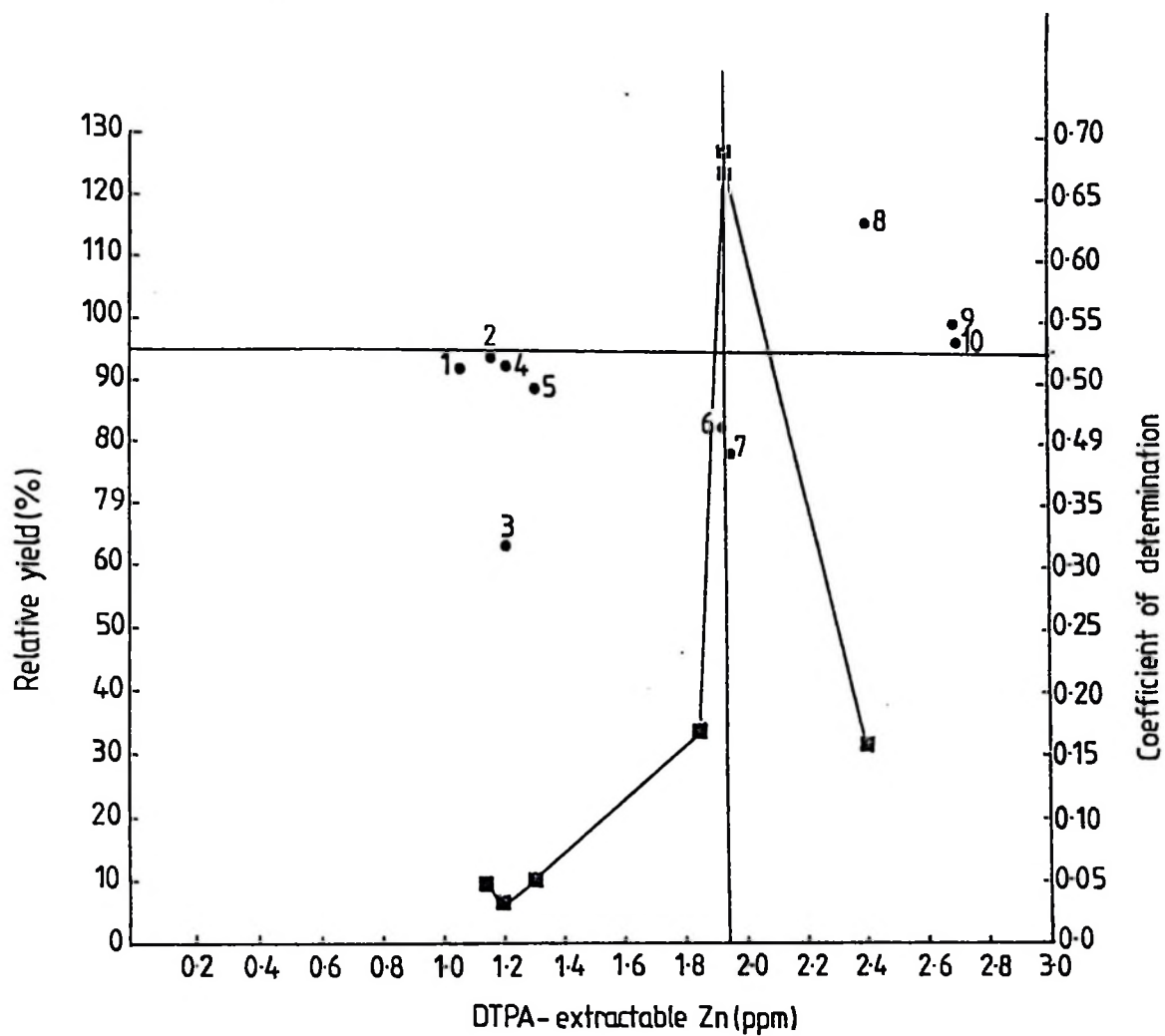


Fig.1. A scatter diagram of the relationship between percentage yield and DTPA-extractable Zn and the R^2 - plot.

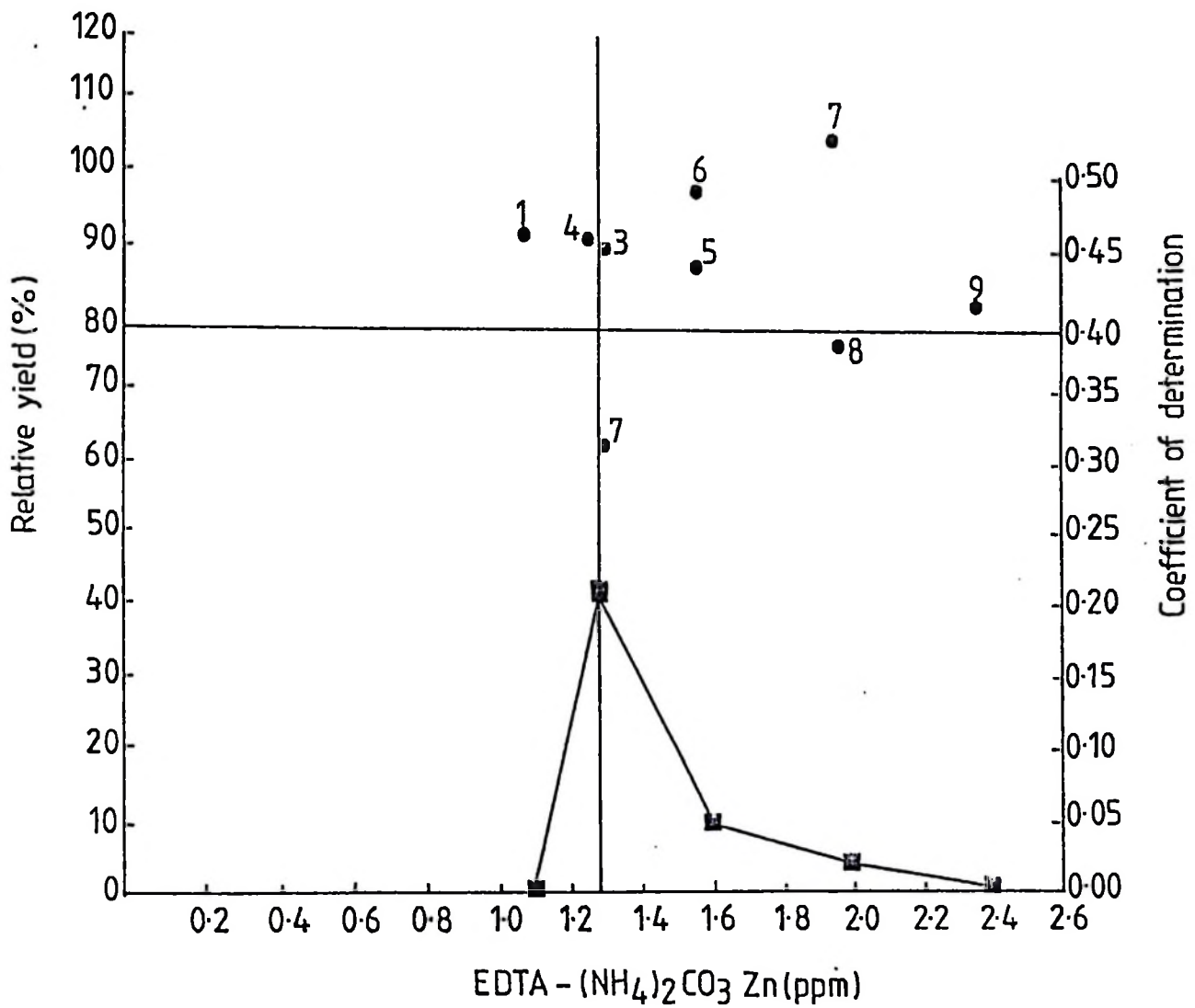


Fig. 2. A scatter diagram of the relationship between percentage yield and EDTA - (NH₄)₂CO₃ extractable Zn and the R² plot.

