ASSESSMENT OF ZINC AND COPPER STATUS IN SOILS OF THE CENTRAL PART OF SOKOINE UNIVERSITY OF AGRICULTURE FARM, MOROGORO, TANZANIA

BY

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ABSTRACT

A study was conducted to assess the zinc and copper status in the soils of the central part of Sokoine University of Agriculture (SUA) farm. Twelve soil samples were collected from selected areas in the farm. Zinc and copper in these soils was extracted with four extractants namely 0.005M DTPA-TEA (pH 7.3), 0.005 DTPA-AB (pH 7.3), 0.1M HCl and double acid (0.05M HCl + 0.0125M H_2SO_4). Two soils (Oxic Haplustult and Typic Rhodustult) out of the twelve soils were used for glasshouse experiment to determine the response of beans (*Phaseolus vulgaris*) to zinc and copper application. The soils were each treated with zinc and copper at the rates of 0, 2.5, 5 and 10 Kg/ha.

Zinc application generally increased the dry matter yield of bean plants in both soils. The increases were significant when compared to the dry matter yields of the controls. Copper application increased dry matter yield in the Oxic Haplustult where there were positive response to copper application. However negative response (decrease in dry matter yield) was observed in the Typic Rhodustult. Zinc and copper tissue concentrations in bean shoots and their uptake were significantly increased in both soils by the application of zinc and copper. However, the tissue zinc and copper concentrations observed were rather high and above the critical concentrations reported in the literature. Of the four extractants tested, 0.005M DTPA-TEA was found most suitable for assessing the available zinc in the soils since it gave significant correlations with plant parameters (dry matter yield, tissue zinc concentrations and zinc plant uptake). The 0.1M HCl was the second in suitability. However, none of the methods was found to be suitable for the extraction of copper in these soils.

DECLARATION

I, Ngerageza Faraja Gideon, 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.

Date 8th APRIL - 1999 Signature..................

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DEDICATION

This dissertation is dedicated to my beloved parents: mzee **Gideon Ngerageza and Specioza Ntare**, who did not consider any other thing more important than to educate me.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

HO = Oxic Haplustult.

P = Paleustult.

UV = Vertic Ustifluvent.

UM = Mollic Ustifluvent.

HU = Udic Haplustalf.

ET = Tropeptic Eutrustox.

PO = Oxic Haplustult.

UT = Typic Ustorthent.

PU = Ultic Paleustalf.

RT = Typic Rhodustult.

SUA = Sokoine University of Agriculture.

CEC = Cation Exchange Capacity.

1.0 INTRODUCTION

With the increase in the use of plant macro nutrient fertilizers and high yielding crop varieties, there will be a corresponding drain on the reserves of the micro-nutrients in the soil. Where these micro nutrient elements are in short supply for plant growth either due to their low concentrations in the parent materials from which the soils were formed and developed or through lack of replenishment of the portion taken up by crops over years of crop production, they may become a limiting factor in crop yields. Cases of trace element deficiencies in crops were first reported at the end of the 19th century (Camp, 1945). It has now been established that various soils or soil types are incapable of supplying plants with sufficient amounts of these nutrient elements (Sillanpaa, 1982). Although in most farming systems the problems of micro-nutrient elements deficiencies are not that crucial, however, with the adoption of intensive farming practices, they need to be considered for sustained high soil productivity.

According to Sillanpaa (1982) most of the soils in Tanzania are deficient in most of the micronutrient elements like copper, zinc, boron, iron just to mention a few. This is because of the low contents of these nutrient elements in the parent materials from which these soils were formed. In Tanzania most of the research work on soil fertility and fertilizers has been directed towards fertilizers which supply the major or primary essential nutrient elements namely nitrogen, phosphorous and potassium (NPK). This trend of research was based on the assumptions that micronutrients were adequate in most soils and generally needed by plants only in very small quantities (Tisdale and Nelson, 1985). Depletion of micronutrients in soils was, therefore, not considered to be a problem.

Although the micro nutrient elements are required in very small quantities for normal plant growth, their roles in the metabolic activities in plants are equally important as compared to the primary nutrient elements and their deficiencies lead to severe depressions in plant growth and yields (Tisdale and Nelson, 1985). The increases in crop yields due to the increased levels of N,P,K fertilization and high yielding crop varieties have correspondingly resulted to increased removal of the micronutrients from the soils and thus hastening the development of the current deficiencies of micronutrients observed in many parts of Tanzania (Silanpaa, 1982).

Inadequate supply of a particular micronutrient can not give optimum yields even with a heavy application of NPK and the other essential nutrient elements (Tandon, 1995). Micronutrient elements are therefore increasingly becoming very important in the production of high yields and good quality produce. For high yields, all nutrients should be at an optimum level, that is, not deficient and not in excess (Tandon,1995).

The Sokoine University of Agriculture (SUA) farm covers approximately 2,300 ha of land (Mpepo, 1986). The objectives and functions of the SUA farm include teaching, conducting basic and applied research in agriculture and providing extension services to farmers in the country. The SUA farm is also engaged in commercial agricultural production. Various crops including rice, sorghum, maize, field beans and several other leguminous crops are grown on the SUA farm under rainfed conditions. For quite some time the yields obtained from these crops have been generally low and decreasing constantly despite of the application of nitrogen and phosphorous fertilizers for long time. Continuation of the low and decreasing yields observed may be attributed to micro nutrient elements deficiencies especially copper and zinc since very little is known about the current status of these micronutrient elements in the soils of the central part of the SUA farm.

Copper and Zinc have been pointed out as among the essential micro nutrient elements that occur in deficient amounts in Tanzanian soils thus affecting the performance of many crops (Silanpaa, 1982). In view of the inherently low contents of copper and zinc, there is a need to undertake more research on these micro nutrient elements (Cu and Zn) so as to generate information on the current status of the levels of copper and zinc in soils of the central part of the SUA farm.

In view of the above, this study was therefore carried out with the following objectives ;

(1) To generate information on the current status of copper and Zn in soils of the central part of the SUA farm.

(2) To select suitable extractant(s) for assessing the available fractions of copper and zinc in soils of the studied area.

(3) To investigate the response of beans to applied zinc and copper applied to the acid soils in the central part of SUA farm.

2.0 LITERATURE REVIEW

2.1 Copper and zinc in soils

2.1.1 Sources of copper in soils

Soils inherit their copper from rocks which have undergone various processes of geochemical and pedochemical weathering during soil formation. Other sources of soil copper are the products of decay and mineralization of plants and animals, natural waters, materials from the atmosphere, fertilizers, fungicides and insecticides (Swaine and Mitchell, 1960).

Copper mainly occurs in soils as oxides, carbonates, silicates, sulphates, sulphide, both simple and complex (Krauskopf, 1972). Examples of oxides are cuprite (Cu_2O) and tenorite (CuO). Copper also occurs in form of carbonates such as malachite ($Cu_2(OH)_2CO_3$) and azurite ($Cu_3(OH)_2(C0_3)_2$), silicates such as crysocolla ($CuSiO_3.2H_2O$) and sulphates such as bronchatite ($Cu_4(OH)_6SO_4$). Simple sulphide include chalcocite (Cu_2S) and covellite (CuS) while complex sulphide are chalcopyrite ($CuFeS_2$), bornite (Cu_5FeS_4) and anargite ($Cu_3A_5S_4$) just to mention a few (Krauskopf, 1972)

2.1.1.1 Total Copper

Soil copper is contained in minerals like charcociate (Cu_2S), oxides such as Cu_2O and CuO, bornite ($CuFeS_4$), enargite ($CuAsS_4$) and chalcopyrite ($CuFeS_2$) (Goldschimidt, 1945). The total copper content in soils generally ranges from 1-200 ppm although amounts greater than 200 ppm occur where excessive copper has accumulated from copper containing sprays, dusts or any other sources like contamination with Cu containing compounds (Fiskel, 1965). For example, Haff (1951) reported total copper of up to 500 ppm in soils that are near copper deposits. However, total copper content in soils is of limited value with respect to soil fertility since it does not give an indication of the fraction which is available to or can be extracted by plants (Tandon, 1995).

2.1.1.2 Available copper and soil parent material

Available copper in the soil is closely related to the type of soil parent material and the extent of weathering. Lal and Biswas (1973) found that old soils formed from alluvial materials had lower copper than the less weathered desert soils formed from aeolian deposits of fine sand. Relatively, more weathered gray brown, red foot hill, yellowish brown and black soils derived from various sedimentary alluvium contained high amounts of available copper (Lal and Biswas, 1973). Nyandat and Ochieng (1976) analyzed 121 soil samples for available copper using EDTA and observed that 34 samples out of the 121 samples had relatively low levels of copper and of these, 14 were derived from volcanic ash and pumice, 8 from sand, sandstone or shale, 5 from phonolite and the rest (7) from various other rocks. Similar results were reported by Kamasho (1980) for pumice while studying the DTPA extractable copper and its distribution pattern in Mbeya district, Tanzania. Kamasho (1980) found that the pumice layer contained invariably less available copper than the overlying or the underlying horizons. Pinkerton (1967) investigated copper deficiency in Nakuru area, Kenya, by examining soils derived from unconsolidated pumice, alluvial deposits, lake deposits, basalt, tranchyte and phonolite. It was observed that soils derived from pumice and ash from mount Mengai, Kenya, were associated with low available copper. Generally, soils derived from volcanic ash, pumice, quartz, shale and phonolite contain low levels of available copper probably due to inherently low copper contents in the parent materials from which these soils were formed (Nyandat and Ochieng, 1976). Alternatively, copper may be retained or may occur in forms which are not easily extractable by the extracting reagents.

2.1.1.3 Available copper distribution in soil profiles

Copper is one of the least mobile of the trace elements, with the result that many soil profiles show little variation of total copper concentration with depth

(Hodgson, 1963). Available copper however, varies with depth in the profile (Swaine and Mitchell, 1960) and is commonly higher in the organic rich surface layers than in the lower (sub-surface) horizons.

The distribution of plant available copper in soil profiles has been reported by Mehta *et al.*(1964). Some investigators have reported that copper contents decrease with depth, while others have found copper to increase with depth. Mayona (1977), working with soils from Tanga, Tanzania, observed that available copper increased with depth. Moshi *et al.* (1981) reported that there was high EDTA (1%) extractable copper in the upper horizon, low in the middle and high again in deeper horizon from soils in non coffee growing areas of Kilimanjaro region, Tanzania. Karim *et al.* (1976) observed that in the majority of the studied agricultural soils, the highest available copper occured in the B horizon. They attributed this to leaching of copper from the A horizon and its deposition in the B horizon. From Mbeya, Tanzania, Kamasho (1980) observed that DTPA extractable copper increased with depth in some of the soil profiles, and in other profiles it increased with depth except in the pumice layer where the amount was much lower than that in the overlain or underlain horizon. It was thus concluded that copper in the pumice layer had leached down to lower horizon (Kamasho, 1980). Results reported by Moshi *et al.* (1981) and Magalhaes *et al.* (1985) in soils contaminated with copper in coffee growing areas of Kilimanjaro and from vineyards in Portugal showed that available copper values were highest in the A horizons and decreased sharply down the profiles. The accumulations of available copper in those soils were associated with prolonged applications of copper containing fungicides as sprays and dusts (Moshi *et al.*, 1981; Magalhaes *et al.*, 1985).

In view of the above, it is evident that there is no consistent trend of available copper distribution in soil profiles. While in some soil profiles available copper is higher in the upper parts and lower in the lower parts, other soil profiles have higher levels in both the upper and lower parts and low in between.

2.1.1.4 Available copper in relation to soil organic matter

Soil organic matter has been found to have effects on the available copper fraction in soils (Hodgson *et al.*, 1965). Available copper normally decreases with increase in soil organic matter content. This is due to the fact that large amounts of copper are retained by soil organic matter as highly stable organo-copper complexes which are not readily available to plants. Hodgson *et al.* (1965)

observed that the retention of copper were highest in peats and mucks where deficiencies of copper were common. Further, Osiname *et al.* (1973) working with soils from Western Nigeria, observed that soil organic matter was not significantly correlated (r=-0.270) with available copper using 0.1M HCl as an extractant. Mayona (1977) using 0.1M HCl, reported negative and non significant correlation (r=-0.23) between extractable copper and organic matter in Tukuyu soils and non significant correlation (r=+0.01) with Tanga soils. With chelates (EDTA and DTPA), Singh *et al.* (1986) reported significant correlations between EDTA extractable copper and organic matter (r=+0.5709), and between DTPA and extractable copper and organic matter (r=0.579). They, however, reported a non significant correlation between 0.1M HCl extractable copper and organic matter (r=-0.146). It could thus be concluded that copper is retained by soil organic matter as highly stable organo-copper complexes which are variably extracted by the common extractants like 0.1M HCl, EDTA or DTPA.

