IDENTIFICATION AND CORRECTION OF SOME MICRONUTRIENT CONSTRAINTS IN A VOLCANIC SOIL FROM MPANGALA VILLAGE, MAKETE DISTRICT FOR OPTIMIZATION OF MAIZE YIELDS

BY

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

MOROGORO, TANZANIA.

2003

ABSTRACT

A study was conducted in field and glasshouse conditions to identify and correct some micronutrient constraints in Mpangala volcanic soil for optimization of maize yields. The study involved routine soil analysis, pot experiments and a field experiment. Soil analysis revealed the level of Cu to be 0.14 mg kg^{-1}, which was ranked as deficient; Zn was 0.86 mg kg^{-1} (marginal) and boron was 0.52 mg kg^{-1} (medium). In the first pot experiment, P and N were applied at constant rates of 160 mg kg^{-1} and 240 mg kg^{-1}, respectively. However in one treatment a higher rate of 320 mg P kg^{-1} was applied in order to test whether a higher rate of P was still required in Mpangala soil. Boron was applied at rates of 0 and 2 mg·kg^{-1}, Cu at rates of 0 and 5 mg kg^{-1} and Zn at rates of 0 and 10 mg kg^{-1}. The results indicated that a combination of Cu, N and P increased yields dramatically. Moreover the treatment that received the high P rate of 320 mg kg^{-1} together with N, B, Cu and Zn fertilizers had significantly ($p = 0.05$) higher DM yield than the Cu treatment. Analyses of plant leaves showed very low concentrations of Cu followed by Zn. However, Zn did not increase DM yield significantly. It was concluded that Zn may be the next limiting nutrient after Cu. A second pot experiment was conducted to estimate the optimum rate of Cu. Nitrogen and P were applied at constant rates of 240 and 320 mg kg^{-1}, respectively, and Cu at rates of 0, 5, 7.5, 10, 15 or 20 mg Cu kg^{-1}. The experiment indicated the rate of 20 mg Cu kg^{-1} to be optimum in Mpangala soil. In the field experiment, significantly ($p = 0.05$) higher grain yield of 5.84 ton ha^{-1} was obtained when 2.5 kg Cu ha^{-1} was applied. The results in this study revealed that Cu was the most limiting micronutrient in Mpangala soil, followed by Zn. Zinc may need to be

added in addition to Cu, after one harvesting cycle, in order to provide proper nutrition to the maize crop in the long run. Higher rates of N and P may still be beneficial, especially if Cu and Zn are optimized.

DECLARATION

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

Signature JmLisuma

Date 24.06.2003

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ACKNOWLEDGEMENTS

Special thanks should go first to my supervisors, Prof. J. M. Semoka and Dr. E Semu, for their tireless close supervision, through guidance, criticisms and patience, without which this study would not have appeared in this form. I would like also to extend my sincere appreciation to the DANIDA (Danish International Development Agency) for sponsoring my research through Minjingu Phosphate Rock Utilization Project.

I would like to express my gratitude to drivers Makoti, Steven and Hussein for driving me safely from Morogoro to Makete district where my field plots were located. My sincere appreciation is extended also to the following laboratory technicians: Ms. Kafui, Mrs. Maeda, Mr. Kilosa, Mr. Salum, Mr. Kamwela and all other technicians in the Department of Soil Science for assisting me during the laboratory work for nutrient analyses. Also, I am highly indebted to all lecturers in the Department of Soil Science at Sokoine University of Agriculture. Particular thanks should go to Dr. J. P Mrema, Prof. B. M. Msanya, Prof. F. B. Rwehumbiza, Dr. A. K. Kaaya, Dr. P. W. Mtakwa and Dr. M. Kilasara, for assisting me academically. In addition to the list I present my special thanks to Mr. M. M. Msolla, and Mr. C. Z. Mkangwa, (PhD students) for their suggestions in producing this manuscript. Special thanks should also go to Mrs. Nyabinyili and Miss Baraka for the printing services of this dissertation. Although it is difficult to mention them all by name, my heartfelt appreciation, however, goes to their tireless advise, comments and criticisms during the preparation of this dissertation.