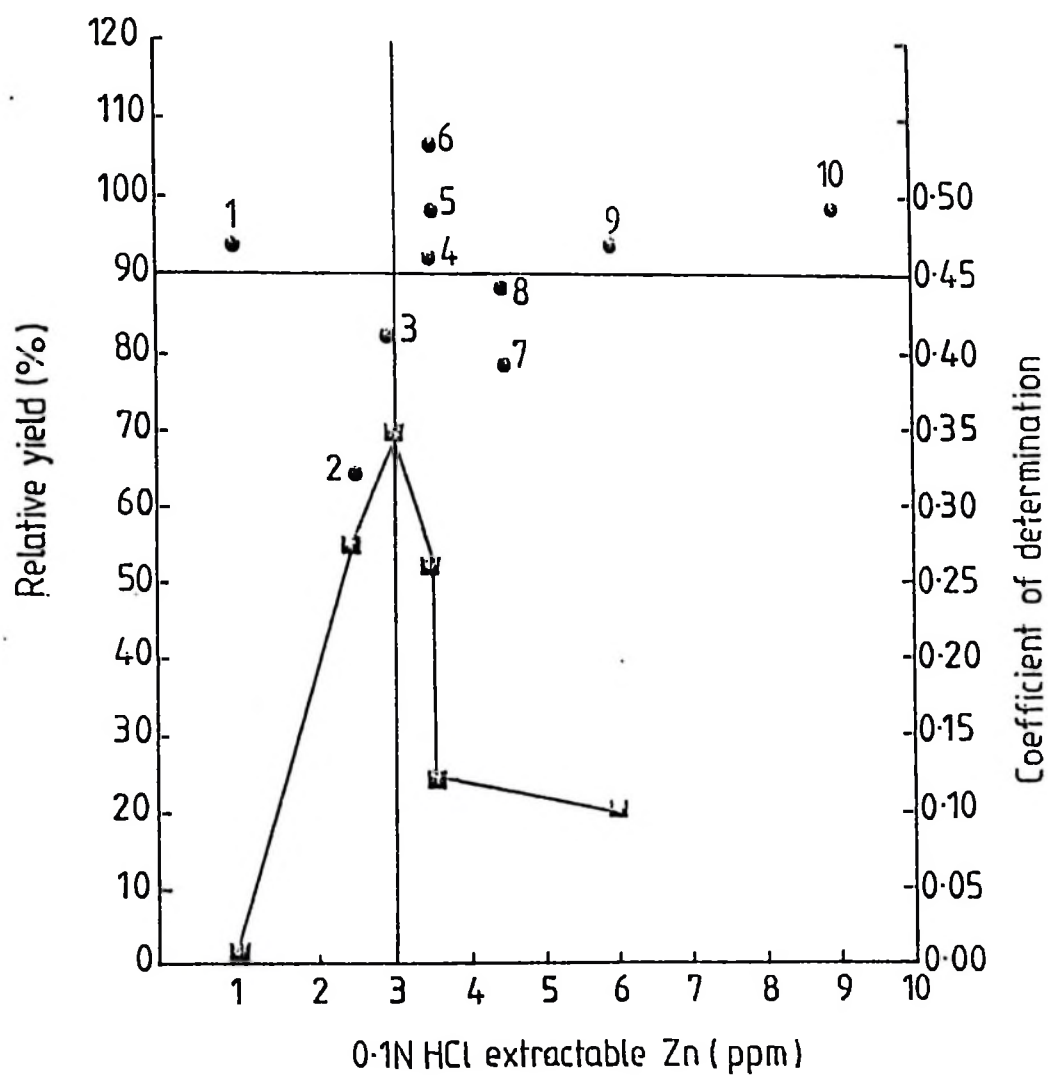


Fig.3. A scatter diagram of the relationship between percentage yield and 0.1N HCl extractable Zn and R^2 plot.