2.1.1.5 Available copper in relation to soil pH

The availability of plant nutrient elements is known to be highly related to soil pH (Lucas and Knezek, 1972). The solubility of copper has been shown to decrease slightly from acid towards the alkaline pH ranges (Lindsay, 1972). Haynes and Swift (1985) observed a general decline in 0.1M

HCl and 0.05M DTPA-extractable copper with increasing soil pH due to liming. The decrease in extracted copper was from 3.4 to 1.5 ppm for HCl and from 2.6 to 1.0 ppm for DTPA (Haynes and Swift, 1985). The decrease in the extractability of copper with increase in pH was attributed to the reduced activity of copper in the soil. Mayona (1977) reported a non significant, negative correlation (r=-0.46) between extractable copper and soil pH for acid soils of Tukuyu. Further, Martens and Chester (1967) reported similar results in which a negative correlation between extractable copper and soil pH in acid soils was -0.259. It could therefore be concluded that the relationship between the amounts of extracted copper and soil pH is rather complex, hence need to be further investigated.

2.1.1.6 Effect of phosphorous on copper availability

Phosphorous interactions with copper may result from heavy or prolonged use of phosphatic fertilizers (Bingham, 1963). Prolonged use of high doses of phosphorous fertilizers have been found to interfere with the soil available copper. Bingham *et al.* (1958) observed severe copper deficiency in citrus where 360 kgP/ha or more were applied to soils in California. Application of copper corrected the symptoms and increased the growth of citrus. Spencer (1966) observed that phosphorous applications reduced concentrations of copper in leaves and roots of Cleopatra mandarin seedlings at four levels of applied copper from 0-250ppm. Bingham and Garber (1960) obtained significant decrease in concentration of copper in sour orange seedlings as the rate of phosphorous increased from 100 to 900 kg P/ha. These observations might have been due to the fact that high doses of phosphorous in the soil tend to interfere with the uptake of copper by plants and hence its translocation in the plants (Barrow, 1987). Macias (1973), reported a negative and significant correlation (r=-0.5116) between soil phosphorous and 0.1M HCl extractable copper in pasture soils of Spain.

2.1.2 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 $Zn(OH)^+$ may also form at high pH values (Xie and Mackenzie, 1988). Zinc ions are released into soil solution during weathering of rocks. Lindsay (1972) reported that the inorganic zinc mineral controlling zinc solubility is unknown. Kittrick (1976), however, indicated that sphalerite (ZnS) may be a factor controlling zinc levels in well aerated soils.

Liang *et al.* (1989) indicated that 60% of the zinc in soil solution exist as organic complexes. Thus, the free ions and various hydrated forms as well as organic complex forms must be considered in the fractions of soluble zinc in soils. Soil zinc can be conveniently classified as total soil zinc content, zinc minerals in soil and available zinc.

2.1.2.1 Total zinc

Total soil zinc is very variable depending on the nature of parent material, clay content and soil type (Shukla and Lyngdoh, 1990). Zinc is found in several minerals namely, sauconite ($ZnSiO_3$), zincite (ZnO), smithsonite ($ZnCO_3$) and sphalerite (ZnS) (Lindsay, 1972). The total zinc in soils varies widely from 25 to 272 ppm with the lowest values being in soils which are almost devoid of clay as well as those with high soil organic Carbon (Singh *et al.*, 1987). The average total zinc in the lithosphere according to Katyal et al. (1982) is estimated as 80-89 ppm.

Various reports indicate that the soil parent rocks influence total zinc content of soils to a significant extent. For instance, Katyal *et al.* (1982) observed that more zinc was contained in soils developed from limestones than those derived from gneisses or quartzite. Soil type is also a factor which influences soil zinc. For example, Sharma and Motiramani (1969) reported that zinc was highest in fine textured vertisols and lowest in coarse textured alluvial soils. Katyal *et al.* (1982) observed that alkaline vertisols had the highest total zinc levels (69 - 76 ppm), whereas the lowest values (24-30) were found in relatively coarse textured oxisols.

Total zinc content in soils however, doesnt reflect availability of zinc to plants. Singh and Abrol (1985) determined available and total zinc in soils from different climatic zones and found that in a tropical agroclimatic zone, available zinc was 0.35 ppm while the total zinc was 62 ppm. In the tropical semi arid climatic zones, available zinc was 0.53 ppm while the total zinc was 253 ppm. Hazra and Mandal (1987) showed that a large proportion of total soil zinc occured in relatively inactive form.

2.1.2.2 Available zinc

Available zinc is the fraction of the total zinc which can be correlated with plant uptake and generally this fraction constitutes only a small fraction of the total soil zinc in soils (Mengel and Kirkby, 1987). Available zinc levels ranging from 0.5 to 0.9 ppm are common in cultivated soils (Wear and Sommer, 1948; Silanpaa, 1982).

In areas surrounding zinc smelting plants extractable (available) zinc levels can be as high as 22 ppm (Singh and Lag, 1976). The amounts of available zinc may vary with soil types, pH and climate (Cottenie *et al.*, 1980; Kanwar and Youngdahl, 1985). Glinski and Thai (1971) working with twenty ferralitic soils from Vietnam extracted between 0.2% and 10.6% of the total zinc using 0.1<u>M</u> HCl. The amounts of zinc so extracted were highly correlated with total zinc (r=0.76). Soepartin *et al.* (1980) found the correlation between total and available Zn extracted by EDTA and dithizone to be low (r=0.55) for Indonesian soils.

Generally, available (or extractable) zinc is minimum in sandy soils, muck soils and soils with high pH due to high degree of leaching, high levels of soil organic matter and reduced zinc solubility respectively (Randhawa and Nayyar, 1982). Light textured soils appear to be more vulnerable to zinc deficiency than other soils and this could be due to the high degree of leaching and low retention capacity because of the low cation exchange capacity (CEC) of sandy soils. Chavan *et al.* (1980) reported that acid oxisols contained more available zinc than neutral to alkaline alfisols and vertisols and this was attributed to the influence of pH on the solubility and activity of zinc in soils.

2.1.2.3 Available zinc distribution in soil profiles

The distribution patterns of available zinc in soil profiles differs widely. Swaine and Mitchell (1960) using 2.5% acetic acid and 1N NH_4OAc (ammonium acetate) buffered at pH 7.0 reported that zinc extracted by these extractants decreased sharply with depth in the soil profiles. Similar observations were reported by Kanehiro and Sherma (1976) and Fagbami *et al.* (1985). Such observations could be attributed to the minimum leaching of zinc as a result of zinc being strongly adsorbed by soil organic matter and thus its accumulation on the surface soil horizons. In contrast, studies conducted in Tanga and Tukuyu (Ngaiza, 1977) and Mbeya (Kamasho, 1980) in Tanzania, showed that there was no specific distribution pattern of available zinc in the soil profiles that were investigated. Moshi *et al.* (1981) analyzed soils from coffee and non coffee growing areas of Kilimanjaro and observed that while available Zn decreased with soil depth in the non coffee growing areas, in the coffee growing areas, the pattern was reversed such that available zinc was high in the surface and lower horizons and low in the middle horizons. This pattern of distribution could be attributed to the complexion of zinc by the soil organic matter in the surface horizon and leaching of the free zinc to the lower horizons. However, more investigation need to be undertaken with respect to the trends of available zinc distribution in soil profiles.

2.1.2.4 Effect of phosphorous on zinc availability

Zinc deficiency in plants has been reported to be associated with high levels of available soil phosphorous. It has been reported that phosphorous fertilization of soils resulted in decreased utilization of zinc by plants and that phosphorous induced zinc deficiency could be severe in soils that are low or marginal in available zinc (Pasricha *et al.*, 1987). Bingham and Garber (1960) using sour orange seedlings as test crop in California reported that high levels of available phosphorous in soils was associated with acute zinc deficiency.

The effect of phosphorous on zinc uptake by crops vary with soils and crops, zinc and phosphorous levels and other factors. It was suggested that phosphorous limits zinc availability by a Zn-P interaction in the plant rather than in the soil (Barrow, 1987). Excess phosphorous fertilization, for example, has been reported to inhibit zinc metabolism in various plants by reducing the absorption rate of zinc by roots, thus inducing zinc deficiency (Barrow, 1987).

Singh *et al.* (1988) using three pedogenically different soils in growth chamber experiments, reported that the phosphorous induced zinc deficiency in beans could be attributed to the interference in the absorption and translocation of zinc by bean plants thus influencing zinc metabolism in bean plants.

2.1.2.5 Available zinc in relation to soil organic matter

Zinc can be bound into organic constituents that are immobile in soils thus constituting a fixation mechanism in which zinc is not readily released and made available to plants. Hodgson *et al.* (1966) demonstrated the presence of zinc-organic complexes in soils and concluded that on average about 60% of soluble zinc in soils is complexed. The degree of complexion of zinc in soils was correlated with organic matter contents (r=0.88). Stevenson and Ardakani (1972) reported that insoluble zinc complexes were most likely bound to the humic fraction, particularly humic acids, while the soluble zinc complexes were mainly bound to amino acids.

2.1.2.6 Zinc availability in relation to soil pH

The solubility of zinc in soils decrease with an increase in soil pH thereby affecting its availability to crops. Hayness and Swift (1985) evaluated the effects of liming on available zinc and observed a general decline in 0.1M HCl, 0.005M DTPA and 0.04M EDTA extractable zinc with increasing soil pH. Singh and Abrol (1985) reported that zinc solubility at pH higher than 7.9 was controlled by (precipitation) zinc as $Zn(OH)_2$ and $Zn(CO_3)$.

2.2 Extractants used for assessing available copper and zinc in soils

Many extractants have been tested for their ability to extract available fractions of copper and zinc in soils. These include water and neutral salts (Stewart and Berger, 1965), acids, particularly 0.1M HCl, and several chelating agents especially EDTA and DTPA (Viro, 1955; Jensen and Lamm, 1961). Out of these, 0.1M HCl, EDTA and DTPA have been tested intensively.

2.2.1 Assessment of available zinc

2.2.1.1 Dilute HCl extractant

Dilute HCl, particularly at the concentration of 0.1M has been widely tested in the extraction of micronutrients. Turkey and Kurtz (1955) reported that there was a good correlation between 0.1M HCl extractable zinc and zinc deficiencies found in the field. Boawn *et al.*, (1957) used 0.1M HCl and neutral NH_4OAC to extract added zinc fertilizers and reported that the former extracted twice as much zinc as the later extractant.

Contrary to the above findings, Stewarts and Berger (1965) reported that 0.1M HCl was not a very suitable extractant, especially when compared with other extractants, because they obtained a better correlation between 2M $MgCl_2$ extractable zinc and uptake (r=0.73). Similar results on performance of the 0.1M HCl extractant on available zinc have been reported by Wear and Evans (1968), Kamasho (1980), Sakar *et al* (1984), Nzabhayanga and Mnkeni (1989) and Singh *et al* (1986). Kamasho (1980) observed that 0.1M HCl was not a suitable extractant of zinc for soils of Mbeya district because, although it was associated with a significant R^2_m value of 0.42 with dry matter yield of wheat, however the relationship with grain yield was non significant (0.06). In soils of Morogoro district, Nzabhayanga and Mnkeni (1989) obtained a lower correlation coefficient between double acid (0.1M HCl + 0.025M H_2SO_4) extractable zinc and maize dry matter yield (r=0.98). They reported a critical concentration of 3.3 ppm for 0.1M HCl as opposed to 1-2 ppm reported by Kanehiro and Sherma (1967) using the same extractant in Hawaiian soil profiles. Sakar *et al* (1984), working with rice and 25 soils of sub Himalayan hill forest region in India, obtained a negative, non significant correlation coefficient (r=-0.192) between 0.1M HCl extractable zinc and plant uptake.

Generally 0.1M HCl has been found to be a satisfactory indicator of zinc 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 zinc extracted is pH dependent.

2.2.1.2 DTPA extractant

The use of DTPA as an extractant for assessing the availability of zinc, iron, manganese and copper in soils was reported by Lindsay and Norvell (1969). This extractant consists of 0.005M DTPA, 0.01M $CaCl_2$ and 0.1M triethanolamine (TEA) buffered at pH 7.3. The selection of pH 7.3 and 0.01M $CaCl_2$ enables the extractant to attain equilibrium with $CaCO_3$. In this way, $CaCO_3$ is not dissolved from the calcareous soils (Singh and Takkar, 1981).