DEDICATION

This work is dedicated first to my late father Bulenga, and my mother Anastazia, who tirelessly laid the foundation of my education. This work is also dedicated to my wife Asnath for the great support she gave me.

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LIST OF ABREVIATIONS AND SYMBOLS

a.s.l	Above sea level
B	Boron
Ca	Calcium
Cu	Copper
CEC	Cation exchange capacity
DTPA	Diethylene Triamine Pentaacetic Acid
DANIDA	Danish International Development Agency
EDTA	Ethylene Diamine Tetraacetic Acid
Fe	Iron
FC	Field capacity
H	Hydrogen
HWSB	Hot Water Soluble Boron
ha	Hectare
K	Potassium
Mg	Magnesium
Mn	Manganese
MPR	Minjingu Phosphate Rock
Na	Sodium
N	Nitrogen
P	Phosphorus
SUA	Sokoine University of Agriculture
TSP	Triple Super Phosphate

<	Less than
>	Greater than
%	Per cent

CHAPTER ONE

1.0 INTRODUCTION

After nitrogen (N), phosphorous (P) is the next most limiting nutrient in many tropical soils (Smith, 2000). Phosphorous deficient soils generally do not support optimum crop yields because plant growth is retarded leading to low yields. The approaches, which have been used to replenish the P status in soil, include crop rotation, manure application, as well as the use of crop residues. However, such materials do not optimize crop yields due to the insufficient P supplied by these materials.

Triple super phosphate (TSP) is another option of P fertilizer material that was produced in Tanga Fertilizer factory using raw phosphate rock from Minjingu, Arusha. However, this factory was closed in the mid 1990s and TSP had to be imported from abroad. Due to high fertilizer prices and low agriculture-based incomes, some farmers use TSP at low rates and most others cannot afford to use it. Nyaki (1997) observed that only 15% of the households in Tanzania use inorganic fertilizers and the average amounts used according to Tanzania-SFI (2000) are as low as 3.3 kg N and 1.9 kg P. This situation of using low rates or not using fertilizer at all is very critical and is one of the main contributing factors to low crop yields.

Currently, there is possibility for most small-scale farmers to use Minjingu Phosphate Rock (MPR) which is cheap and locally available. Some field experiments conducted using MPR on low P soils have shown good crop response (Semoka, 2000). One area with low levels of P is Mpangala, in Matamba Division of Makete District. On this site MPR has been applied for three years now (since 1998). While some response to MPR has been observed, the yield levels obtained todate are still relatively low (Semoka, 2000). The highest yields from the best treatment ($N_{100}P_{120}$) for three seasons have been 3.4, 0.7 and 4.3 t ha^{-1} for 1998/99, 1999/00 and 2000/01, respectively. It appears that some other nutrient may also be limiting yields. The yields could go beyond 6 t ha^{-1} once the limiting nutrients are corrected (Semoka, 2000, personal communication).

In addition to N and P other nutrients suspected to be limiting in the Mpangala soil include boron, copper and zinc. Kamasho (1980) found low levels of Cu and Zn in soils derived from volcanic ash in Mbeya district. Mpangala soils seem to have similar geologic origin as those of Mbeya (Harris, 1961) and could have low levels of these nutrients. Geographically, the Mpangala area is located in the proximity of the Livingstone volcanic mountain range of Mbeya district, which may have spread its volcanic ash as far as Mpangala. Furthermore, volcanic ash soils have also been observed to strongly adsorb Cu and Zn. McBride (1981) observed of all the divalent transition and heavy metals that Cu^{2+} to be the most specifically adsorbed. They are usually adsorbed by Fe, Mn and Al oxides and oxyhydroxides, which are also dominant in most of the volcanic ash soils.