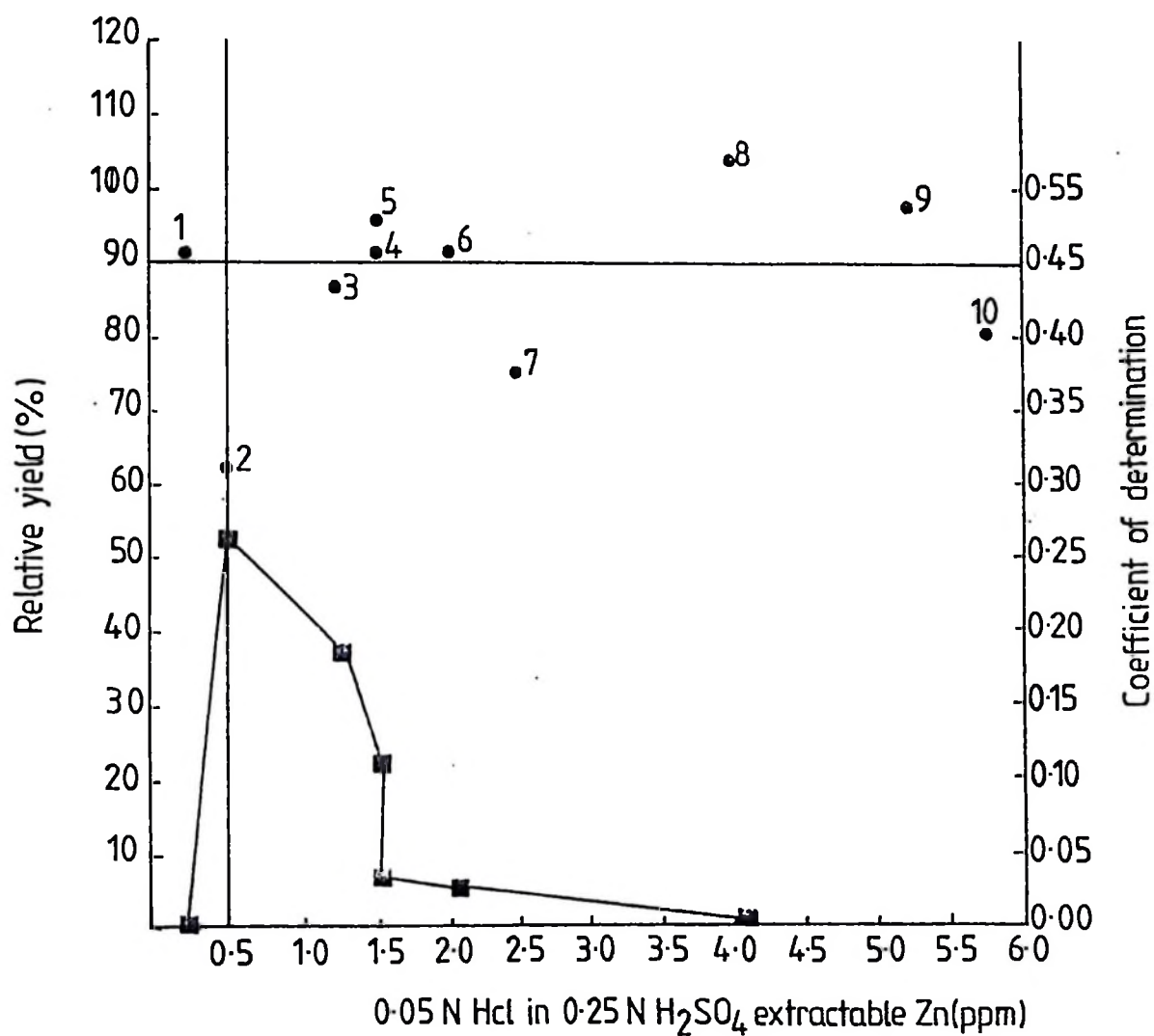


Fig. 4 . A scatter diagram of the relationship between percentage yield and 0.05 N Hcl in 0.25 N H₂So₄ extractable Zn and the R²-plot.

obtained by this method is close to that of Sakal et al. (1984) who reported a critical value of 1.18 ppm which is within the range of 0.5 to 2.3 ppm suggested by Sanchez (1976) for tropical soils.

Figures 3 and 4 show scatter diagrams and R^2 -plot for 0.1N HCl and 0.05N HCl + 0.25N H_2SO_4 extractable- Zn, respectively, vs percentage yield. The two extractants did not give significant correlations, perhaps because they extract Zn which is not available to plants. Their predictive values were not significant apart from being much lower than that of DTPA. Therefore the two extractants appear unsuitable for predicting Zn availability to maize in soils of Morogoro district.

The data on DMY from the Zn-control (threshold yield), Zn fertilized (plateau yield) and the percent relative yields are given on Table 5. The simple correlation coefficient (r), R^2_m and critical soil test values with respect to percent yield are given on Table 6.

Among the extractants evaluated, DTPA was the most suitable for the soils of Morogoro district because both the simple correlation coefficient and R^2_m values were highest and statistically significant. Singh and Takkar (1981), pointed out that the high correlation value of DTPA with plant data is due to the fact that Zn-extraction by this extractant was least affected by soil properties such as soil pH and $CaCO_3$. The reason is that the pH of this extractant has been carefully selected and

controlled. This prevents gross destruction of acid-soluble soil minerals such as carbonates and oxides especially in calcareous soils which may release occluded Zn that is normally not accessible for use by plants. The suitability of the DTPA extractant has been reported by other workers e.g. Cox and Wear (1977) and Sakal et al. (1984). The $\text{EDTA}-(\text{NH}_4)_2\text{CO}_3$ extractant came second with a significant 'r' value and R^2_m value. This implies that this extractant could serve as an alternative method. The suitability of $\text{EDTA}-(\text{NH}_4)_2\text{CO}_3$ has also been reported by other workers, for example Takkar and Randhawa (1979); Sakal et al. (1984) and Cox and Wear (1977).

$\text{EDTA}-(\text{NH}_4)_2\text{CO}_3$ and DTPA extractants are both designed to equilibrate soil CaCO_3 (Lindsay and Norvell 1978). The results obtained in this study suggest that these extractants extract Zn from the same pool as plants.

The 0.1N HCl and 0.05N HCl + 0.25N H_2SO_4 extractants are not suitable extractants in these soils because they probably dissolve water-insoluble carbonates and extract unavailable Zn. The unsuitability of 0.1N HCl and 0.05N H_2SO_4 extractants has also been reported by other workers. For instance, Kanehiro and Sherman (1967) cautioned that 0.1N HCl extractant has some limitations especially in alkaline soils. Thus, equal quantities of labile Zn show greater availability in acid than in alkaline soils.

4.3.4 Critical Zn level in maize plants

The scatter diagram for the relationship between percentage yield and the Zn concentration in shoots is shown in Figure 5. By using the graphical method of Cate and Nelson (Cate and Nelson 1965) the critical Zn concentration in maize shoots was found to be 17 ppm. This means that plants containing less than 17 ppm Zn will respond to Zn application and those containing more than 17 ppm will not respond. All the soils which fell below the critical level gave significant increase in dry matter yield upon Zn application whereas those which fell above the critical level gave a non significant or negative responses to Zn application.

The critical level obtained in this study is not very different from those reported by others. For example, Viets et al. (1954) concluded from field experiments with maize that 15 ppm Zn in the mature leaves was adequate. Banda and Singh (1989) reported a critical level of 15 ppm in maize shoots grown in soils from the rainfall areas of northern Zambia.

4.3.5 Rice plant performance

Vivid chlorosis was observed on rice plants grown without applied Zn in Dakawa 2 soil. As time advanced,

Table 5. Threshold (control), Plateau (Zn-treated) and percent yields obtained from the glasshouse experiment with soils from different locations.

Site	Dry matter yields (g/pot)		
	Threshold	Plateau	Percent yield
SUA	7.28	7.98	91.22
Magadu	9.00	11.06	81.37
Pangawe	9.41	12.19	77.19
Kingolwira	6.77	6.60	97.49
Mlali	10.15	11.41	88.96
Melela	11.19	12.39	90.31
Mvomero	10.28	10.32	99.61
Wami-Vijana	12.95	12.25	105.71
Dakawa 1	11.68	12.66	92.26
Mindu	8.50	13.48	63.06

Table 6. Range of soil-test values, correlation coefficients, R^2_m and critical soil test values for extractants used for assessing Zn availability in soils of Morogoro district.

Extractant	Range of soil-test values (ppm)	Correlation coefficients	R^2_m	Critical soil-test value (ppm)
DTPA	0.6-2.7	0.56*	0.67**	1.95
EDTA-(NH ₄) ₂ CO ₃	1.1-3.2	0.45*	0.35*	1.30
0.1N HCl	0.1-9.0	0.39ns	0.22ns	3.0
0.05N HCl +0.25N H ₂ SO ₄	0.1-5.7	0.35ns	0.27ns	0.5

*, ** Significant at $p \geq 0.5$, $P \geq 0.01$ respectively.
ns = not significant.