Kamasho and Singh (1982), compared DTPA, EDTA and 0.1M HCl for zinc extraction in soils of Mbeya district. They found DTPA to be better correlated with zinc uptake by wheat and suggested a critical value of 3.7 ppm in soil. Banda and Singh (1989) recommended the use of DTPA for assessing zinc extractability by maize plants in high rainfall areas of Zambia and established a critical level of 0.7 ppm in soil. Singh and Takkar (1981), found DTPA to be the best method for estimating zinc availability for rice in salt affected soils of India and recommended a critical level of 0.86 ppm in soil.

Brown *et al* (1971) compared several extractants for determining available zinc using 92 neutral calcareous Californian soils. Their predictive values for DTPA, dithizone, 0.1M HCl and EDTA were 83, 79, 73 and 72 % respectively. They recommended a critical level of 0.5 ppm extractable zinc as a separator for deficient and non deficient soils.

However, in some cases DTPA may not be a suitable extractant for estimating soil available zinc fraction. Sedberry *et al.* (1979) reported that there were no significant correlation between DTPA extractable zinc and zinc concentration in maize (r=0.332), zinc uptake (r=0.388) and dry matter yield (r=0.326). Similary, for Morogoro soils, DTPA has been reported to be inferior extractant when compared with the double acid (HCl + H_2SO_4) method (Nzabhayanga and Mnkeni, 1989). These workers reported that DTPA extractable zinc gave a significant but slightly lower correlation coefficient (r=0.78) than double acid (r=0.93) with dry matter yield. Also Mkangwa, (Personal communication, 1988) found DTPA to be inferior to 0.1M HCl when assessing the zinc status of soils of

Iringa district. Dolar and Keeney (1971) obtained poorer results with DTPA buffered at pH 10.9 instead of 7.3 compared to 0.1M HCl and EDTA buffered at pH 7.0. Mikkelsen and Kuo (1977) also found the DTPA to be ineffective for some alkaline soils although it was suitable for others.

In view of the above observations, it can be pointed out that, DTPA is a promising extractant for most soils tested, except in a few cases where it has been reported to be relatively inferior to other extractants.

2.2.1.3 Double acid extractant

The double acid extractant is most useful in soils where cation exchange capacity (CEC) is less than 10me/100g (pH 7.0) and have relatively low organic matter (Wear and Evans, 1968). Wear and Evans (1968) obtained the best correlation between extractable zinc and zinc uptake by corn ($r = 0.89$) with the double acid extractant in acid soils with coarse to medium texture. Nzabhayanga and Mnkeni (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 zinc to separate zinc deficient soils from non deficient soils. Coffman and Miller (1973) obtained correlation coefficient of 0.83, 0.85 and 0.79 for double acid, 0.1M HCl and 0.1M

EDTA-$(NH_4)_2CO_3$. Double acid gave better correlation coefficient than the other two extractants. Double acid extracted zinc gave better correlation coefficient with zinc uptake by corn (r = 0.89).

However, other workers have found the double acid extractant to be inferior to other extractants for example 0.1M HCl, DTPA and EDTA-$(NH_4)_2CO_3$ (Singh *et al*,. 1987).

2.2.2 Assessment of available copper

2.2.2.1 Dilute HCl extractant

Several workers have compared the extracting ability of 0.1M HCl with other extractants. Neelkantan and Mehta (1961) in soils of Kaira district, India, observed a non significant correlation r=0.217 between 0.1M HCl available copper and copper uptake by sorghum plants when evaluating seven extractants for assessing the available copper in soils namely neutral NH_4OAC, 0.1M HCl, 0.5N NHO_3, 0.05M EDTA, 1N HCl, Morgans universal solution and 1N HNO_3. Other workers reported similar results on performance of 0.1N HCl available copper. In Mbeya district, Kamasho (1980) reported the least and non significant R^2_m (0.28) value with respect to 0.1M HCl extractable copper and dry matter when he evaluated the extracting ability of 0.1M HCl, 0.05M EDTA and 0.005M DTPA using wheat as a test crop. In Bangldesh, Singh *et al*., (1986) evaluated five extractants among which was 0.1M HCl. They reported that 0.1M HCl extractable copper had the least and non significant correlation coefficients in relation to copper concentration in wheat (r=0.109), copper uptake (r=0.170), relative yield (r=0.282) and percentage copper in plants (r=0.072). Martens (1961) working with 16 soil series from Virginia, reported that there were no correlation between 0.1M HCl extractable copper and copper uptake (r=0.55) by oats.

From the available information, it can be concluded that extracting copper using 0.1M HCl is not significantly correlated with concentration in plants, copper uptake, relative yield or dry matter. These findings suggest that among many extractants tested on diverse soils, 0.1M HCl is not a suitable extractant for assessing the available fraction of copper in soils.

2.2.2.2 DTPA-TEA extractant

Lindsay and Norvell (1969) developed DTPA as an extractant for micronutrients in Colorado. They used it for the extraction of copper, zinc, iron and manganese and managed to separate 77 Colorado soils into zinc deficient and non deficient categories. Since then the method has been tested by many workers.

Sharma (1987) cited by Lindsay and Norvell (1978), reported a significant correlation between 0.005M DTPA extractable copper and plant copper uptake. They also reported a soil critical concentration of 0.2 ppm. Kamasho (1980), after evaluating DTPA, EDTA and HCl, reported that 0.005M DTPA was the most suitable extractant for assessing copper availability in the soils of Mbeya district, since it yielded significant R^2_m values with respect to dry matter (0.9) and grain yield (0.71) of wheat. He reported a critical concentration of 0.7 ppm DTPA extractable copper. Singh *et al.* (1986), found that four out of six extractants tested were more promising for the prediction of critical level and response of barley grown in pots to copper application on young alluvial soils of Bihar, India. It was observed that 0.005M DTPA was more promising than other extractants tested since it gave the highest significant correlation coefficients with respect to copper concentration in plants (r=0.981), copper uptake (r=0.872), relative yield (r=0.827) and percent copper uptake (r=0.819). Contrary to the above findings, Haq and Miller (1972) reported that, DTPA was not a suitable extractant for copper for soils of Ontario, Canada, using maize as a test crop.

However, from the surveyed literature, the DTPA extractant is likely to be a good extractant because it has given consistent results for the determination of plant available copper in a number of diverse soil types. The critical concentration in soil for this extractant seems to be between 0.6 - 0.7 ppm.

2.3 Response to copper and zinc fertilization

2.3.1 Crop response to copper

Many crops have been tested for response to copper application; some of which responded while others didnt. Bridger *et al.* (1962), reported on $Cu(NH_4)PO_4.H_20$ as a source of copper for foliar and soil application for sorghum, turnips, radishes and snap beans. According to their results, this compound appeared to be an effective source of copper with both methods of application. Berger (1965), cited by Murphy and Walsh (1972), investigated the copper requirement and responses of crops in Wisconsin and reported yield increase in oats, red beets, carrots, cabbage, potatoes, field beans, sweet corn and onions from application of 28 Kg CuO/ha.

Reith (1968), investigated copper deficiencies in crops in Scotland. He noted corrections of copper deficiency in spring seeded oats by soil application of 11-12 Kg copper sulphate per hectare. Barnes and Cox (1973) in north Carolina, reported that a rate of 2.8 Kg Cu/ha from either complexed or sulphate sources increased significantly the yield of wheat and soyabeans. Makarim and Cox (1983) working with maize, wheat and soyabeans, reported that there were yield increase due to copper application at three out of seven sites with wheat and two out of five sites with soyabeans. Maize did not respond in all sites tested.

Kruger *et al*. (1985), conducted a number of field trials on several soils belonging to classes 2 (<0.2 ppm) and 3 (0.2-0.4 ppm) using DTPA extractant and wheat as a test crop. They reported that in six of the eight experiments carried out in soils of clsss 2 there was an increase in grain yield of up to 50% and in soils of class 3, there was no increase in yield as a result of copper fertilization. The response to copper application by wheat is therefore a function of the copper status in the soil.

Copper deficiency in wheat and barley has been observed in Mbeya district as far back as (1973) Kamasho (1980). At Mbimba experimental station, root malformation was observed in wheat especially where copper was not applied and on soils with 1.5-2 ppm DTPA extractable copper.

Application of copper together with nitrogen and phosphorous enabled wheat and barley to head and to produce yield (Nilson, 1973). Round potatoes also responded to copper application at Uyole Agricultural Centre and at Mbimba Experimental Station (Jacobsen 1976; Kamasho and Ley, 1976). Also, Kamasho (1980) reported that application of copper at 5 Kg/ha increased both dry matter and grain yield of wheat substantially in Mbeya district. In Iringa district, Akehurst and Sreedhann (1966), fertilized flu-cured tobacco with Cu and obtained a slight response in two out of the three seasons tested. They concluded that copper was not a limiting nutrient in soils of Iringa with respect to tobacco growth.

Working with soils of Iringa, Semoka *et al.* (1981), observed that there was a significant response on flu-cured tobacco when copper was applied to soils testing less than 1 ppm EDTA extractable copper. Murphy and Walsh (1972), gave a summary showing crops that are high, medium and low in copper response. They reported that the high copper responsive crops include oats, onions, lettuce, spinach, carrots and wheat while the medium copper responsive ones are sweet corn, maize, barley and cabbage, and the low copper responsive crops are beans, peas, potatoes and soyabeans.

2.3.2 Crop response to zinc

Reuter *et al.* (1982), classified Zn deficient soils as those that gave a response to application of zinc. Generally, zinc uptake was found to increase with increasing rates of zinc applied. Numerous workers have reported response of crops to zinc application. Singh (1986), fertilized 17 zinc deficient soils (containing < 0.54 ppm DTPA extractable zinc) with zinc fertilizer and obtained marked response of cluster beans in all soils. The percent mean response at 10Kg Zn/ha was 70%. Sanzo *et al.* (1984) and Raju *et al.* (1986) found that paddy yields of 3.36 tons/ha in rice given 100 Kg N/ha were increased to 3.9 tons/ha by applying 18.2 Kg Zn/ha. Wheat, lucerne and maize grown on some soils of Mbeya, Tanzania, responded to application of 10 Kg Zn/ha as $ZnSO_4$ (Kamasho, 1980). Semoka *et al.* (1981), reported that there was a significant increase in yield of flue-cured tobacco when zinc was applied to soils of Iringa district containing less than 1ppm EDTA extractable zinc. Nzabhayanga and Mnkeni (1989) observed that, only two out of eight soils from Morogoro district responded to zinc fertilization with maize as the test crop. The soils which responded to zinc application contained less than 2.8 ppm double acid extractable zinc. Long term trials in Iringa district by Akehurst and Sreedharn (1986), indicated a slight response to zinc fertilization on tobacco in one out of the three seasons tested. They concluded that zinc was not deficient in the soils of Iringa district.

Reports from elsewhere indicate that field crops may or may not respond to zinc fertilization. In India, Kanwar (1962), reported that there was 15% yield increase on potatoes due to zinc application. Raju *et al.* (1985), evaluated rice response to zinc, potash and phosphate application alone and in combination. The grain yield data revealed that all elements tested, positively increased yield both alone and in combination.

Contrary to the above results, Hilton and Zubriski (1985) in Virginia Dakota, reported that there were no response to zinc fertilization by maize and sunflower even when the extractable zinc was below 0.5 ppm DTPA-$(NH_4)_2CO_3$ extractable zinc. In soils of Saskatchewan, Canada, Singh *et al.* (1987) obtained a significant response to zinc in only one trial out of 23 trials using wheat, barley, peas, alfalfa and maize as test crops. Safaya and Malakondaiah (1985), reported that none of the tested plants (wheat and barley) showed any serious disorder even when the DTPA extractable zinc in the soil was as low as 0.28 ppm.

The above observations indicate that the susceptibility of crop plants to zinc deficiency varies considerably depending on species and even varieties. According to Viets *et al.* (1954), cereals such as wheat, oats, barley and rye are rather insensitive to zinc. Other crops such as potatoes, tomatoes and lucerne are only moderately sensitive while maize and field beans are highly susceptible to zinc deficiency.