There are also possibilities of boron deficiency in volcanic soils of Makete district and other parts of the southern highlands. Kaihura (1991) found boron to be a limiting factor in a few soils of Iringa district. Boron deficiency is more common in volcanic soils, or in soils derived from igneous rocks. Golov and Bakhova (1996) observed low contents of boron in Russian volcanic ash soils. Sims and Bingham, (1968) observed that appreciable contents of hydroxides of iron and aluminium in volcanic ash soils adsorbed boron and hence reduced its available form in soils. It is of interest to determine whether boron deficiency may be present in Mpangala soils, since these soils are derived from volcanic ash.

Very little work has been done on micronutrients in the Mpangala soil and the status of boron, copper and zinc in these soils are not known. However, as discussed, above there are high possibilities for Mpangala soil to have low levels of these micronutrients due to the origin of these soils. Otherwise, the area has favourable climate and the soils have good physical properties such as good tilth, high water holding capacity and good aeration. Such conditions are favourable for high yield once any limiting nutrients are corrected.

The present study was, therefore, conducted to evaluate the levels of boron, copper and zinc in the Mpangala soil and to assess whether use of these micronutrients would increase maize yields in this area soil and, possibly, in other soils with similar characteristics.

The specific objectives were:

i. To assess the status of boron, copper and zinc in soils from Mpangala village, Makete district.

ii. To establish the need for any of these micronutrients in this soil.

iii. To evaluate maize yield responses to use of the micronutrients that may be deficient.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 General overview of B, Cu and Zn in volcanic soils

Several researchers have provided general overviews of the contents of boron, copper and zinc in volcanic ash soils. Golov and Bakhova (1996) conducted extensive studies on the content of micronutrients in volcanic ash arable soils in Russia and found that a large percentage (51%) of the investigated soils (58,000 ha) were poorly supplied with available forms of B. The content of mobile boron was found to be the likely limiting nutrient for crop yields on the majority of soils. Srivastava *et al.* (1999) also found B deficiency to severely limit the yields of chickpea and other crops in Nepal.

Kamasho (1980) studied the DTPA extractable copper and its distribution pattern in Mbeya district, Tanzania, and found that the pumice layer invariably contained less available copper than the overlaying or the underlaying horizons. Pinkerton (1967) investigated copper deficiency in Nakuru area of Kenya, by analyzing soils derived from unconsolidated pumice, alluvial deposits, lake deposits, basalt, tranchyte and phonolite and reported that soils derived from pumice and ashes from mount Menengai were associated with low available copper. Maskall and Thornton (1989) obtained similar results in soils of Lake Nakuru National Park area in Kenya. Walker *et al.* (1994) conducted a greenhouse study to assess the mineral nutrient status of two soils derived from volcanic ash in south west Oregon. The results confirmed that copper was in the range (<3 mg kg^{-1}) of expected deficiency in some of the samples.

Zinc concentrations in volcanic soils differ widely. Walker and Gessel (1991) found that Zn concentrations in volcanic soils of USA were not low enough to indicate definite deficiency. In some volcanic soils zinc was low. For example in Russia about half (46%) of the arable lands were characterized by a low content of zinc (<2 mg kg^{-1}), 35% of them had an avarage content, and only 19% were well supplied (Golov and Bakhova, 1996). Bajwa (1984) associated clay type in volcanic ash soils with widespread Zn deficiency on certain important wetland rice soils of India. He found Zn deficiency to be prevalent in volcanic ash derived soils having amorphous and smectitic clays. Other clay mineral such as chlorite, vermiculite, kaolinite, halloysite and hydrous mica did not appear to be related to Zn deficiency on those soils.

In general, soils derived from certain materials e.g. volcanic ash, pumice, quartz, shale and phonolite contained low levels of available copper, zinc and boron. There are possibilities of deficiencies of these micronutrients in Mpangala soils because these soils are also derived from volcanic ash.