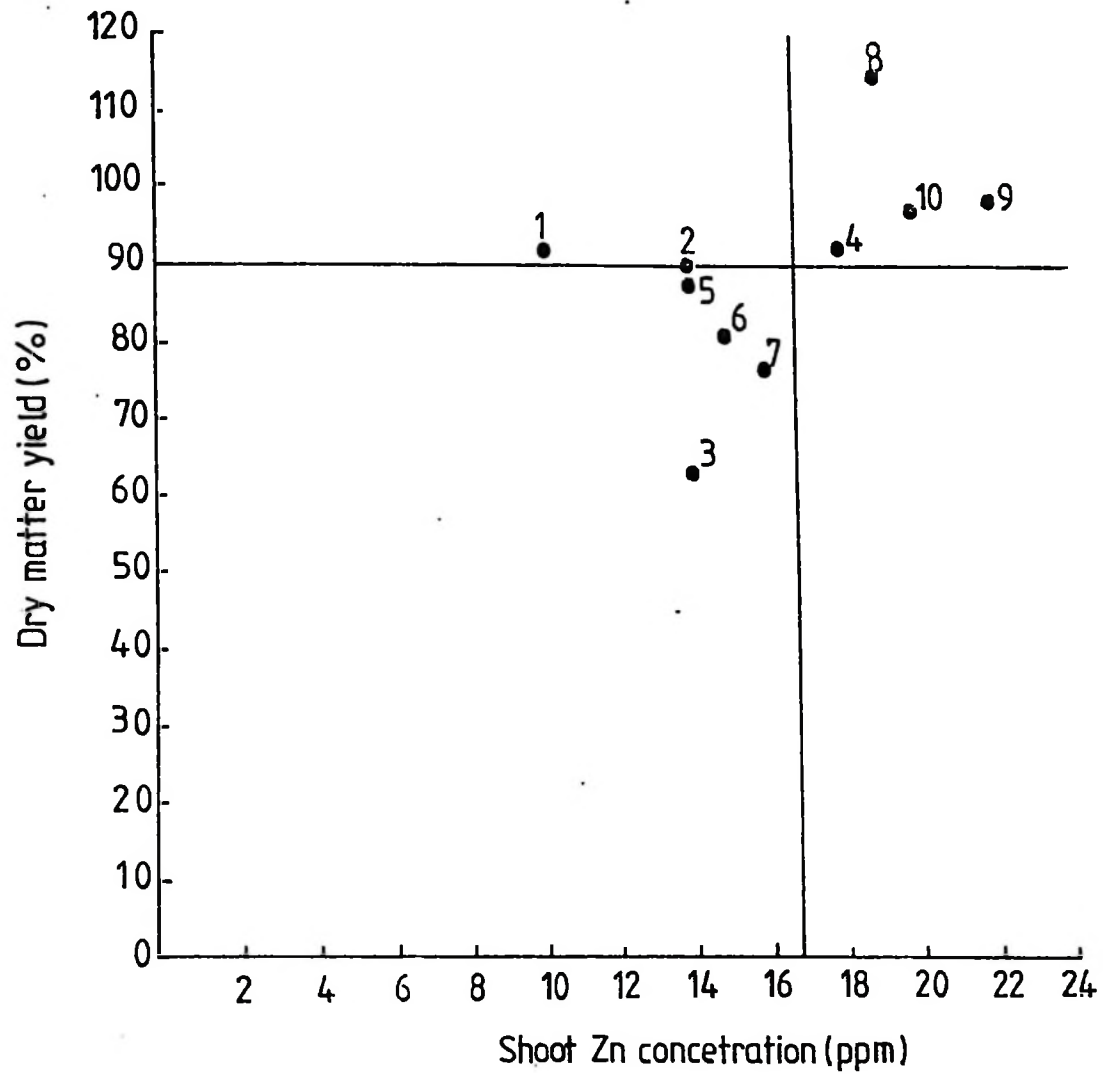


Fig. 5 . A scatter diagram for a relationship between shoot Zn concentrations and percent dry matter yield of maize

the chlorosis became more conspicuous and minute reddish brown specks developed on the upper edges of the chlorotic area. Nene (1969) and Gangwar and Mann (1972) have reported similar symptoms.

However, growth abnormalities were recorded in rice plants grown on Dakawa 3 soil irrespective of treatment. Plant growth was slower, leaves developed pale yellow colour and started falling down and as the problem advanced some leaves became almost white. In some pots some plants died. Spraying the plants with a solution of ferrous sulphate (strength 5%) corrected the problem and the remaining plants grew well thereafter. Thus, at harvesting time, some pots had fewer plants than others. Also the severity of the deficiency was not uniform in all the pots so that when the problem was eventually controlled there were large differences in plant size arising from this problem.

4.3.6 Response of rice to Zn application

The DMY and Zn uptake by rice are presented in Table 7. The results show that application of N, P and K increased the DMY significantly on all soils except Dakawa 3 soil. This indicated that N, P and K either singly or in combination were very limiting on these soils. In Dakawa 3 soil a problem of plant establishment was encountered as discussed in the section on plant

performance and this might have limited response to N, P and K.

Application of Zn significantly increased dry matter production of rice in Dakawa 2 and Dakawa 3 soils (Table 7). The DMY of the Zn control pots in Dakawa 2 was 3.83 g/pot as compared to 5.21 g/pot in the pots which received 5 mgZn/kg soil. The dry matter response in percent at 2.5 mgZn/kg soil and 5 mgZn/kg soil were 11.5 and 36%, respectively. The DMY of the Zn control pots in Dakawa 3 was 0.59 g/pot as compared to 3.69 g/pot in the pots which received 2.5 mgZn/kg soil. The dry matter response in percent at 2.5 mgZn/kg soil and 5 mgZn/kg soil were 525 and 176%, respectively.

The positive response on Dakawa 2 and Dakawa 3 soils were expected because the DTPA-extractable Zn value of these soils were well below the critical level of 0.86 ppm Zn reported by Singh and Takkar (1981) for soils of India. These soils contained 0.6 and 0.7 ppm Zn, respectively (Table 7) which fall in the deficiency range for rice.

The Zn concentrations in plants from the Zn control were 17.00 and 20.00 ppm in Dakawa 2 and Dakawa 3, respectively. These concentration values are both below critical level for rice of 21.5 ppm reported by Sakal et al. (1984). The Zn uptake by rice in Dakawa 2 soil ranged from 71.51 ug/pot to 144.16 ug/pot in the Zn control and 5 mgZn/Kg soil, respectively. The Zn uptake in Dakawa 3 soil ranged from 12.58 ug/pot to 88.56 ug/pot in the Zn

Table 7. Effect of Zn application on dry matter yield, Zn concentration and uptake by rice in the glasshouse study

Site	DTPA Zn (ppm)	Dry matter yields (g/pot)		Mean over Zn levels	DMY percent response to Zn between 0&2.5; 0&5	Shoot Zn of Zn control (ppm)	Zinc uptake (ug/pot)		Increase in Zn uptake (%) between 0 & 2.5; 0 & 5				
		Absolute control	Zinc rates (ppm)				0	2.5		5			
Dakawa 2	0.5	0.77 ^a	3.93 ^b 4.27 ^b	5.21 ^a	4.44 ^a	11.5	36	17.00	71.51 ^b	95.35 ^b	144.16 ^a	33.34	101.53
Dakawa 3	0.7	0.50 ^b	0.59 ^b 3.69 ^a	1.63 ^a	1.97 ^a	525	176	20.00	12.53 ^a	83.56 ^a	45.64 ^b	503.97	252.3
Dakawa 1	1.2	2.05 ^b	6.65 ^a 7.26 ^a	7.41 ^a	7.12 ^a	9.2	11.4	21.00	141.34 ^a	183.99 ^b	212.40 ^a	29.65	49.75
Nindya	1.5	1.89 ^b	6.33 ^a 6.89 ^a	6.63 ^a	6.81 ^a	-7.2	-4.4	21.33	147.92 ^a	162.92 ^a	137.04 ^a	10.15	-7.3
Mean	1.0	1.10	4.50 5.53	5.22	-	-	-	-	-	-	-	-	-