2.4 Copper and zinc in plants

2.4.1 Copper in plants

The evidence of the essentiality of copper for green plants was reported as far back as 1931 (Sommer, 1931). Optimum copper contents in plants differ with plant species, plant parts, stage of maturity and soil conditions. But generally, they are in the range of 2-22 ppm (Reuther and Labanauskas, 1966). Bowen (1979) has reported that in most plants the range of copper concentration is from 5-15 ppm and in crop plants, the usual range is 5-20 ppm (Jarvis, 1981). The common copper content found in plant tissues of various vegetable crops is 1-40 ppm and for beans the concentration is between 15-30 ppm (Geraldson *et al.* 1973). Low copper content in plant materials were reported by Gough *et al.* (1980) for western wheatgrass (0.34-9.8 ppm). In citrus leaves, the adequate copper range has been reported as 5-16 ppm (Jones and Smith, 1964). Makarim and Cox (1983), reported that the optimum copper content in wheat ranges between 2.8-9.8 ppm. Tso (1972), reported the adequate copper content in flue-cured tobacco to range from 14.9 - 21.1 ppm. Rogers (1975), analyzed the copper content of some ranger grass from Selous Game Reserve in South East Tanzania. He reported that *Londentia* spp had 2.6-6.2 ppm when the leaves were dry and 8.1-11.6 ppm when the leaves were green, *Andropogon* spp had 2.8-8.2 ppm when the leaves were green. The copper levels observed were adequate for the nutrition of range animals.

Differences in the concentration of copper varies from one plant part to another. For oats, Mathur *et al.* (1979) reported the mean copper concentration in roots, straw and grain to be 80.95; 6.84 and 5.46 ppm, respectively. Similar trend was observed in roots and tops of silver beans by Merry *et al.* (1985). The copper concentration in tops was 91 ppm while in the roots it was 205 ppm.

The stage of maturity or age has some implications on copper content of a plant grown on the same soil conditions. Jones (1972) noted that at ten days after emergence of soyabeans the copper concentration in leaves was 12 ppm, this increased to 15 ppm at pod formation and then decreased to 13 ppm at maturity. In rice, Haque *et al.* (1979) reported copper concentration values of 5.5 ppm and 3.3 ppm at 30 and 60 days after transplanting, respectively. Sekhon *et al.* (1975) reported copper concentration of wheat plants at initial tillering to be 6-60 ppm and while at heading it was 1-60 ppm.

Since copper requirements differ from plant to plant, critical levels also differ considerably. Karim and Vlamis (1962) reported the critical level for copper in mature rice plants to be 6 ppm. Jones and Eck (1973) reported the critical level of copper in maize as 5 ppm. Other critical levels reported are 10ppm for soyabeans (Small and Ohlrogge, 1973), 4 ppm for wheat (Makarim and Cox, 1983) and 6.75 ppm for barley (Singh 1986).

2.4.2 Zinc in plants

The usual levels of zinc in plants range from 10-100 ppm for most field crops and pastures (Chapman, 1973). Zinc content is generally highest in very young seedlings and decreases with age (Carrol and Loneragan, 1968). The concentration of zinc varies from one plant or one plant part to another. For example Tso (1972) observed that the optimum growth for tobacco was recorded when leaf zinc content was 51-84 ppm. According to Karlson (1952), optimum zinc content for most pasture plants range between 14-18 ppm zinc. Barber and Olsen (1968), observed that maize grew optimally when the earleaf zinc content was in the range of 20-70 ppm and for maize at 32 days the range was between 54.5-73.2 ppm (Ragab, 1980).

Differences in zinc concentration between crops are exhibited even under excessive zinc fertilization. Boawan and Rasmussen (1971) reported zinc concentrations of various field crops after the application of 100 ppm zinc in a growth chamber as follows : field beans 60 ppm, snap beans 46 ppm, pea 132 ppm, potato 67 ppm, field maize 205 ppm, sweet corn 255 ppm, sugar beet 162 ppm and tomato 150 ppm.

Plant age exerts an impact on zinc concentration even from the same soil conditions. Jones (1972) working with soyabeans, reported that zinc concentration of the stem decreased from 38 ppm at 10 days after emergence to 19 ppm at maturity. The concentration in wheat plants was observed to be 7-210 ppm at initial tillering while at heading it was between 2-27 ppm (Sekhon *et al*., 1975).

Plants differ in their ability to accumulate zinc from the same soil nutrient solution. Some plants have greater ability than others. Using rice as the test crop and soils treated with 75 Kg zinc sulphate per hectare, Singh and Singh (1976) reported that zinc concentrations in the roots, leaf sheathes and leaf blades were 90, 63.6 and 68.2 ppm, respectively. Mascianica and Baker (1979) reported that when the soil was supplied with 50 ppm Zn EDTA, the zinc content of radish shoots ranged from 178-249 ppm while the root content ranged from 123 to 184 ppm.

Zinc requirements between plant species differ and hence the critical levels also differ considerably. Andrew *et al.* (1981), worked with 8 tropical and sub tropical pastures and legumes which were grown in pots. The tentative critical zinc levels observed were 20, 34, 22, 24, 19, 17 and 16 ppm for *Centrocema pubescens, Stylosanthes humilias, Lotononis bainessi, Neonotania wightii, Macroptilium atropurpureum, Desmodium nitortum, Vigna senensia and Medicago sativa*, respectively. Coffman and Miller (1973), using maize as a test crop reported that at 30 days after emergence the critical level of zinc in maize above which no further significant increase in dry matter yield occured was 12 ppm.

From the literature surveyed, it can be pointed out that crops differ in their sensitivity to zinc supply or in zinc requirements. Some crops require more zinc while others require less.

3.0. MATERIALS AND METHODS

3.1 General characteristics of the SUA farm

3.1.1 Location and extent

The SUA farm is located near the town of Morogoro, Tanzania (Fig 1) between longitude 37^0 39' E and latitude 6^0 51' S. It is bordered by Morogoro town to the east, Uluguru mountains to the south-east, Mindu mountains to the west and Lugalla hills to the north-west.

The farm covers approximately 2300 ha of land (Mpepo, 1986). The central part of the SUA farm which is the focus of this study covers approximately 420 ha of land between Morogoro-Iringa road from the farms border with Morogoro town.

3.1.2. Soils, geology and mineralogy

According to Kasseba *et al.* (1972), the soils in the study area are presumed to have been derived from colluvial materials from the Uluguru mountains. The soils along the Ngerengere river which crosses the farm have been derived from parent materials brought from Uluguru mountains by fluvial erosion followed by deposition along the Ngerengere flood plain (Msanya, 1980).

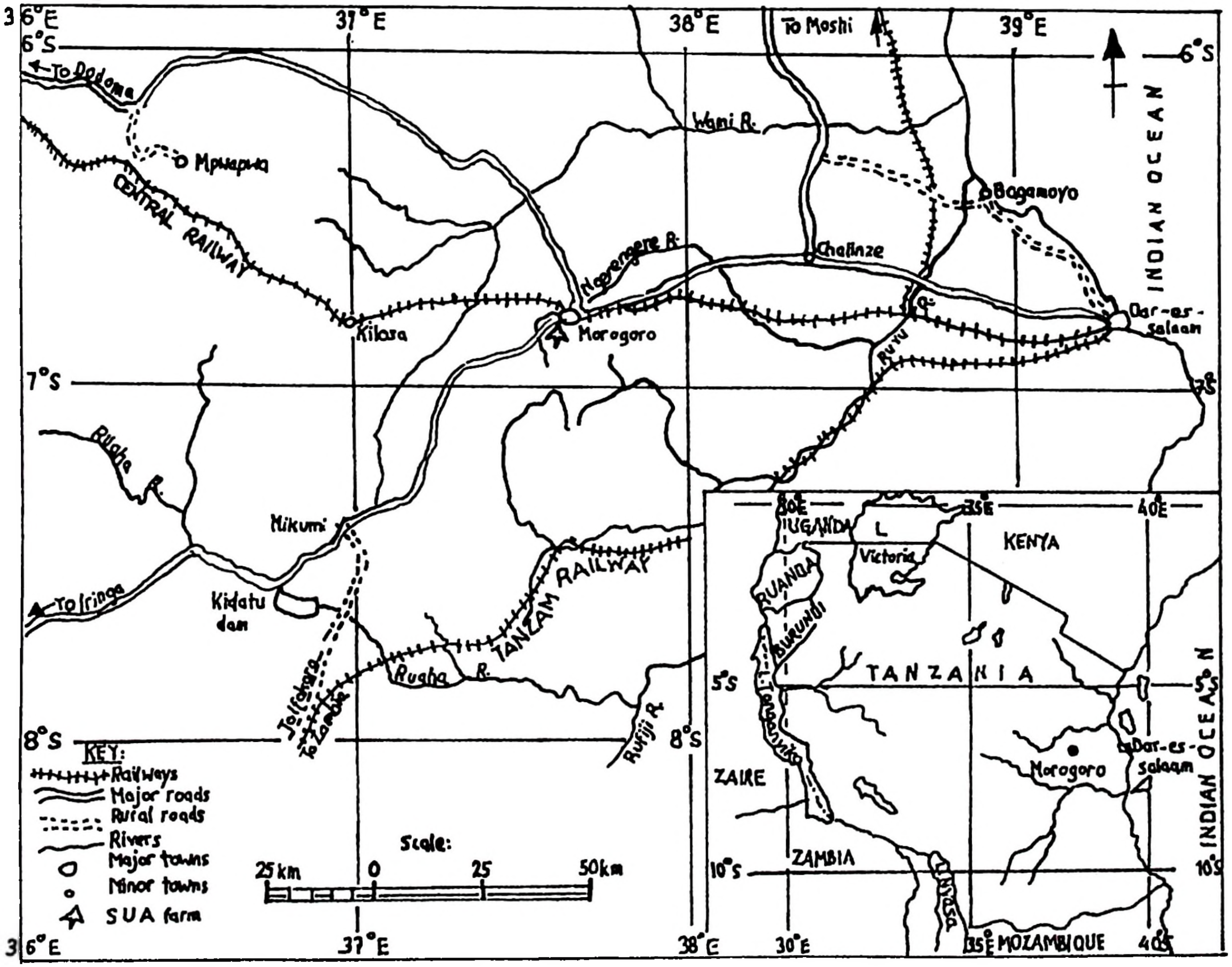

Figure 1. Location of the central part of SUA farm, Morogoro, Tanzania

Geological survey of Morogoro area by Sampson *et el.* (1961) indicate that the study area is covered by red and reddish brown soils. The Uluguru and Mindu mountains belong to the metasediments of the Usagaran System of the Mozambican Belt (Saggerson, 1962).

3.1.3 Geomorphology and drainage

Mpepo (1986) described the SUA farm as having a saucer-like shape because it is surrounded by the Uluguru mountains which rise to a height of over 2000 m above sea level, and the Mindu mountains and Lugalla hills which rise to heights of 1200 and 820m above sea level, respectively (Commissioner of Surveys, 1970). The study area is generally on undulating slopes to almost flat at an altitude of 480 to 600 m above sea level.

There are two seasonal streams from the Uluguru mountains which drain into the study area. These streams remain dry for most of the time in a year except during the heavy rains period.

3.1.4 Climate

The climate at the SUA farm is of a sub-humid tropical type (Sharma, 1987). The area experiences bimodal rainfall pattern characterized by two peaks in a year. The short and lighter rains last from November to January with their peak in December. The long and heavier rains last from March to May with their peak period in April. The distribution pattern of the long rains is irregular and unreliable. Since most of the crops in the SUA farm and areas around it are cultivated under rainfed conditions, this irregularity and unreliability of rainfall has most often resulted in low yields or failure of crops because planting dates cant be predicted accurately and most often the rainfall period lasts for shorter period than the growing periods of many crops. The SUA farm is on the leeward side of the Uluguru mountains and this is likely to be responsible for the low rains received at the farm.

3.1.5 Vegetation and current land use

Nearly all the natural vegetation in the farm have been interfered by man through cultivation. The local vegetation is mainly grassland dominated by *Andropogon spp*, *Hyperrhenia spp* and *Themeda spp*. Cultivation of maize and sorghum is the main land use which is practised in the study area. Beans and rice are also cultivated. Various other leguminous crops are grown in experimental plots. All these crops are grown under rainfed conditions.

3.2 Soil sampling

Twelve soils in the area (Figure 2) were collected from the plough layer (0-20cm) based on the soil map of the central part of the SUA farm (Kaaya, 1989). Fifteen soil samples from each location were taken and bulked to make one bulk sample. The soils were composited, air dried and grounded to pass through 2 mm sieve for the glass house pot experiments and for chemical and physical analysis. Two soils namely Oxic Haplustult and Typic Rhodustult were selected for the glass house pot experiments for both micro nutrients elements (copper and zinc).

3.3 Routine soil analyses

3.3.1 Soil pH

Soil pH was measured electrochemically using 1:2.5 soil:0.01$\underline{M}$ $CaCl_2$ suspension (Peech, 1965).

3.3.2 Available phosphorous

The available phosphorous was determined following the Bray-1 procedure (Bray and Kurtz, 1945). Phosphorous in the extract was determined colorimetrically after developing blue colour with ascorbic acid as described by Murphy and Rickey (1962).