2.2 Contents of selected micronutrients in volcanic ash soils

2.2.1 Boron

2.2.1.1 Sources of boron in soils

Boron is the only nonmetal among the micronutrient elements (Tisdale *et al.*, 1993). In geologic environments, B solutions contain chiefly H_3BO_3 and $H_2BO_3^-$ (Mortvedt *et al.*, 1972). Although B may exist as an impurity in many rocks and minerals, most of the B in soils is present in the form of tourmaline ($H_2MgNa_2Al_3(BO)_2Si_4O_{20}$), a highly insoluble borosilicate containing 3 – 4% B (Sillanpaa, 1982). Tourmaline is a minor accessory mineral of ordinary granitic rocks but much more abundant in pegatite dikes, contact deposits and in some volcanic rocks. Weathering B minerals found their way into sedimentaly rocks, particulary shales and clay minerals (Mortvedt *et al.*, 1972).

2.2.1.2 Total boron in soils

Total boron contents of soils generally ranges from 2 – 100 mg kg^{-1} and may average about 30 mg kg^{-1} (Shorrocks, 1974). Berger and Pratt (1963) observed variations from 5 – 10 mg kg^{-1} in igneous rocks and 5 mg kg^{-1} in seawater. Clay sediments of marine origin contain the highest B levels (3 – 300 mg kg^{-1}) due to the relatively high B contents of seawater. Boron is conserved during sedimentation and soil formation and is largely present in the soil parent materials of extreme insolubility (Shorrocks, 1974).

2.2.1.3 Available boron in soils

The amounts of available B in soils range from 0.15 mg kg^{-1} to over 50 mg kg^{-1}, as hot water soluble boron (HWSB) (Berger and Truog, 1939). In soils of humid temperate regions, values ranging from 0.2 – 1.5 mg B kg^{-1} are frequent while soils of arid and semi - arid areas may contain 10 – 40 mg B kg^{-1} or more. The deficiency limit may be in the range of $\leq$ 0.5 mg B kg^{-1} depending on the conditions and time of extraction and on soil factors such as pH and organic matter content. According to Shorrocks (1974) boron deficiency frequently occurs when available B is about 0.5 mg kg^{-1} in medium textured soils and 0.3 mg kg^{-1} in light textured (sandy) soils. In heavy textured soils as much as 0.8 mg B kg^{-1} may be required while more than 1.0 mg B kg^{-1} may be required in calcareous soils. Generally, soils in which B deficiency is most likely to occur are those derived from acid igneous rocks and from fresh water sedimentary deposits, acid soils from which much of the original B content has been removed by leaching, soils low in organic matter, alkaline soils containing free lime, and acid peat soils (Shorrocks and Blaza, 1973).

There is conclusive evidence that many soils are deficient in B and will not produce a satisfactory crop under any system of soil management unless this element is supplied (Reeve and Shive, 1944). On average, at less than 1 mg B kg^{-1}, soils may not supply sufficient B to support plant growth, while values of over 5 mg B kg^{-1} may be toxic (Mengel and Kirkby, 1982). Melsted *et al.* (1969) and Lockman, (1972) gave the level considered critical and diagnostic in the interpretation of total plant B of the maize at tasseling stage to be 8 – 10 mg B kg^{-1} in the leaf at or opposite and below the ear level.

2.2.1.4 Factors affecting boron availability

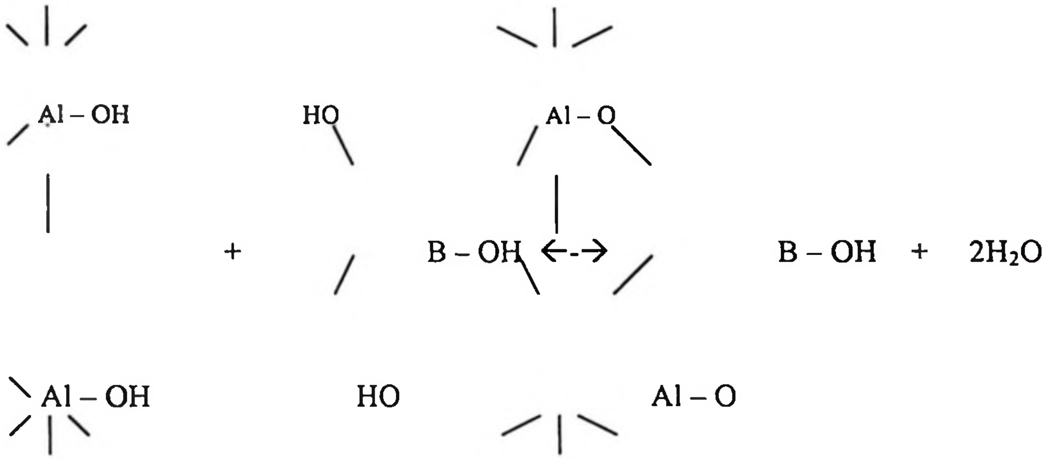
Factors affecting boron availability for plants include soil moisture, soil texture, organic matter, soil pH, nutrient interactions and parent material.