Means in the same row followed by the same letter are not statistically different (P<0.05) using Duncan's Multiple Range Test.

control and 2.5 mgZn/Kg soil, respectively. Thus, the DTPA-extractable soil Zn, the plant Zn concentration and the Zn uptake of the Zn control were in the deficiency range and hence accounting to Zn additions. Katyal and Ponnamperuma (1974) has shown positive response of some crops to Zn additions. In addition the two soils; Dakawa 2 and Dakawa 3 had high pH values of 7.9 and 8.1, respectively. Such high pH values are often associated with Zn deficiency due to low solubility (Patrick and Reddy 1977). The practice of flooding in rice culture also amplifies the problem further because flooding favours the precipitation of $\text{Zn}(\text{OH})_2$ and ZnCO_3 and precipitation of ZnS under very reduced soil conditions. Also under highly reduced conditions resulting from continuous flooding, the concentrations of Fe^{2+} and Mn^{2+} are greatly increased. These ions have antagonistic effects on Zn^{2+} absorption and translocation of Zn by rice (Giordano et al. (1974). Mandal et al. (1986) observed Zn deficiency under similar conditions of submergence.

The response of Dakawa 1 and Mindu soils to Zn additions was not statistically significant at $P \leq 0.05$. The DMV of the Zn control in Dakawa 1 was 6.65 g/pot as compared to 7.41 g/pot in the pots which received 5 mgZn/kg soil. The DMV response in percent at 2.5 mgZn/kg soil and 5mg Zn/kg soil were 9.2 and 11.4%, respectively. The DMV of the Zn control pots in Mindu soil was 6.93 g/pot as compared to 6.88 g/pot in the pots which received

2.5 mgZn/kg soil. The dry matter response in percent at 2.5 mgZn/kg soil and 5 mgZn/kg soil, was non significant.

The lack of response to Zn additions in Dakawa 1 and Mindu soils were expected because the DTPA-extractable Zn value of these soils were above the critical levels reported by other workers (Sakal et al. 1984; Banda and Singh 1989).

The Zn concentration in plants from the Zn control were 21.00 ppm and 21.33 ppm in Dakawa 1 and Mindu, respectively. These concentrations were just at the rice critical level as stated above. With the neutral pH, Mindu soil was expected to benefit from Zn additions. Lack of response to Zn additions in this soil might have been attributed to other factors which limited growth. Contrary to DMY of rice in Dakawa 1 soil, the Zn uptake showed a positive significant trend with Zn additions. This might have been attributed to other things which may determine response. For example, flooding the soil increases the pH to about 7.0 which may reduce the supply of Fe^{2+} . The non response of some crops to Zn additions has also been observed by others e.g. Mnkeni and Nzabayanga (1989) and Uyole Agricultural Center (1974).

4.4 Field experiments

4.4.1 Maize response to Zn application

The data for straw and grain yields of maize are presented on Table 8. There was no significant response of maize to Zn additions. The following trends in yield were observed: Pangawe, Magadu and Mlali soils showed a positive trend whereas Mvomero and Wami-Vijana displayed slight negative trends to Zn additions. No response was observed in Mkundi soil which is contrary to the results obtained in the glasshouse study. Grain data from Magadu field is missing because the plants were destroyed by animals before harvesting time. Kingolwira showed inconsistent results. This site showed uneven growth of plants which were not related to the treatments applied. As a result straw and cob weights from this site were not measured. The trend shown by these sites was unexpected since some of the sites had low DTPA- extractable Zn. However, severe moisture stress was experienced from the fifth week after planting which is close to tassel emergence, a very critical period in maize growth, and continued up to harvesting time. This must have limited response to Zn and other fertilizers.

Some workers have reported the effect of moisture on soil Zn. For example Takkar and Randhawa (1979); Gangwar and Mann (1972); and Brar and Sekhon (1976) reported

greater responses to Zn additions under wet conditions than under dry conditions.

Some explanations might be offered to account for this observed pattern. One is that under dry conditions the root system of the plants is not well developed so that their feeding zone is restricted. The other one might be that drought prevents the movement of Zn^{2+} because its transportation and absorption requires watery medium (Gangwar and Mann 1972).

4.4.2 Rice response to Zn application

Table 9 shows the weights of straw and paddy from two experiments in rice fields in Dakawa. The results indicated that application of Zn significantly increased both straw and paddy weights of rice ($P \geq 0.01$) in the Dakawa 2 field. There was no significant response to Zn additions in Dakawa 1. Application of 5, 10 and 15 kgZn/ha increased straw weight at Dakawa 2 by 485, 653 and 473%, respectively. Paddy weights at the same site increased by 358, 530 and 330% by the application of 5, 10 and 15 kgZn/ha, respectively. The largest response in both straw and paddy occurred at the rate of 10 kgZn/ha, suggesting that this might be the optimum rate of Zn application in this soil. The DTPA-extractable Zn of this soil was 0.6 ppm which is less than the soil critical level for rice of 0.86 ppm established by Singh and Takkar (1981). The

Table 8. Straw, cob and grain weights of maize from field experiments at different levels of applied Zn

Site	DTPA extractable soil Zn	Yield component	Absolute control	Zinc rates kg/ha			
				0	5	10	15
tonnes ha ⁻¹							
Pangawe	1.95	Straw	4.43	4.80	5.65	5.13	5.20
		Cob	3.50	3.68	4.10	4.50	4.10
		grain	3.43	2.75	2.90	3.53	3.04
Magadu	1.85	Straw	1.50	2.40	2.55	2.85	3.10
		Cob	—	—	—	—	—
		grain	—	—	—	—	—
Mlali	1.30	Straw	5.16	5.29	5.10	5.00	6.33
		Cob	2.56	2.21	2.47	2.79	3.10
		grain	1.29	1.66	1.27	1.47	1.66
Mvomero	2.70	Straw	6.47	6.70	7.50	7.82	6.62
		Cob	2.60	3.79	4.81	4.94	4.62
		grain	1.55	2.50	2.49	2.24	2.05
Wami-Vijana	2.40	Straw	3.90	3.82	3.50	2.22	2.41
		Cob	2.59	1.52	1.22	1.49	1.29
		grain	1.13	0.97	0.75	0.92	0.74
Mkundi	1.20	Straw	8.56	9.08	8.88	9.35	8.25
		Cob	2.59	3.26	2.92	3.22	2.10
		grain	1.23	1.85	1.77	1.89	1.43
Kingolwira	2.70	Straw	—	—	—	—	—
		Cob	—	—	—	—	—
		grain	0.49	0.78	1.62	0.62	1.17

Table 9. Straw and paddy yields from field experiments at different levels of applied Zn.