3.3.3 Organic carbon

Total organic carbon was determined by the wet digestion method of Walkley-Black (Allison, 1965).

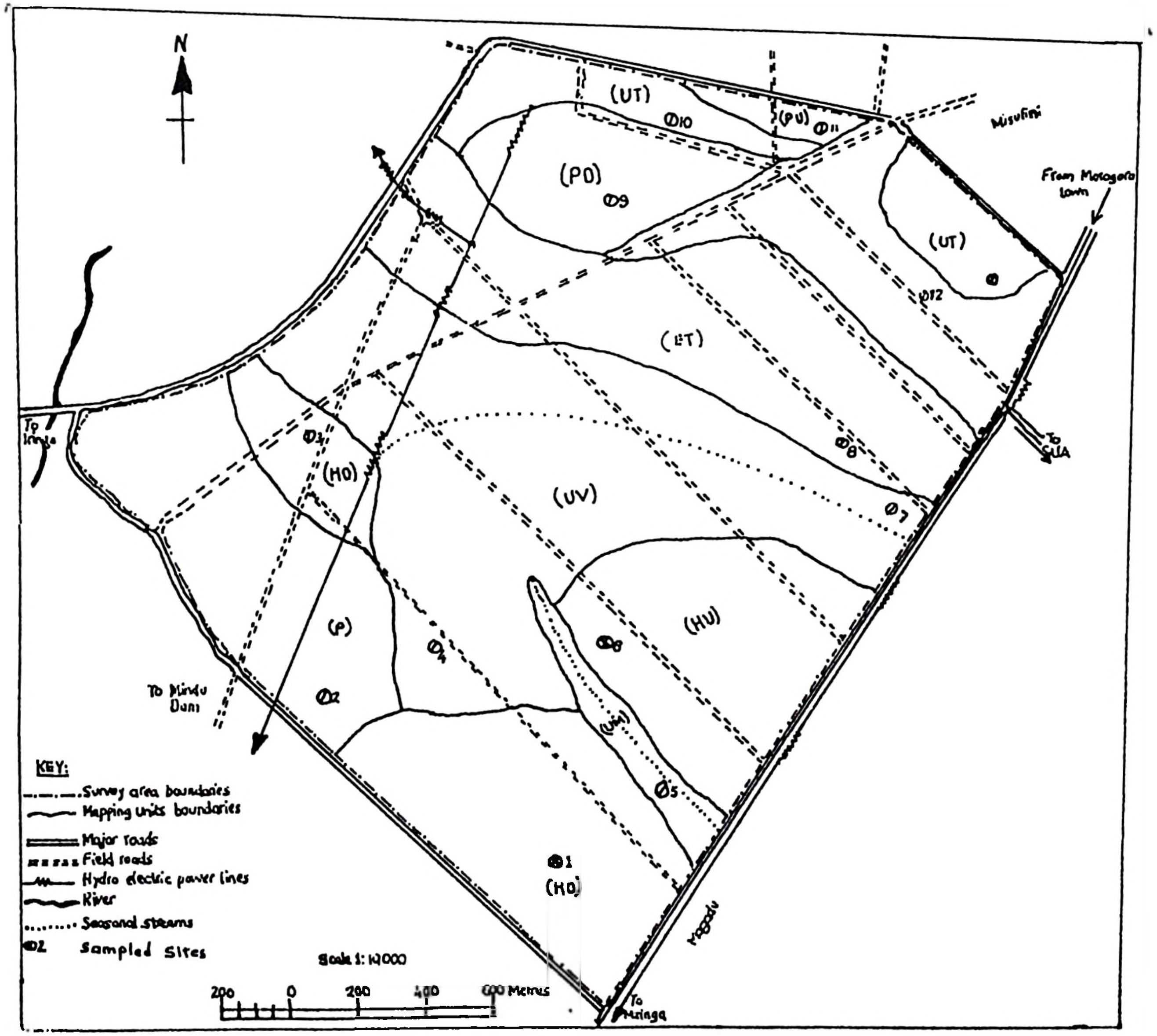

Figure 2. Soil map of the central part of SUA farm, Morogoro, Tanzania

3.3.4 Total nitrogen

The total nitrogen was determined by the micro-kjeldahl digestion and distillation method (Bremner, 1965).

3.3.5 Cation exchange capacity and exchangeable bases

The cation exchange capacity was determined by the ammonium acetate saturation method as described by Chapman (1965). The amounts of K, Na, Ca and Mg (exchangeable bases) in the NH_4OAC-filtrate were determined using AAS.

3.3.6 Particle size distribution

Particle size distribution was determined by the Bouyoucos Hydrometer method (Day, 1965) after dispersion of soil particles with sodium hexametaphosphate solution.

3.4 Determination of available copper and zinc in soils

Four extractants were used in the determination of available copper and zinc in the soils. These extractants were;

(1) 0.005$\underline{M}$ DTPA-TEA (pH 7.35).

The method used was described by Lindsay and Norvell (1969, 1978). The extraction solution consisted of 0.005$\underline{M}$ DTPA, 0.01$\underline{M}$ $CaCl_2$ and 0.1$\underline{M}$ Triethanolamine (TEA) adjusted to pH 7.35.

(2) 0.005M DTPA-AB (pH 7.6).

The method used was described by Soltanpour and Schwab (1977). The extraction solution consisted of 0.005M DTPA and 1.0M NH_4HCO_3 (Ammonium bicarbonate).

(3) 0.1M HCl.

The method used was described by Brown *et al.* (1971) and Whitney (1988).

(4) 0.05M HCl + 0.0125M H_2SO_4.

The method used was developed by Cox (1968). It consists of 0.05M HCl and 0.0125M H_2SO_4 (double acid).

3.5 Glasshouse experiment

Two soils were used in the glasshouse experiments. These soils were Oxic Haplustult and Typic Rhodustult. Two glasshouse pot experiments, one for each element (copper and zinc) was conducted in the glasshouse at SUA. A complete randomized block design with three replications was used for each element and four levels of 0, 2.5, 5 and 10 Kg/ha for both copper and zinc were tested using copper and zinc sulphate as sources of copper and zinc respectively.

Nitrogen and phosphorous was applied uniformly to each pot as Ammonium sulphate (SA) and tripple superphosphate (TSP) in amounts equivalent to 100 Kg N/ha and 80 Kg P/ha so as to meet crop requirements for optimal crop growth. Also zinc was applied to copper experiment in amounts equivalent to 10 Kg Zn/ha while copper in the zinc experiment was applied in amounts equivalent to 5 Kg Cu/ha. Nutrients were added prior to planting to 4 Kg air-dried soil sieved through 2 mm mesh screen, mixed thoroughly and put in 5 litre plastic pots with perforated bottoms. Soils were watered with distilled water, incubated for about four days and then five bean seeds (*Phaseolus vulgaris* L.) were planted in each pot.

Thinning to two seedlings per pot was done seven days after germination and nitrogen fertilizer was applied two weeks after planting. Watering of the plants was done whenever possible to avoid water stress on plants.

3.5.1 Plant sampling, sample preparation and analysis

Bean plants were harvested four weeks after germination by cutting shoots close to the soil surface, washed, dried at 70°C and weighed to get weight of dry matter. Samples were grounded to pass through 40 mm mesh sieve for analysis of copper and zinc using dry ashing method as described by Chapman and Pratt (1961).

3.6 Data analysis

Data obtained from pot experiments were subjected to Analysis of Variance using MSTAT- Statistical package so as to assess treatments effects in pot experiments based on the model :

$Y_{ij} = U + T_i + Bj + E_{ij}$.

Where Y_{ij} = Response for i^{th} treatment (level).

U = General mean.

T_i = Effect due to i^{th} treatment (level).

B_j = Effect due to j^{th} block (replications).

E_{ij} = Random effect due to i^{th} treatment and j^{th} block.

Means were separated using Duncan New Multiple Range Test (DNMRT). Simple correlation coefficients were also calculated between the plant parameters (dry matter yields, tissue concentrations and plant uptake) and soil test-values due to extractants so as to assess the suitability of the extractants for assessing available fractions of zinc and copper in the soils of the central part of SUA farm.

4.0 RESULTS AND DISCUSSION

4.1 Some of the properties of the soils used in the study

4.1.1 Soil pH

The soil pH data as determined in water and 0.01M $CaCl_2$ are presented in Table 1. The pH values in water ranged from 5.3 to 6.8 while the range was from 4.3 to 6.1 for pH values in 0.01M $CaCl_2$. In water there were three soils with pH values below 6.0 and nine soils with pH values of ≥ 6.0. The pH values obtained are almost similar to those obtained by Semoka *et al.* (1981) in some soils of Iringa, Tanzania for which the pH range was 5.5 to 6.6. 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). In view of this the pH of the soils in the central part of SUA farm can be rated as medium and the range could be considered as optimum for crop production, when other soil and plant factors are not limiting.

4.1.2 Total nitrogen

The data for total nitrogen of the soils are presented in Table 1. The total nitrogen content ranged from 0.09% to 0.21%. Metson (1961) cited by Landon (1984) categorized soil total nitrogen 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%). With the exception of the Mollic

Ustifluvent soil which fell under the medium category, the rest of the soils in the central part of SUA farm contained low and very low total nitrogen levels. The low levels of total nitrogen observed in these soils is probably due to grass burning prior to cultivation practised by the farm management and low return of crop residues to the soil and rapid decomposition of organic matter. These practices probably causes nitrogen volatilization and leaching of nitrogen. Thus, for high and sustained crop production in the central part of SUA farm adequate amounts of nitrogen should be applied in all the soils.

4.1.3 Organic carbon

The organic carbon data ranged from 0.8% to 2.4% as presented in Table 1 with an average of 1.57%. Landon (1984) categorized percent organic carbon as follows: very high (>20) ; high (10 -20) ; medium (4-10) ; low (2-4) and very low (<2). From the results obtained, most of the soils (10 soils) fell under the very low category with the exception of Paleustult and Mollic Ustifluvent soils which fell under the low category. This indicates that the levels of soil organic matter in the central part of SUA farm are low when compared with the data reported by Birch and Friend (1956) for some soils of East Africa which averaged 1.77%. Prolonged cultivation on the same piece of land and repeated burning of crop residues may probably account for the low organic carbon contents obtained in the soils of the central part of SUA farm.

4.1.4 Available phosphorous

The Bray 1 extractable phosphorous ranged from 1.2 ppm to 25.5 ppm as presented in Table 1. Landon (1984) categorized extractable phosphorous in soils as follows: high (>50); medium(15-50) and low (<15). Based on this categorization, only 2 soils (Mollic Ustifluvent and Udic Haplustalf) had medium phosphorous levels while the remaining soils (10 soils) have low levels of phosphorous. Phosphorous deficiency symptoms often occurs when soils contain less than 15 ppm available phosphorous (Sperow, 1975). Singh and Uriyo found the phosphorous critical level to be 25 ppm for maize in Morogoro, Tanzania. Thus, high crop production in this part of the SUA farm requires the application of phosphorous in the form and fertilizer.

4.1.5 Exchangeable potassium

The exchangeable potassium data is given in Table 1. It ranged from 0.48-1.64 me/100g. Doll and Lucas (1973) reported a critical concentration of potassium of 0.22 me/100g for most field crops. Thus, the soils studied in the central part of SUA farm contain adequate potassium

Table 1. Chemical and physical characteristics of soils used in the study. See page xvi for the explanation of the abbreviations.

Soil	pH H_20	pH $CaCl_2$	OC %	Total N %	Available P (ppm)	Exchangeable bases (me/100g)				CEC (me/100g)	Particle size analysis (%)			
						Ca	Mg	Na	K		Silt	Clay	Sand	Textural class
HO	5.3	4.3	1.5	0.13	2.0	0.37	1.35	0.35	0.81	6.8	10.3	18.2	71.5	SL
P	5.5	4.7	2.4	0.13	2.6	0.68	1.96	0.32	1.64	7.1	6.0	57.9	36.1	C
HO	6.0	5.4	1.9	0.13	1.4	1.16	2.38	0.32	1.61	10.7	8.4	46.4	45.2	SC
UV	6.5	6.1	0.8	0.15	2.1	1.98	4.52	02	0.75	12.5	6.2	44.8	49.0	SC
UM	6.5	6.1	2.3	0.21	17.3	1.51	1.82	0.28	0.63	7.9	9.3	24.2	66.5	SCL
HU	6.8	6.1	1.5	0.09	25.5	1.44	1.72	0.35	1.27	7.6	4.3	20.0	75.7	SL
UV	6.4	5.5	1.5	0.14	1.5	0.72	1.61	0.30	0.83	6.0	5.2	40.8	54.0	SC
ET	5.8	4.7	1.7	0.11	1.6	0.67	1.3	0.32	1.34	5.8	6.7	34.0	59.3	SC
PO	6.1	5.3	1.2	0.14	1.2	0.80	1.77	0.31	0.58	6.7	4.9	30.1	65.0	SCL
UT	6.6	5.9	1.2	0.16	2.6	1.12	1.89	0.33	0.88	7.2	6.2	19.8	74.0	SL
PU	6.4	5.7	1.2	0.10	1.6	0.78	1.73	0.31	0.62	6.6	6.2	30.2	63.6	SCL
RT	6.5	5.8	1.6	0.14	3.4	0.81	1.98	0.35	0.48	6.3	7.5	35.0	57.5	SCL

levels. In some soils of Morogoro district, Shelukindo (1992) reported potassium levels of 0.59 to 1.79 me/100g while in Iringa district, Akehurst and Sreedharn (1966) and Semoka *et al.* (1981) reported potassium ranges of 0.04 to 0.50 and 0.09 to 0.20 me/100g, respectively.