a. Soil moisture

Boron deficiency has been reported to occur under extremes of climatic conditions. Soils in high rainfall areas are often deficient in B, due to the rapid leaching of the non-ionized borate (Gupta, 1979). Under drought conditions, B availability decreases partly because there is no moisture to dissolve tourmaline and partly due to the reduced number of microorganisms that can release B from organic materials (Bowen, 1977). additionally, plants encounter less available boron when they extract moisture from soil at a lower depth during dry conditions (Fleming, 1980). Wetting and drying cycles increase the extent of boron fixation (Biggar and Fireman, (1960).

b. Soil texture and clay minerals

Soil texture greatly influences B availability. Berger and Truog (1939) reported that the leaching of soluble borates was high in porous sandy soils, while B was fixed proportionately with increase in clay content in the soil, probably due to borate adsorption. Among soil minerals, illite is a stronger B sorbent than kaolinite, which in turn is stronger than smectites (Hington, 1964). Sims and Bingham, (1967, 1968) found that access to the interlayer surface of expanding clay lattices was essential for high B sorption. They suggested that hydroxy iron and aluminum materials present in the interlayer, as coatings of clay particles or as independent particles, were principally responsible for B adsorption in soils, and that hydroxy Al adsorbed more B than hydroxy Fe, possibly via the formation of a borate-diol-like complex (Hatcher *et al.*, 1967) as shown by the equation shown below.



This reaction could explain the large B adsorption capacity of many volcanic soils having substantial quantity of amorphous Fe and Al hydroxides oxides (Bingham *et al.*, 1971).

c. Organic matter

Boron associated with soil organic matter originates from B assimilation in microbial biomass. Although B in soil organic matter is not immediately available to plants, it is considered to be the main source of available B when released through mineralization (Gupta, 1968). The role of organic matter in B distribution between the liquid and solid phases of soils is not yet fully understood. Boron deficiency has been observed in soils with high organic matter contents (Hue *et al.*, 1988; Mascarenhas *et al.*, 1988). This deficiency has been shown to be related to the high affinity of organic matter to B (Yermiyahu *et al.*, 1995; Liu *et al.*, 1989). It has been suggested that complex formation between B and dihydroxy or ∝-hydroxy carboxylic functional groups of organic matter is an important mechanism for B retention (Parks and White, 1952; Fleming, 1980). These complexes may be broken down by microbial action with subsequent slow release of B to plants. Thus, organic matter is probably one of the main sources of B in acid soils, as relatively little B adsorption on the mineral fraction occurs at low pH (Okazaki and Chao, 1968) probably due to low affinity. Garate and Meyer (1983) concluded that the main factors affecting B retention by organic matter were pH, Ca and fulvic acid contents, and the humic : fulvic acid ratio.

Boron adsorption by organic matter and soils has been described by a competitive adsorption model (Mezuman and Keren, 1981). This model allows for the fact that two aqueous B species, $B(OH)^0_3$ and $B(OH)_4$ having different affinities to the adsorbent, are involved and that their proportions in the equilibrium solution vary with pH. With this adsorption model, the B adsorption capacity of the soil and composite organic matter mixture was seen to increase with composite organic matter (Yermiyahu *et al.*, 1995).

d. Soil pH

Soil pH is one of the most important soil factors affecting B availability to plants. Generally B becomes less available to plants with increasing soil pH. The best pH range for B availability was established by Lucas and Davis (1961) to be 4.5 – 6.5.