Site	DTPA extractable soil Zn (ppm)	Yield components	Absolute control	Zinc rates (kg/ha)				Percent response to Zn application at		
				0	5	10	15 tonnes ha ⁻¹	5	10	15
Dakara 2	0.6	Straw	1.12 ^c	1.24 ^c	7.25 ^b	9.34 ^a	7.10 ^b	4.55	6.53	4.73
		Paddy	0.65 ^b	0.60 ^b	2.75 ^a	3.78 ^a	5.52 ^a	3.58	5.39	3.30
Dakara 1	1.20	Straw	7.73 ^b	14.67 ^a	14.55 ^a	14.31 ^a	12.74 ^a	0.8	-2.5	-12.2
		Paddy	3.14 ^b	5.50 ^a	5.07 ^a	5.07 ^a	4.69 ^a	-7.8	-7.2	-11.09

Means in the same row followed by the same letter are not statistically different (P≤0.05) using Duncan's Multiple Range Test.

Dakawa 2 soil is calcareous in nature with pH of 7.9. These properties are associated with Zn deficiency. Thus, addition of Zn is important for good yield of crops on this soil. Response of rice yields to Zn additions has been found by other workers. Krishnamoorthy et al. (1971) obtained an increase of 1.8 tonnes/ha of rice grain in a calcareous red soil (Alfisol, pH 7.6) with 10 kgZn/ha in Gujarat, India.

Application of 15 kgZn/ha significantly decreased straw weight but the decrease in paddy weight was not significant. This trend is probably due to nutrient imbalance. The Dakawa 2 area appears to have marginal levels of Fe. Indeed Dakawa 3 which is about 2km from Dakawa 2 showed severe Fe deficiency in the glasshouse study.

Slight negative responses to Zn additions were observed at Dakawa 1 (Table 9). Application of 5, 10 and 15 kgZn/ha decreased straw weight by 0.8, 2.5 and 13.2%, respectively whereas paddy yields decreased by 7.7, 7.7 and 11.14%, respectively. The results indicated that this soil had adequate initial amount of Zn for rice production and that further additions of Zn caused detrimental effects to the crop. The DTPA-extractable soil Zn was 1.20 ppm and soil pH was 5.8. At such soil pH native Zn is highly soluble and available. Thus, additions of Zn was detrimental to the crop (Sims 1986). Coffman and

Miller (1973) found a decrease in DMY of corn by applying 40 KgZn/ha.

4.4.3 Zinc status of soils in Morogoro district

The zinc fertility status of soils of Morogoro district is presented in Appendix 7 and summarized in Table 10.

Table 10. Distribution of soil samples collected for the survey of DTPA-extractable Zn status under soils of various fertility categories

Fertility category	Zn-soil test covered range (ppm)	Average values (ppm)	Number of samples in each category
Low 0.0 < 1.95	0.85-1.95	1.48	28
High > 1.95	2.00-2.75	2.34	15

The DTPA extractable Zn of the thirty soils tested ranged from 0.85 to 2.75 ppm. On the basis of critical level of 1.95 ppm established in section 4.3.3 above the thirty soil samples were divided into two categories. Soils with < 1.95 ppm DTPA Zn were ranked as low in Zn fertility and these constituted 65% of the soils whereas 35% were ranked as high in Zn fertility. The average DTPA Zn for the low category was 1.48 ppm. Trace element content of a soil is largely dependent on the rocks from which the parent

material was derived. The parent material of Morogoro district consists mainly of deeply weathered granite, and old alluvium (calcareous) which are liable to Zn deficiency according to Mikkelsen and Kuo (1977) and Mengel and Kirkby (1987)

5.0 CONCLUSIONS

The soils used in this study varied widely in their physico-chemical properties which reflect the actual phenomena of the soils in nature.

The amount of Zn extracted by the extractants evaluated was in the order $0.1\text{N HCl} > 0.05\text{N HCl} + 0.25\text{N H}_2\text{SO}_4 > \text{DTPA} > \text{EDTA}-(\text{NH}_4)_2\text{CO}_3$. Overall, the amount of Zn extracted ranged from 0.1 ppm to 9.0 ppm. Among the four extractants compared, 0.005M DTPA (pH 7.3) gave the highest and significant correlation coefficient value ($r = 0.67$, $p=1\%$) between soil test values and DMY of the Zn control data. The other extractants viz: $\text{EDTA}-(\text{NH}_4)_2\text{CO}_3$ (pH 8.6), 0.1N HCl and $0.05\text{N HCl} + 0.25\text{N H}_2\text{SO}_4$ had r values of 0.45, 0.39 and 0.35, respectively.

The 0.005M DTPA extractant was thus rated as the best predictor of Zn status in soils of Morogoro district. Variations in the amounts of Zn extracted from the soils by the various extractants were attributed to differences in physical and chemical properties of those soils. Further, different chemical extractants extracted variable amounts of Zn from the same soil. This was attributed to the differences in extracting power and also Zn in soils is present in different forms which are extracted differently by those extractants.

The dry matter yields on the Zn-control treatment for maize ranged from 6.67 g/pot to 12.95 g/pot while the

range for rice was 0.59 g/pot to 6.93 g/pot. Positive yield response to added Zn was observed in soils from SUA-Gate, Melela, Mkundi, Mlali, Magadu and Pangawe soils planted with maize. The increases of DMY in these soils were 8.2, 9.8, 58.6, 12.4, 22.8 and 23.4%, respectively at 2.5 mgZn/Kg soil and 9.6, 10.7, 43.1, 3.7, 22.7 and 29.6% at 5 mgZn/kg soil. The response was expected because the extractable Zn contents of these soils were below the Zn-critical of 1.95 ppm established in this study.

Results from Wami-Vijana, Mvomero and Kingolwira were not significant statistically probably because Zn was not a limiting element in these soils. The Dakawa 2, and Dakawa 3 soils planted with rice gave significant yield response to added Zn. The increase in DMY was 9.2 and 525% at 2.5 mgZn/Kg. Addition of 5 mgZn/kg resulted in DMY increase of 11.4 and 176%, respectively. The positive response was expected because these soils were well below the critical level of 0.86 ppm established by Sakal et al. (1984) for similar soils of Himalayas. Zinc application to Mindu soil showed a slight but non significant decrease in DMY. The reason might be that Zn is not limiting in this soil.

The zinc concentrations of maize from the Zn-control treatment ranged from 10.0 ppm to 22.0 ppm whereas the Zn uptake ranged from 121.8 ug/pot to 323.7 ug/pot. For the rice plants the Zn concentration ranged from 17.00 to 21.33 ppm Zn whereas the Zn-uptake ranged from 12.6 to

147.8 ug/pot. Both the Zn-concentration and Zn-uptake for maize and rice behaved in the same trend as the DMY above.

The Zn critical level for maize was 17 ppm Zn. Thus the responses of maize observed in the study was expected.