4.1.6 Exchangeable calcium

The exchangeable calcium levels ranged from 0.37 to 1.98 me/100g (Table 1). Chapman (1973) reported that soils with pH 5.0 or lower are likely to be deficient in calcium. In Puerto Rico, Abrunal *et al.* (1970) reported that 0.4 me exchangeable calcium/100g were inadequate for nutrition of most field crops. Since most soils studied had exchangeable calcium value greater than 0.4 me/100g and pH values above 5.0, it can be concluded that the soils contain adequate levels of exchangeable calcium for crop production.

4.1.7 Exchangeable sodium

Exchangeable sodium ranged from 0.28-0.52 as presented in Table 1. Landon (1984) categorized soil exchangeable sodium as follows :- high (> 1) and low (< 1). Thus soils studied recorded low levels of exchangeable sodium. But these levels are not expected to interfere with the nutrition of most field crops rendering the soils free from salinity hazards. Msolla (1991) reported exchangeable sodium levels of 0.35-2.9 me/100g for some soils of Nzega and Igunga districts while Shelukindo (1992) reported a range of 0.22-2.69 me/100g for some soils of Morogoro district, Tanzania.

4.1.8 Exchangeable magnesium

The data on the exchangeable magnesium are presented in Table 1. The exchangeable magnesium ranged from 1.35 to 4.52 me/100g. According to Landon (1984), the soils studied were in the medium level (0.5-4.0 me/100g). Shelukindo (1992) reported exchangeable magnesium ranges of 1.0-5.0 me/100g for soils of Morogoro district, while Msolla (1986) obtained a range of 0.19-4.28 me/100g for soils of Igunga and Nzega districts.

4.1.9 Cation exchange capacity (CEC)

The cation exchange capacity ranged from 5.8-12.5 me/100g soil. Landon (1984) categorized CEC as follows :- very high (> 40); high (25-40); medium (15-25); low (5-15) and very low (< 5). From the results (Table 1), all the soils had low CEC values. The range obtained is a typical CEC range of sands and loamy sands.

The variations in soils properties as presented in Table 1 somehow confirm to the findings of Nzabhayanga and

Mnkeni (1984). 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 Relative efficiency of extractants for available copper and zinc

4.2.1 Available copper

The amounts of copper extracted by 0.005M DTPA-TEA (pH 7.3), 0.005M DTPA-AB, 0.1M HCl and double acid (0.05M HCl + 0.0125M H_2SO_4) are as given in Table 2. The amounts of copper extracted ranged from 0.47 to 2.02 ppm for 0.005M DTPA-TEA, 1.78 to 6.81 ppm for 0.005M DTPA-AB, 0.20 to 2.6 ppm for 0.1N HCl and 0.06 to 0.50 ppm for double acid respectively. Thus on average, 0.005M DTPA-AB extracted more copper followed by 0.005M DTPA-TEA, 0.1N HCl while double acid extracted the least.

Similar trends in the amount of copper extracted by these extractants have been reported by other workers. Singh *et al*. (1986) using alluvial soils, reported that the average extractable copper values for 0.005M DTPA and 0.1M HCl

Table 2.The amounts of available copper extracted by different extractants.

	Soil available copper (ppm)			
Soil	0.005M DTPA-TEA	0.005M DTPA-AB	0.1M HCl	0.05M HCl + 0.0125M H2SO4
HO	1.18	3.06	1.28	0.39
P	1.22	4.15	1.57	0.39
HO	2.02	6.81	2.60	0.50
UV	1.28	4.28	0.81	0.08
UM	1.40	2.26	0.25	0.06
HU	1.76	3.40	0.93	0.18
UV	1.14	4.12	1.34	0.36
ET	0.50	2.77	0.53	0.21
PO	0.47	1.78	0.20	0.13
UT	1.13	3.51	1.51	0.41
PU	1.02	3.35	1.45	0.48
RT	1.90	3.31	1.13	0.40
RANGE:	1.13 - 2.02	1.78 - 6.81	0.20 - 2.60	0.06 - 0.50
MEAN:	1.25	3.55	1.13	0.30

were 1.10 and 0.61 ppm, respectively. Working with some soils of Kaira district, India, Neelkantan and Mehta (1961) reported that the average values of 0.005M DTPA and 0.1N HCl extractable copper were 3.52 and 1.5 ppm. The probable reason for the higher amounts of available copper extracted by chelates was due to their ability to react with metal ions in solution. These metal ions form soluble complexes which reduced the ability of the free metal ions in solution. This reaction cause labile solid phases to release more metal ions into the solution (Lindsay, 1972).

The above observations are contrary to those observed by Kamasho (1980) who observed that 0.1M HCl extracted more copper than DTPA. Martens and Chester (1967) attributed this to the ability of HCl to extract some organic-bound copper which is usually not available to plants. The average organic carbon in soils of the central part of SUA farm is 1.57% (Table 1) and lower than the 3.44% for soils of Mbeya district as reported by Kamasho (1980). Based on such observations it appears that available copper from the soils of the central part of SUA farm is extracted chiefly from adsorbed Cu^{2+} and various copper complexes and smaller quantities from organic matter which is very low.

When compared to soils from other areas, the soils from the central part of SUA farm contain relatively low amounts of available copper. In Spain Macias (1972), reported that the mean copper concentration was 3.20 ppm for the 0.1M HCl extractant. Martens and Chester (1967) in Virginia reported that the average 0.1M HCl extractable copper was 1.29 ppm. In view of this, the soils of central part of SUA farm appear to be inherently low in copper content probably due to the low copper content of the parent material from which the soils were formed. In addition, continuous cultivation and the coarse texture of the soil may have aggravated the problem.

4.2.2 Available zinc

The extractable zinc levels of the soils by the four extractants are presented in Table 3. The amounts of available zinc extracted by 0.1M HCl ranged from 1.34-4.72 ppm, that by double acid ranged from 0.56-3.38 ppm, that by DTPA-TEA ranged from 0.56-2.25 ppm and from 0.46-2.36 ppm for DTPA-AB. The average values obtained by these extractants were 2.12 ppm for 0.1M HCl, 1.62 ppm for double acid, 1.19 ppm for DTPA-TEA and 1.03 ppm for DTPA-AB. Thus on average, the relative efficiencies of the four extractants were in the order: 0.1M HCl > 0.005M HCl+0.0125M H_2SO_4 > DTPA-TEA > DTPA-AB. The trends of these

Table 3. The amounts of available zinc extracted by different extractants.

	Soil available zinc (ppm)			
Soil	0.005M DTPA-TEA	0.005M DTPA-AB	0.1M HCl	0.05M HCl + 0.0125M H_2SO_4
HO	0.99	0.95	1.38	0.96
P	1.15	1.03	1.78	1.29
HO	1.24	1.21	2.36	1.54
UV	0.56	0.46	1.39	0.56
UM	2.25	2.36	4.72	3.48
HU	1.50	1.20	3.38	2.41
UV	1.09	0.89	1.89	1.66
ET	1.07	0.83	1.34	1.24
PO	1.12	0.90	1.75	1.48
UT	1.06	0.90	2.10	1.59
PU	0.92	0.71	1.59	1.36
RT	1.32	0.91	1.71	1.83
RANGE:	0.56 - 2.25	0.46 - 2.36	1.34 - 4.72	0.56 - 3.48
MEAN:	1.19	1.03	2.12	1.62

results are not very different from those reported by Alley *et al* (1972) for some soils of USA. They found the amounts of zinc extracted decreased in the order : 0.05M HCl + 0.0125M H_2SO_4 > 0.1M HCl > DTPA.

Further, Singh and Takkar (1981) found that the order of the extractants decreased as 0.005M DTPA > 0.05M HCl+0.0125M H_2SO_4 > 0.1M HCl. Banda and Singh (1989) found extractable zinc to decrease in the order 0.1M HCl > 1N NH_4OAC >DTPA for soils of high rainfall areas of Zambia. Kamasho (1980) reported that 0.1M HCl extracted more zinc followed by 0.05M EDTA while DTPA was the last. In some soils of Morogoro, Nzabhayanga and Mnkeni (1989) reported that 0.1M HCl extracted more zinc than DTPA and EDTA in the soils studied.

The relatively higher values obtained with acidic extractants compared to the chelating agents were due to the ability of acids to acidify the soil and in this way may cause the soil to release organically bound zinc during extraction (Lindsay and Norvell, 1978) whereas chelates keep the pH close to that of the soil.

However, the observations made in this study are contrary to studies reported by Osiname *et al*. (1973) who reported that 0.005M DTPA extracted more zinc than 0.1M HCl extractant. The possible explanation was provided by Lindsay (1972) who said that chelating agents combine with free Zn^{2+} according to the reaction: $Zn^{2+} + L^{-n} \rightleftharpoons ZnL^{(n-2)-}$ where L represents the chelating ligand and n the negative charge of free ligand. During the reaction, chelating zinc accumulates in solution as the chelating agent combines with Zn^{2+}, causing more Zn^{2+} to be released from the labile solid pool.

The mean available zinc of the soils of the central part of SUA farm is relatively low compared to the values from other areas. In Spain, Macias (1973) using 0.1M HCl obtained an average of 5.70 ppm extractable zinc. Nzabhayanga and Mnkeni (1989) in some soils of Morogoro observed that the mean available zinc extracted by 0.1M HCl was 4.26 ppm. Kanehiro and Sherma (1967) observed an average of 4.5 ppm available zinc using 0.1M HCl as an extractant.

The differences in the trends of available zinc extracted by the four extractants from the above discussion could be attributed to differences in soils physico-chemical properties such as soil pH, organic carbon and texture. Differences in amounts extracted by different extractants might also be associated with the differences in the extractants in zinc extracting power. The extractants are expected to dissolve different forms of zinc in the soil differently.

4.3 Glasshouse experiment

4.3.1 Response of beans to zinc and copper application

4.3.1.1 Beans response to zinc application

Results for dry matter yield of beans and percent dry matter response to zinc application are presented in Table 4. The data in Table 4 show that, overall, zinc application increased the dry matter yield significantly. The dry matter yield of the zinc control pots ranged from 3.0 to 4.0 g/pot compared with 4.0 to 6.0 g/pot in the zinc treated soils. The dry matter response in percentage at 10 mg Zn/Kg range from 34 to 37.67%. The highest response in dry matter yield as a result of zinc application was observed between the control and 5 ppm as compared with those between control and 2.5 ppm and also between control and 10 ppm. The mean percentage responses between these levels were 52, 34 and 35%, respectively.

From the data presented in Table 4, it is evident that there were positive-significant response to zinc application in soils planted with beans. Addition of 2.5 mg Zn/kg increased the dry matter yield by 40 and 28% for Oxic Haplustult and Typic Rhodustult soils,

Table 4. Effect of zinc application on beans dry matter yield (DMY)

	Dry matter yield (g/pot) at :					% DMY response between Zn levels		
Soil	0 ppm	2.5 ppm	5 ppm	10 ppm	mean	0 and 2.5	0 and 5	0and 10
Oxic Haplustult	3.0b	4.2a	5.1c	4.0ab	4.1	40	70	34
Typic Rhodustult	4.4c	5.6b	5.9b	6.0a	5.46	28	33	37
Means	3.7	4.9	5.5	5.0	-	34	52	35

Means within the same row followed by the same letter are not significantly different ($P < 0.05$) according to Duncan New Multiple Range Test (DNMRT).

respectively. Further increase in the rate of zinc to 5 and 10 mg Zn/Kg increased positively the dry matter yield by 70 and 33% and by 34 and 37% for Oxic Haplustult and Typic Rhodustult.