Gu and Lowe, (1990) observed that, boron adsorption by soils was very low in acidic to near neutral soil pH, but may be of greater significance in high pH soils in the presence of organic matter. Some workers have reported negative correlations between B uptake by plants and soil pH (Benneth and Mathias, 1973; Fox, 1968). Studies by Peterson and Newman (1976) showed that a negative relationship between soil pH and plant B occurred when the soil pH levels are greater than 6.3 – 6.5.

e. Nutrient interactions

Nitrogen, applied as NH_4NO_3 as observed by Willet *et al.* (1985) decreased B uptake and B concentration of *Medicago sativa.* Without added B, N application retarded the lucerne growth, probably by inducing B deficiency. With added B, the lowest rate of N application increased lucerne yields but further additions of N depressed yield. Decreased B availability to plants due to excess N was also reported by Wikner (1983), and this could be due to antagonistic effects.

Increasing concentrations of Ca and K have been found to accentuate B deficiency symptoms (McUrath and Bruyn (1956). Contradicting results by Stiles (1961) showed that the presence of B indeed resulted in a considerable increase in the amount of Ca absorbed by plants and that toxic effects of another nutrient element in the plant are usually common if the Ca supply is low.

Graham *et al.* (1987) found that boron uptake by barley was lower if zinc was applied than if it was not. Further studies showed that low levels of zinc and high levels of phosphorus both increased the rate of boron accumulation. Therefore, applying zinc may reduce boron accumulation, and lessen the risk of toxicity in plants.

f. Parent material

In general, soils derived from igneous rocks and those in tropical and temperate regions, have much lower boron content than soils derived from sedimentary rocks, and those in arid or semi-arid regions (Shorrocks and Blaza, 1973). Soils of marine shale origin are usually high in boron. Low boron content can be expected in soils derived from acid granite and other igneous rocks, fresh-water sedimentary deposits, and in coarse-textured soils low in organic matter (Liu *et al.*,1983). Plant available boron is also low in soils derived from volcanic ash (Sillanpaa and Vlek, 1985) and in soils rich in aluminum oxides (Bingham *et al.*, 1971). Golov and Bakhova (1996) conducted extensive studies on the content of micronutrients in volcanic ash arable soils in Russia and found that a large percentage (51%) of the investigated soils (58,000 ha) were poorly supplied with available forms of B.

2.2.1.5 Boron requirement of plants

The supply of boron required for seed and grain production is usually higher than needed for vegetative growth only (Marschner, 1990). Direct effects of boron on plant growth and development are reflected by the close relationship between boron supply and the pollen producing capacity of the anthers, as well as the viability of the pollen producing grains (Agarwala *et al.*, 1981). In maize, minimum boron content of 3 $\mu g\ g^{-1}$ dry weight in the silk is required for pollen germination and fertilization.

Gupta (1980) conducted an experiment by growing maize on a sandy soil of pH 6.0 in the greenhouse with B treatments ranging from 0 – 4 mg kg^{-1} and noted that there were no observable deficiency symptoms in all treatments. The range of 8 – 38 mg B kg^{-1} in plant tissue was found to be sufficient.

Reports by Elliot (1972) on the level of B found in flue-cured tobacco grown on 32 Ontario farms indicated values of 23, 24 and 18 mg kg^{-1} respectively in the tenth leaf of the tobacco plant. In all cases, the B levels were reported to be in the normal range for tobacco.

2.2.1.6 Response of crop plants to boron

Positive responses to B application, which provide clear evidence of B deficiency, have been reported in over 80 countries and on 132 crops over the last 60 years (Shorrocks, 1997). Shorrocks also reported that, for many crops it is the B requirement for successful fertilization that is of critical importance. Even crops with a small B requirement, such as the cereals, can suffer impaired seed set due to B shortage at a critical time.