The Zn status of some soils of Morogoro district indicate that 65% and 35% of the soils are Zn-deficient and Zn sufficient, respectively. Thus a large proportion of the soils are Zn-deficient.

The field results for maize gave non-significant results because of moisture stress which was experienced from the fifth week after planting all the way to the harvesting stage. This interfered with the tasselling process, cob filling and Zn-fertilizer utilization. Thus, the non-significant results obtained were expected.

In the Dakawa 2 site where rice was planted, significant responses were obtained. Additions of 5, 10 and 15 kgZn/ha resulted in of paddy yields of 2.75, 3.78 and 2.58 tonnes/ha, respectively. Thus highest yield occurred at 10 Kg/ha and thus this rate is tentatively recommended for use in this field. The Dakawa 1 site did not respond to Zn additions probably because of the effect of some other soil factors e.g. pH.

The following conclusions may be made in view of the results of these investigations:

(1) The DTP₃-extractant was most suitable for assessing Zn availability in the soils of the Morogoro district. A critical level of 1.95 ppm Zn was established

for maize under greenhouse conditions. However, there is a need to verify its suitability under field conditions before adopting it. The EDTA- $(\text{NH}_4)_2\text{CO}_3$ extractant may serve as an alternative extractant because it followed closely the trend shown by DTPA.

(2) Application of ZnO fertilizer increased grain yield of rice in Dakawa 2 field significantly. A rate of 10 KgZn/ha can be tentatively used in this field.

(3) Based on the evidence obtained in this study, it is strongly felt that there is an indication for including Zn in fertilizer recommendations. However, this has to be based on soil test results so as to apply the right amount to the most needy soil for economic production of crops. A generalized recommendation may yield discouraging results.

(4) Future research on the response of Zn to maize is necessary as moisture stress has interfered with the performance of the crop in these studies.

(5) A large portion of soils of Morogoro district (65%) appeared to be deficient in Zn. Application of Zn fertilizer will certainly be required for optimum production of maize and rice especially on soils testing low in available Zn.

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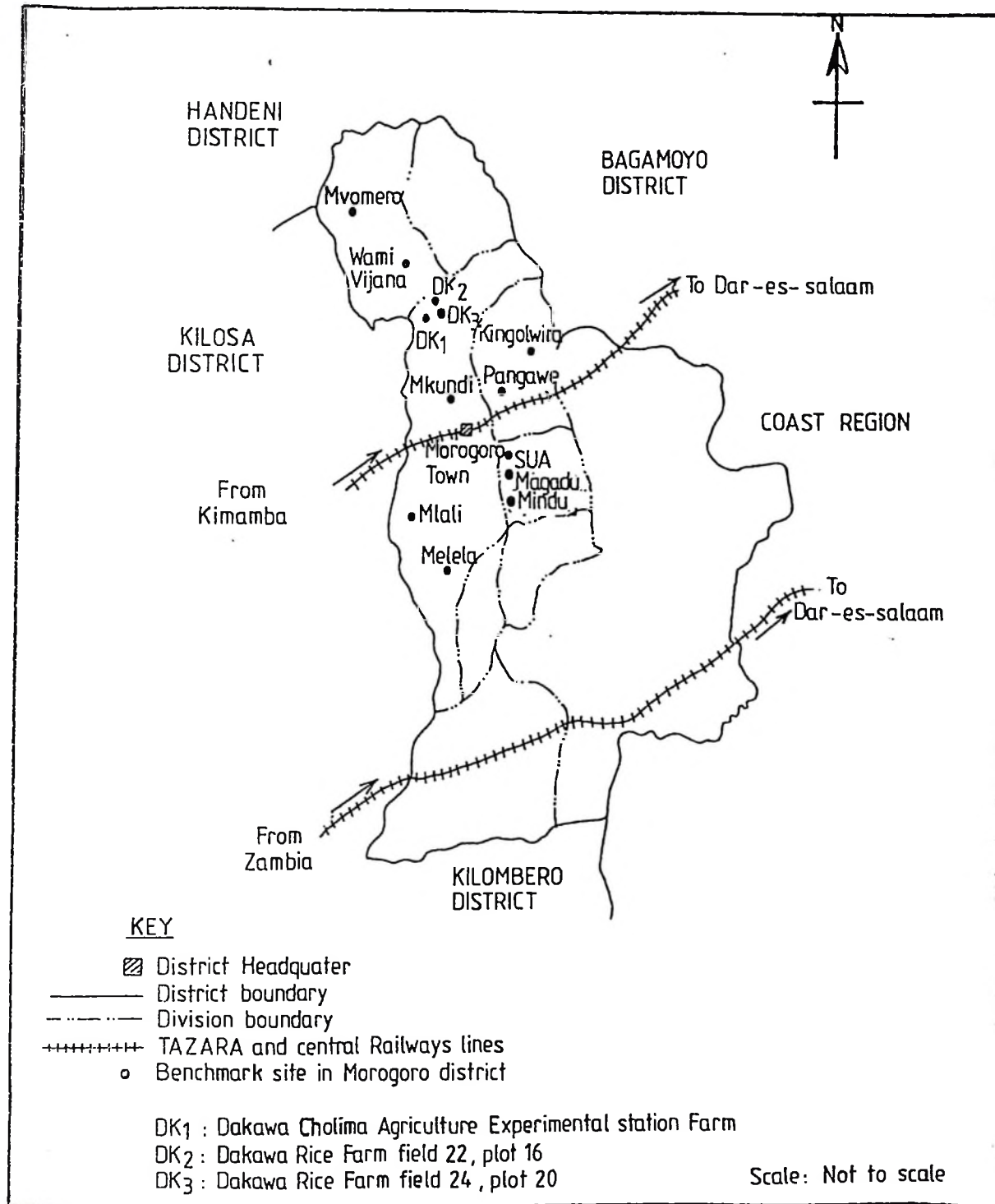
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7.0 APPENDICES



Appendix 1. Location of Benchmark sites in Morogoro district

Appendix 2. Soil water content at field capacity (FC) for soils used in glasshouse studies

Site	Weight of water added (g)	Bulk density (g/cm ³)	Weight of soil wetted (g)	Water content at FC (%)
Dakawa 1	15	1.00	65.00	23.07
Dakawa 2	15	1.14	56.82	26.34
Dakawa 3	15	1.06	55.32	27.11
Wami-Vijana	15	1.14	72.70	20.60
SUA-Gate	15	1.12	67.40	22.25
Mlali	15	1.14	59.10	25.38
Mindu	15	1.08	58.69	25.55
Mvomero	15	1.16	81.00	18.52
Pangawe	15	1.16	76.77	19.55
Melela	15	1.25	62.50	24.00
Kingolwira	15	1.05	55.78	26.89
Mkundi	15	1.23	96.29	15.58
Magadu	15	1.08	76.08	19.72