Positive responses to zinc application observed in these soils could be due to the fact that these soils had low DTPA-TEA extractable zinc (Table 2) compared to the critical level for this extractant of 1.95 ppm established by Shelukindo (1992) for soils of Morogoro. The results obtained in this study confirm to those obtained by Singh and Steenberg (1974). Singh (1986) fertilized seventeen soils which had less than 0.54 ppm DTPA extractable zinc with zinc fertilizer. He reported that in all the soils, beans responded to zinc application and the mean responses was 70% at 10 Kg Zn/ha. Mhosole (1995) in Mufindi district observed a positive response in tea yields as a result of zinc application in soils with less than 1.77 ppm DTPA extractable zinc. Further, in some soils of Morogoro, Tanzania, Shelukindo (1992) reported an increase in yields of rice and maize as a result of zinc fertilization in soils testing less than 1.95 ppm.

In view of the above, the soils studied contained marginal levels of zinc, and as such addition of zinc to such soils significantly increased the dry matter yield of beans.

4.3.1.2 Zinc concentration in bean shoots and zinc uptake

The zinc concentrations and uptake in bean shoots harvested 30 days after germination are as presented in Table 5. Values in Table 5 show that both the zinc concentrations in shoots and zinc uptake responded significantly to the zinc levels applied and that there was a significant increase in both the zinc concentrations and uptake at 2.5 ppm, 5 ppm and 10 ppm over the zinc control. The increase was expected because the plants had more available zinc at their root zone. It was probably easy for the plant roots to absorb the zinc applied.

The zinc uptake by plants grown in Oxic Haplustult soil was lower than that from Typic Rhodustult soil. Their mean uptake were 137 µg/pot and 178 µg/pot (Table 5). The difference might be attributed to the differences in the physical and chemical properties of the soils (Table 1). The Oxic Haplustult soil had a relatively higher pH and sandy loam texture than the Typic Rhodustult soil, characters prone to zinc deficiency (Lindsay, 1972).

Table 5. Zinc concentrations in shoots and uptake by bean plants.

	Zinc concentrations (ppm) at:				Mean concentration	Zinc uptake (μg/pot) at:				Mean uptake
Soil	0ppm	2.5ppm	5ppm	10ppm		0ppm	2.5ppm	5ppm	10ppm	
Oxic Haplustult	30.0a	32.5c	34.0b	36.7b	33.3	90c	137b	173a	147ab	137
Typic Rhodustult	28.0b	30.6a	33.4a	37.0c	32.3	122a	171c	195c	222b	178
Mean	29.0	31.6	33.7	36.8	-	106	154	184	185	-

Means within the same row followed by the same letter are not significantly different ($P < 0.05$) according to Duncan New Multiple Range Test (DNMRT).

Several other workers have also noted an increase in zinc concentration and uptake upon zinc application. Singh (1986) found that every increase in the dose of zinc sulphate applied resulted in a progressive increase in zinc content of beans, the same to zinc uptake. Singh and Abrol (1985) observed that zinc application significantly increased the DTPA extractable zinc and thereby zinc uptake by rice over the zinc control. Other workers like Shelukindo (1992) and Wear and Evans (1968) reported similar observations in different areas. However, the zinc concentrations in bean shoots observed in this study were more than 20 ppm which is the sufficient range for most field crops (Jones, 1972).

4.3.2.1 Beans response to copper application

Table 6 shows the effect of copper application on dry matter yield and percent dry matter yield response. The dry matter yield was 2.7 and 3.7 g/pot in control pots and it ranged from 3.4 to 4.8 g/pot in copper treated soils. The response of bean plants to added copper varied between the two soils tested. Significant positive responses of bean plants were observed in the oxic haplustult soil. Addition of 2.5 mg Cu/Kg increased the dry matter yield by 41% in this soil. Increasing the rates of copper to 5 and 10 mg Cu/Kg caused a substantial increase in dry matter

Table 6. Effect of copper application on bean dry matter yield (DMY)

	Dry matter yield (g/pot) at: :					% DMY response between Cu levels :		
Soil	0ppm	2.5ppm	5ppm	10ppm	Mean	0 and 2.5ppm	0 and 5ppm	0 and 10ppm
Oxic Haplustult	2.7a	3.8c	4.2b	4.8bc	3.9	41	54	76
Typic Rhodustult	3.7b	3.6b	3.5b	3.4b	4.8	-1.7	-5.4	-7.8
Mean	3.2	3.7	3.8	4.1	-	-	-	-

Means within the same row followed by the same letter are not significantly different ($P < 0.05$) according to Duncan New Multiple Range test (DNMRT).

yield by 54 and 76%. These results indicated that this soil (Oxic Haplustult) can benefit from copper application for sustainable higher crop production. Since this soil has a pH value of less than 7.0, Table 1, the increased demand for copper might be attributed to other soil properties such as soil texture (clay content), presence of Ca^{2+} and Mg^{2+} ions. Of the two soils studied (Oxic Haplustult and Typic Rhodustult), the Oxic Haplustult soil had a relatively lower DTPA-TEA extractable copper (1.2 ppm) compared to 1.90 ppm for typic rhodustult soil. This difference in the amounts of extracted copper could also partly explain the observed positive response of beans to copper application.

Positive responses of crops to copper application has been reported elsewhere. Bridger *et al.* (1962) reported that yields of beans, sorghum and turnips increased due to copper application. In Mbeya district Tanzania, Kamasho (1980) observed that application of copper increased both dry matter and grain yield of wheat substantially. Mkangwa (1992) working with some soils of Iringa district reported that the dry matter yield of maize was increased by application of copper in the soils studied.

Non-significant negative response to copper application was observed in Typic Rhodustult soil. In this soil, application of 2.5 mg Cu/Kg to this soil resulted in dry matter yield decrease by 1.7%. Further application of 5 and 10 mg Cu/Kg resulted in even greater reductions in dry matter of 5.4 and 7.8% respectively. These results indicated that the soil had adequate initial amounts of copper and that further additions of copper was detrimental to the crop. This soil had a DTPA-TEA extractable copper of 1.90 ppm (Table 3) which is more than the critical level of 1.20 ppm for this extractant (Gough *et al.*, 1980), hence the response to copper application in this soil was not expected. Further more, the Typic Rhodustult soil had a low acidic pH value (5.3), at such pH value copper solubility and availability may have been so high to the extent that further additions of the element caused a decrease in dry matter yield.

Lack of response to copper application has been reported by other workers. Makarim and Cox (1983) reported that maize didnt respond to copper application in soils studied. Semoka *et al.* (1981) noted lack of response in tobacco as a result of copper fertilization in some soils of Iringa, Tanzania. In soils of Saskatchewan, Canada, Kruger *et al.* (1985) reported that there was no increase in yield of wheat as a result of copper application in soils with copper concentration which ranged from 0.20-0.40 ppm DTPA extractable copper.

4.3.2.2 Copper concentration in bean shoots and copper uptake

Copper concentration in bean shoots and copper uptake in bean shoots which were harvested 30 days after germination as influenced by copper application are presented in Table 7. Copper content of bean shoots in the controls were 8.0 and 10.8 ppm while those in copper-treated soils ranged from 10.8 to 13.9 ppm. The application of copper at 2.5 and 5 mg Cu/Kg increased both copper concentration in bean shoots and uptake significantly. The average copper Concentration in bean shoots increased from 9.4 ppm in the control to 13.3 ppm in copper treated soils. The copper uptake by bean plants in controls were 29.2 and 29.6 µg, as compared to that in copper-treated soils which ranged from 39 to 65 µg respectively.

Thus, in view of the above, bean shoots from both soils had copper concentration higher than 5 ppm, which is the lower value of copper sufficiency range for most crops (Jones, 1972), and can therefore be considered to contain adequate amounts of copper for crop growth.

Table 7. Copper concentrations in shoots and uptake by bean plants.

	Cu concentration (ppm) at :				Mean concentration	Cu uptake (µg/pot) at :				Mean uptake
Soil	0ppm	2.5ppm	5ppm	10ppm		0ppm	2.5ppm	5ppm	10ppm	
Oxic Haplustult	10.8b	13.0c	13.9a	13.7a	12.8	29.2a	49.4b	57.8c	64.8bc	50.3
Typic Rhodustult	8.0a	10.8b	12.7c	11.6c	10.8	29.6b	39.3a	44.5c	39.6a	38.3
Mean	9.4	11.9	13.3	12.6	-	29.9	44.4	51.1	52.2	-

Means within the same row followed by the same letter are not significantly different ($P < 0.05$) according to Duncan New Multiple Range Test (DNMRT).

4.4 Selection for suitability of extractants tested

4.4.1 Zinc

Results in Table 8 show the correlation coefficients (`r`) between zinc extracted by different extractants and plant parameters. The plant parameters involved were dry matter yield (g/pot), zinc leaf concentration in plants (ppm) and zinc uptake (µg/pot).

Results show that of the four extractants tested for suitability, 0.005M DTPA-TEA was highly and significantly correlated with the plant parameters. The correlation coefficients (`r`) were 0.96 and 0.75, 0.72, and 0.86 and 0.76 for dry matter yield, zinc leaf concentration and Zinc uptake. 0.1M HCl came the second by also showing significant correlation with plant parameters. The correlation coefficients with this extractant were 0.84 and 0.68 for dry matter yield and 0.72 for zinc uptake.

Since 0.005M DTPA-TEA was highly correlated with plant parameters, then it is suggested that this is the most suitable zinc extractant for these soils. In addition to this, 0.1M HCl could serve as an alternative method because it was also significantly correlated with plant parameters. These results further suggest that these extractants (0.005M DTPA-TEA and 0.1M HCl) extract zinc from the same pool as the plant. The 0.005M DTPA-AB and double acid extractants did not show significant correlation with any plant parameter. These extractants are not suitable extractants in these soils because they probably dissolve water-insoluble carbonates and extract unavailable zinc.

The suitability of 0.005M DTPA-TEA and 0.1M HCl extractants to estimate the available fraction of zinc from the soil has been reported by other workers as well. In Igunga and Nzega districts of Tabora, Tanzania, Msolla (1991) reported that 0.005M DTPA was positively and significantly correlated with plant parameters. The correlation coefficients were DMY (\`r\` =0.95), zinc leaf concentration (\`r\` = 0.73) and plant uptake (\`r\` = 0.82). Shelukindo (1992) working with some soils of Morogoro Tanzania, observed that of the four extractants used, 0.005M DTPA-TEA was found to be the most suitable for assessing available zinc in the soils. He obtained correlation coefficient (\`r\`) with plant uptake of 0.56. Cox and Wear (1977) and Sakar *et al* (1984) has also reported the suitability of 0.005M DTPA-TEA extractant. Mkangwa (1992) and Nzabhayanga and Mnkeni (1989) reported that 0.1N HCl extractant was suitable in some soils of Iringa and Morogoro district, Tanzania.

Table 8. Correlation coefficients between zinc extracted by different extractants and plant parameters

	Dry matter yield(g/pot) at:				Zinc concentration (ppm) at:				Zinc uptake (µg/pot) at:			
Extractant	0ppm	2.5ppm	5ppm	10ppm	0ppm	2.5ppm	5ppm	10ppm	0ppm	2.5ppm	5ppm	10ppm
0.005M DTPA-TEA	0.96^{**}	0.75^{*}	0.32	0.39	0.61	0.68	0.72^{*}	0.41	0.86^{**}	0.76^{*}	0.45	0.59
0.005M DTPA-AB	0.46	0.08	0.35	0.30	-0.13	0.10	0.01	0.09	0.01	0.37	0.33	0.05
0.1M HCl	0.84^{**}	0.68^{*}	0.53	0.49	0.49	0.56	0.55	0.49	0.72^{*}	0.53	0.48	0.59
DA	0.37	-0.02	0.41	0.07	0.24	-0.06	0.31	0.21	0.31	-0.34	0.01	0.09

** Significant at P = 0.05

* Significant at P > 0.01

DA - Double Acid

Singh and Takkar (1981) pointed out that the high correlation value of DTPA with plant parameters is due to the fact that zinc 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 zinc which is normally not accessible for use by plants.

4.4.2 Copper

The correlation coefficients between copper extracted by different extractants and plant parameters are presented in Table 9. None of the extractants tested gave significant correlation with any of the plant parameter, suggesting that none of the extractants tested extracted copper which was related to plant growth. This indicates that the four extractants tested did not adequately reflect the ability of the soil to supply copper under the conditions that prevailed in the glasshouse pot experiment.