Some research workers sometimes failed to indicate any statistical significance to crop yield upon B application (Touchton and Boswell, 1975). Murdock *et al.* (1977)

studied the response of maize grain yield to applied B under various growing conditions and maize production systems for 5 years. Average yields from all sites with and without B were 134 and 135 bu acre^{-1} respectively, and B at the rate of 1 – 3 kg ha^{-1} was likely to decrease yields. Kaihura (1991) reported that soils with < 0.21 mg B kg^{-1} are likely to respond to B fertilization while those > 0.21 mg B kg^{-1} are not likely to respond to B fertilization.

Waren and Guines (1986) examined the effects of B rates of 0, 1.1, 2.2 and 4.4 kg B ha^{-1} on yield and quality of established stands of seven Bermuda grass (*cynodon dactylon*). They observed 2.2 kg B ha^{-1} to be the best rate but that rate gave a significant response in only two soil types out of seven.

Ahmed and Alam (1994) studied the response of wheat to application of boron on four soils of different pH. The results showed the highest yield by application of 1 kg B ha^{-1} to the soil having the lowest pH (5.2). Mungbean (*vigna radiata*) grown on Typic Fluvaquent soil, where available soil B content was 0.40 mg kg^{-1} showed a 14% increase in seed yield over the control by application of 2.5 kg B ha^{-1} (Ahmed, 1987).

2.2.2 Copper

2.2.2.1 Sources of copper in soils

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

Copper in soils mainly occurs 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 ($Cu_2(OH)_2CO_3$), silicates such as crysocolla ($CuSiO_3.2H_2O$) and sulphates such as bronchatite ($Cu_4(OH)_6SO_4$) (Krauskopf, 1972).

2.2.2.2 Total copper in soils

The total copper content in soils generally ranges from 1 – 200 mg kg^{-1} although amounts greater than 200 mg kg^{-1} occur where excessive Cu has accumulated from copper containing sprays, dusts or any other sources like contamination with Cu containing compounds (Fiskel, 1965). The natural Cu concentration in the earth's crust has been estimated to be 70 mg kg^{-1} and its concentrations in soils range from 2 to 100 mg kg^{-1} (Guony and Comillo, 1970). Baker (1991) concluded that Cu in the earth's crust ranged from 24 – 55 mg kg^{-1} and the average Cu content for soils was 30 mg kg^{-1}. 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).

2.2.2.3 Available copper in soils

Available copper in the soil is closely related to the type of soil parent material and the extent of its weathering (Pinkerton, 1967; Lal and Biswas, 1973; Nyandat and Ochieng, 1976; Kamasho, 1980). Pinkerton (1967) investigated copper deficiency in Nakuru area, Kenya, by examining soils derived from unconsolidated pumice, alluvial deposits, lake deposits, basalt, tranchyte and phonolite. He observed that soils derived from pumice and ash from mount Mengai were associated with low available copper. Kamasho (1980) studied the DTPA extractable copper and its distribution pattern in Mbeya district, Tanzania, and found that the pumice layer invariably contained less available copper than the overlaying or the underlaying horizons. In general, soils derived from certain materials e.g. volcanic ash, pumice, quartz, shale and phonolite contain low levels of available copper.

2.2.2.4 Factors affecting copper availability

The availability of copper in soils is influenced by, nutrient interactions, quantity of soil organic matter, soil pH, and clay content and oxides.