Appendix 3 Calculations of R^2 values for the DTPA extraction method

Site	Extractable Soil Zn	Percent yield	Mean RY in pop.1	CSS ¹	Mean RY in pop.2	CSS ²	CSS ¹ + CSS ²	R^2
SUA	1.05	91.22	91.22	0.00	85.54	691.61	691.61	0.02
Melela	1.15	90.33	90.71	-1.401	88.24	672.07	670.67	0.05
Mkundi & DK 1	1.20	77.66	86.40	113.18	90.34	573.38	686.56	0.03
Mlali	1.30	88.96	87.04	118.09	90.71	552.86	670.95	0.05
Magadu	1.85	81.37	85.90	148.97	93.82	438.43	587.40	0.17
Pangawe	1.95	77.19	84.45	210.50	102.13	25.63	236.13	0.67
Wami-Vijana	2.40	105.71	87.49	594.42	98.55	0.0	594.42	0.16
Mvomero	2.70	98.55	88.87	705.00	-	-	-	-
Kingolwira	2.70	-	-	-	-	-	-	-

Appendix 4 Calculations of R² values for the EDTA-(NH)₄CO₂ extraction method

Location	Extractable Soil Zn	Percent Yield	Mean RY in pop.1	CSS ¹	Mean RY in pop.2	CSS ²	CSS ¹ + CSS ²	R ²
Dakawa 1	1.1	92.26	92.26	0.00	78.29	16383.9	16383.9	0.00
Mkundi	1.3	63.06	77.66	426.32	91.48	622.57	1048.9	0.22
Melela	1.3	90.31	81.88	531.88	531.36	617.30	1148.66	0.15
SUA-Gate	1.3	91.22	84.21	600.16	91.72	618.96	1219.12	0.09
Mlali	1.6	88.96	85.16	618.21	92.27	611.66	1229.87	0.09
Kingolwira	1.6	97.49	87.22	739.67	90.97	573.96	1313.63	0.03
Wami-Vijana	2.0	105.71	89.86	1034.50	86.06	282.55	1317.05	0.03
Pangawe	2.0	77.19	88.28	1169.70	90.49	166.35	1336.05	0.09
Magadu	2.4	81.37	87.51	1215.60	99.61	0.0	1215.00	0.10
Mvomero	3.2	99.61	88.72	-	-	-	-	-

Appendix 5 Calculations of R² values for the 0.1N HCl extraction method

Location	Extractable Soil Zn	Percent yield	Mean RY in pop.1	CSS ¹	Mean RY in pop.2	CSS ²	CSS ¹ + CSS ²	R ²
Melela	1.0	90.31	90.31	0.00	88.54	1249.88	1349.88	0.00
Mkundi	2.5	63.06	76.69	369.75	91.73	612.16	981.91	0.27
Magadu	3.0	81.37	78.25	384.35	93.21	489.50	873.85	0.35
SUA-Gate	3.5	91.22	81.49	512.14	93.54	486.75	998.89	0.26
Kingolwira	3.5	97.49	84.69	716.94	92.75	468.03	1184.97	0.12
Wami-Vijana	3.5	105.71	88.19	1088.70	89.51	258.08	1346.78	0.00
Pangawe	4.5	77.19	86.62	1190.60	93.61	59.45	1250.05	0.07
Mlali	4.5	88.96	86.91	1198.90	95.94	25.09	1223.99	0.09
Dakawa 1	6.0	92.26	87.51	1215.60	88.72	0.00	1215.6	0.10
Mvomero	9.0	96.61	88.72	1247.38	-	-	-	-

Appendix 5 Calculations of R^2 values for the 0.1N HCl extraction method

Location	Extractable Soil Zn	Percent Yield	Mean RY in pop.1	CSS ¹	Mean RY in pop.2	CSS ²	CSS ¹ + CSS ²	R^2
Melela	1.0	90.31	90.31	0.00	88.54	1249.88	1349.88	0.00
Mkundi	2.5	63.06	76.69	369.75	91.73	612.16	981.91	0.27
Magadu	3.0	81.37	78.25	384.35	93.21	489.50	873.85	0.35
SUA-Gate	3.5	91.22	81.49	512.14	93.54	486.75	998.89	0.26
Kingolwira	3.5	97.49	84.69	716.94	92.75	468.03	1184.97	0.12
Wami-Vijana	3.5	105.71	88.19	1088.70	89.51	258.08	1346.78	0.00
Pangawe	4.5	77.19	86.62	1190.60	93.61	59.45	1250.05	0.07
Mlali	4.5	88.96	86.91	1198.90	95.94	25.09	1223.99	0.09
Dakawa 1	6.0	92.26	87.51	1215.60	88.72	0.00	1215.6	0.10
Mvomero	9.0	96.61	88.72	1247.38	-	-	-	-

Appendix 6 Calculations of R^2 values for the $0.05N \text{ HCl} + 0.02N \text{ H}_2\text{SO}_4$ extraction method

Location	Extractable Soil Zn	Percent Yield	Mean RY in pop.1	CSS ¹	Mean RY in pop.2	CSS ²	CSS ¹ + CSS ²	R^2
Melela	0.25	90.31	90.31	0.00	88.54	1349.80	1349.80	0.00
Mkundi	0.50	63.06	77.69	369.75	91.73	612.16	981.91	0.27
Mlali	1.25	88.96	80.77	474.96	92.12	610.76	1085.70	0.19
Dakawa 1	1.50	92.26	83.65	568.96	92.09	618.11	1187.07	0.12
Kingolwira	1.50	97.49	86.42	720.47	91.02	574.02	1294.50	0.04
SUA-Gate	2.00	91.22	87.22	739.67	90.97	573.97	1313.60	0.03
Pangawe	2.50	77.19	85.78	834.47	95.56	322.69	1157.16	0.14
Wami-Vijana	4.00	105.71	88.28	1169.67	90.47	166.35	1336.02	0.01
Mvomero	5.25	99.61	89.53	1298.10	88.72	0.00	1298.10	0.03
Magadu	5.75	81.37	88.72	-	-	-	-	-

Appendix 7. Categorization of Zn-fertility status
in Morogoro district

Site	Soil pH	DTPA extractable Zn (ppm)	Category
Mkindo	6.6	2.03	H
Hembeti	6.5	2.00	H
Dihombo	6.2	1.37	L
Makuyu	7.2	2.70	H
Milama	6.6	1.50	L
Kibuku Farm	6.8	2.25	H
ANC Camp	6.5	1.48	L
Mgongola C	6.5	1.85	L
Kihonda	6.3	2.25	H
Fulwe	6.7	1.65	L
Lukobe	7.5	1.28	L
Mikese	6.9	1.70	L
Mkono wa Mara A	7.1	0.90	L
Mkono wa Mara B	6.8	1.28	L
Bigwa	7.0	1.75	L
Misongeni	7.2	2.38	H
Kiloka	6.7	2.60	H
Kikundi	6.8	1.50	L
Mkuyuni	7.5	2.73	H
Kinole	5.3	1.75	L
Tangeni	6.8	2.55	H
Konga	6.8	1.65	L
Kauzeni	6.7	1.48	L
Mzumbe	6.5	1.48	L
Sangasanga	6.6	1.48	L
Kipera	6.6	1.95	L
Mkata	6.6	0.85	L
Doma	7.1	1.33	L
Msongozi	6.7	2.00	H
Ng'wambe	7.2	1.80	L