Table 9. Correlation coefficients between copper extracted by different extractants and plant parameters

	Dry matter yield (g/pot) at:				Cu concentration (ppm) at:				Cu uptake (µg/pot) at:			
Extractant	0ppm	2.5ppm	5ppm	10ppm	0ppm	2.5ppm	5ppm	10ppm	0ppm	2.5ppm	5ppm	10ppm
0.005M DTPA-TEA	0.16	0.23	0.31	0.09	0.51	0.41	-0.03	0.04	0.13	0.32	-0.10	0.20
0.005M DTPA-AB	0.35	-0.32	0.22	-0.35	0.15	0.06	0.24	0.31	-0.06	0.19	0.26	0.33
0.1M HCl	-0.11	0.25	0.40	0.05	0.08	-0.22	0.42	0.41	0.34	0.01	-0.09	0.28
DA	0.13	0.02	0.07	0.30	0.25	0.35	0.05	-0.30	0.11	0.36	0.23	-0.05

DA - Double Acid

Unsuitability of the extractants tested to estimate the available fraction of copper from soil has also been reported by other workers as well. In Mbeya district Tanzania, Kamasho (1980) reported a non significant correlation coefficient (\`r\` = 0.28) value with respect to 0.1M HCl-extractable copper and dry matter yield of wheat. Singh *et al.* (1986) in India, reported non significant correlation coefficients with respect to 0.005M DTPA and 0.1M HCl-extractable copper on dry matter yield of barley. The correlation coefficients (\`r\`) were 0.22 and 0.10 for DTPA and HCl extractants respectively. In Virginia, Martens and Chester (1967) working with 16 soil series reported that there was no correlation between 0.1M HCl-extractable copper and copper uptake (\`r\` = 0.55) by oats. Haq and Miller (1972) reported non significant multiple regression correlation (R^2) between tissue copper concentration and DTPA (0.32) extractable copper. These results suggest that additional work for screening a suitable extractant for copper is required.

4.5 Zinc and copper status of the soils of the central part of SUA farm

4.5.1 Zinc

Data for DTPA-TEA extractable zinc of the twelve soils tested are presented in Table 3. The values ranged from

0.56 to 2.25 ppm with an average of 1.19 ppm. On the basis of critical concentration of 1.95 ppm established by Shelukindo (1992), the twelve soil samples from the central part of SUA farm were divided into two categories. Soils with < 1.95 ppm DTPA-TEA extractable zinc were ranked as low in zinc whereas those with > 1.95 ppm DTPA-TEA extractable zinc were ranked as high in zinc. Eleven soils i.e 92% of all the soils tested contained < 1.95 ppm DTPA-TEA extractable zinc and thus were expected to respond to zinc fertilization. Only one soil had DTPA-TEA extractable zinc >1.95 ppm, suggesting little or no likelihood of response to zinc fertilization. This soil was thus categorized as having high zinc fertility.

The poor zinc status in these soils emanated probably from the parent material from which the soil were developed. Trace element content of a soil is largely dependent on the rocks from which the parent material was derived. The parent materials of Morogoro district consists mainly of deeply weathered granite and old alluvium (calcareous). Parent materials of these types are liable to zinc deficiency problems according to Mengel and Kirkby (1987); Mikkelsen and Kuo (1977). They indicate zinc rich minerals to be augite, hornblende and biotite.

4.5.2 Copper

Data for 0.005M DTPA-TEA, 0.005M DTPA-AB, 0.1M HCl and double acid (0.05M HCl + 0.0125M H_2SO_4) extractable copper are given in Table 2. The 0.005M DTPA-TEA extractable copper ranged from 0.47 to 2.02 ppm with an average of 1.25 ppm, 0.005M DTPA-AB ranged from 1.78 to 6.81 ppm with an average of 3.55 ppm, 0.1M HCl ranged from 0.20 to 2.60 ppm with an average of 1.13 ppm while that of double acid ranged from 0.06 to 0.50 ppm averaging 0.30 ppm. None of these extractant was found to be suitable for the assessment of copper status in the soils of the central part of SUA farm and hence a reliable critical concentration for these soils could not be pointed out. In view of this, the delineation of copper fertility categories was not possible.

5.0 CONCLUSION AND RECOMMENDATIONS.

This study involved greenhouse experiments coupled with soil analysis of samples from the study area. A total of 12 soil samples were collected from selected areas in the central part of the SUA farm from the plough layer (0 - 20 Cm). Two soils namely Oxic Haplustult and Typic Rhodustult were used for glasshouse studies for each element (zinc and copper) and common beans (*Phaseolus vulgaris*) as the test crop. Four treatments were tested for both zinc and copper trials. The objectives of this experiment were to study the response (effect) of zinc and copper applications on bean growth. This experiment was also used to screen a suitable extractant for zinc and copper availability to crops. Available zinc and copper in the soils were extracted using four extractants which were tested for suitability. These extractants were 0.005$\underline{M}$ DTPA-TEA (pH 7.3), 0.005$\underline{M}$ DTPA-AB (pH 7.3), 0.1$\underline{M}$ HCl and double acid (0.05$\underline{M}$ HCl + 0.0125$\underline{M}$ H_2SO_4) and the results were correlated with plant parameters (dry matter yield, tissue concentration and uptake).

The results indicated that zinc application generally increased bean dry matter yields in both soils. The increases were significant if compared to dry matter yields of the controls. Copper application increased the bean dry matter yields in one soil (Oxic Haplustult) where there were positive response to copper application. But negative response (decrease in dry matter yield) were observed in Typic Rhodustult soil.

The zinc concentrations in bean shoots were significantly increased by the application of zinc and ranged from 28 to 30 ppm in controls and from 31 to 37 ppm in the zinc treated soils. Also zinc uptake by bean plants was significantly increased by zinc application with a range of 90 and 123 µg/pot in controls and from 137 to 222 µg/pot in zinc treated soils. Similarly, copper concentrations in shoots and the uptake by beans increased significantly. The copper concentration ranged from 8.0 to 10.8 ppm in the controls and from 10.8 to 13.9 ppm in the copper treated soils. The uptake was 29.2 and 29.6 µg/pot in the controls and from 39.3 to 64.8 µg/pot in copper treated soils. The tissue zinc and copper concentrations were rather high and above the critical concentration reported in the literature.

Among the four extractants tested, 0.005M DTPA-TEA was the suitable zinc extractant for the soils under investigation. Zinc extracted by this method gave significant correlations with dry matter yields, tissue concentrations and plant uptake. 0.1M HCl was ranked the second after correlating significantly with dry matter yields and zinc uptake. On the basis of the critical concentration of 1.95 ppm established by Shelukindo (1992) for this extractant, 11 of the soils in the study area were ranked as low in zinc fertility and 1 soil was ranked as high in zinc fertility. However, it was not possible to delineate soil fertility categories for copper since no suitable copper extraction method was found.

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

(1) The 0.005M DTPA-TEA extractant was most suitable for assessing zinc availability in the soils of the central part of SUA farm. The 0.1M HCl extractant may serve as an alternative extractant since it followed closely the trend shown by DTPA- TEA.

(2) A large portion of soils in the farm appeared to be deficient in zinc.

(3) Soils in the central part of SUA farm are likely to benefit from zinc fertilization, but this needs to be confirmed with field experimentations before realistic recommendations can be made.

(4) Further screening of extractants for copper need to be done, because no suitable method was found in this study.

(5) More research on the response of beans to zinc and copper fertilization basing on field experimentation is necessary.

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7.0 APPENDICES

Appendix 1.0: SOIL PROFILE DESCRIPTIONS

Appendix 1.1: Profile no. 1.

I: **Information on the site**:

(a) **Profile number**: 1

(b) **Higher category classification**:

FAO: Dystric Nitosol.

USDA: Oxic Haplustult.

(c) **Date of examination**: 1st April, 1987.

(d) **Location**: UTM Zone 37 M CC 500428.

(e) **Elevation:** 524m

(f) **Land form**:

Physiographic position: gentle convex slope

Surrounding land form: Undulating.

Microtopography: Nil.

(g) **Slope on which profile is sited**: gentle (3-4%).

(h) **Land use**: At the time of examination the land was covered by tall grass (Hyparrhenia rufa) but it was previously undercultivation of maize and beans.

(i) **Climate**: As described under section 3.1.4

II: General information on the soil:

(a) **Parent material**: Colluvial material from meta-sediments of Uluguru mountains

(b) **Drainage**: Class 4-well drained.

(c) **Moisture conditions in the profile**: moist below 106cm.

(d) **Depth of ground water table**: below 152cm at all times of the year.

(e) **Presence of surface stones and rock outcrops**: none.

(f) **Evidence of erosion**: none detected.

(g) **Presence of salt or alkali**: none.

(h) **Human influence**: slight and confined to the plough layer.

III: Brief description of the profile.

Deep, well drained yellowish red with sandy clay topsoil over clayey subsoil. Diagnostic horizons present include an ochric A over an argillic B horizon.

IV: Profile description

A_p 0-11cm Brown to dark brown (7.5YR 4/4) moist and brown (7.5YR 5/4) dry; sandy clay; moderate medium and coarse crumb; slightly sticky, slightly plastic (wet), friable (moist), hard (dry), very frequent very fine and few fine roots; abrupt, smooth boundary.

$B_{21}t$ 11-36cm Yellowish red (5YR 4/8) moist and yellowish red (5YR 5/8) dry; clay; moderate fine subangular blocky; slightly sticky, slightly plastic, friable moist), hard (dry); common very fine and few fine tubular pores; frequent very fine fine and few fine roots; clear, wavy boundary.

$B_{22}t$ 36-82cm Yellowish red (5YR 5/8) moist and reddish yellow 5YR 6/8) dry; clay; moderate fineangular blocky; slightly sticky, slightly plastic (wet); very friable (moist), slightly hard (dry); many very fine and few fine tubular pores; few weathered gravels (0.5-1.0cm); few termites burrows; few very fine roots; gradual, wavy boundary.

$B_{23}t$ 82-153+cm Yellowish red (5YR 6/8) moist and reddish yellow (5YR 6/8) dry; clay; moderate fine angular blocky; slightly sticky, slightly plastic (wet); friable (moist), slightly hard (dry); many very fine and few fine tubular pores; few weathered gravels, very few fine roots.

Appendix 1.2 Profile number 12.

I: Information on the site:

(a) **Profile no.:** 12

(b) **Higher classification category:**

FAO: Dystric Nitosol

USDA: Typic Rhodustult

(c) **Date of examination:** 11th April, 1987

(d) **Location:** UTM Zone 37 M CC 509443

(e) **Elevation:** 526m

(f) **Land form:**

Physiographic position: Level plateau

Surrounding land form: almost flat

Microtopography: nil

(g) **Slope on which profile is sited:** Flat (< 1%)

(h) **Land use:** At the time of examination the land was cultivated with a good growing sorghum crop.

(i) **Climate:** As described under section 3.1.4

II: General information on the soil

(a) **Parent material:** Plagioclase and quartz-rich meta-sediments. (b) **moisture conditions in the profile:** dry throughout.

(c) **Presence of surface stones and rock outcrops:** none.

(d) **Evidence of erosion:** none detected.

(e) **Presence of salt or alkali**: none.

(f) **Human influence**: Slight and confined to the plough layer.

III: **Brief description of the profile**:

Deep, well drained, red with sandy clay loam topsoil over sandy clayey subsoil. There is an ochric A horizon lying over argillic B horizon.

IV: **Profile description**.

A_p 0-17cm Dark reddish brown (5YR 3/3) moist and reddish brown (5YR 4/3) dry; sandy clay loam; moderate medium and coarse granular, sticky, slightly plastic (wet), friable (moist), hard (dry); many fine and common medium inped tubular pores; frequent very fine and fine roots; abrupt, smooth boundary.

B_{21}t 17-42cm Dark red (2.5YR 3/6) moist and red (2.5YR 4/6) dry; sandy clay; moderate medium angular blocky; sticky, plastic (wet), friable (moist), hard (dry), frequent fine roots; gradual smooth boundary.

B_{22}t 42-100cm Red (2.5YR 4/6) moist and red (2.5YR 4.5/6) dry; sandy clay; moderate fine subangular blocky; sticky, plastic (wet), friable (moist), slightly hard (dry), many fine and few medium tubular pores; few fine roots; abrupt, smooth boundary.

B_{23}t 100-121cm Red (2.5YR 4/6) moist and red (2.5YR 4.5/6) dry; sandy clay; moderate fine subangular blocky; sticky, plastic(wet), friable (moist), slightly hard (dry); dominant angular quartz gravels (1-3cm); abrupt, smooth boundary.

B_{24}t 121-150cm+ Dark red (2.5YR 3/6) moist and red (2.5YR 4/6) dry; clay; moderate fine subangular blocky, sticky, plastic (wet), friable (moist), hard (dry); common very fine and fine tubular pores; very few fine roots; abrupt, smooth boundary.