a. Interaction of copper with other nutrients

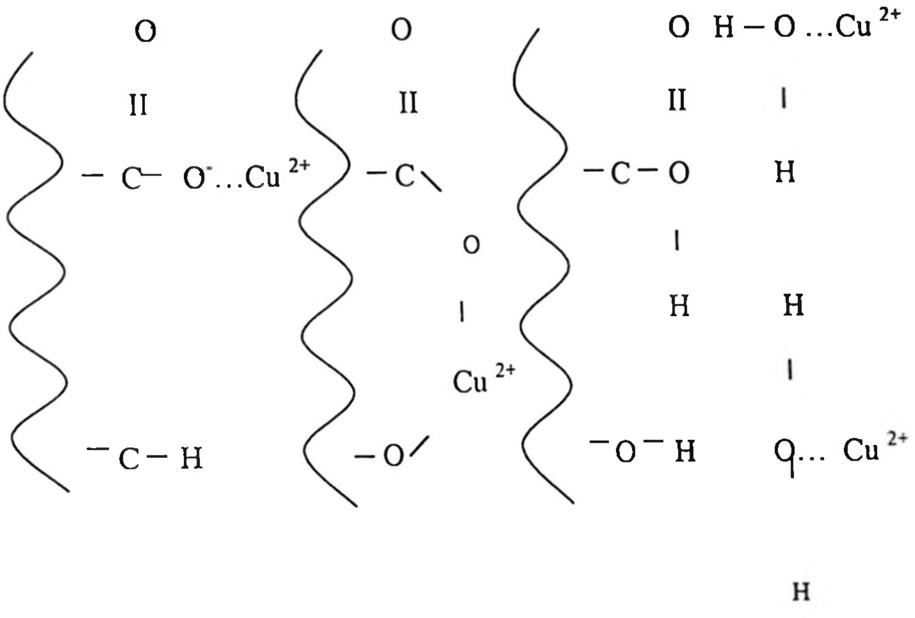
It has been showed that the interaction between Cu and N is either antagonistic or synergistic (Tandon, 1995). Copper deficiencies following the use of acid-forming nitrogen fertilizers may be related to increased Al^{+3} and Fe^{+3} levels in the soil solution (Tisdale et al., 1993) resulting in the formation of free aluminium and iron oxides on which Cu is adsorbed. In addition to that, increased growth resulting from the application of nitrogen without the application of Cu to copper deficient soils proportionally dilutes the copper concentrations in the plants. It has been stated that nitrogen accentuates copper deficiency and when nitrogen supply is high, copper is required for maximum yields (Robson and Reuter, 1981). Camp and Fudge (1939) as quoted by Gilbert (1952) were the first to report that copper deficiency symptoms became more apparent when N was applied to soils deficient in copper.

Phosphorus interaction with copper may result from heavy or prolonged use of phosphatic fertilizers (Bingham, 1963). The prolonged use of high doses of phosphorus fertilizers have been found to interfere with the soil available copper (Bingham, 1963). Barrow (1987) also reported that high doses of phosphorus in the soil tend to interfere with the uptake of copper by plant and its translocation within the plant. Bingham and Garber, (1960) found a significant decrease in concentration of copper in sour orange seedlings as the rate of phosphorus increased from 100 to 900 kg P ha^{-1}. Bingham *et al.* (1958) observed severe copper deficiency in citrus where 360 kg P ha^{-1} or more were applied to calcic and noncalcic brown planosols in California (USA) having soil pH values ranging from 4.4 – 7.4.

Copper has been shown to act antagonistically with zinc in different plant species. Copper and zinc on wheat in alkaline calcareous soil of Pakistan inhibited the uptake of each element but in rice only copper uptake was reduced when zinc was applied (Kauser *et al.*, 1976).

b. Effect of soil organic matter on available copper

A large portion of Cu is retained in soil organic matter as highly stable organo-copper complexes making this Cu fraction not readily available to plants. Due to this behavior Cu availability normally tends to decrease with increasing soil organic matter content (Hodgson *et al.*, 1965). For example, humus in which fulvic acids predominate fixes a noticeable amount of Cu (Stepanova, 1974). Stepanova (1974) also reported that Cu is the best flocculator of humic substances and in acidic soils organic matter can fix large amounts of Cu. Strong complexation of Cu^{2+} by organic matter through such mechanisms as electrostatic (coulombic) attraction (1), co-ordination/chelation (2) and water bridging (3), as depicted in reaction products shown below account for its reduced availability.



(1) (2) (3)

The carbonate and hydroxycarbonate minerals of Cu are much too soluble to permit the stability of Cu in soils. If these complexes consist of solids they act like fixation products and make Cu less mobile in soils and thereby decreases its availability to plants (Lindsay, 1978). Singh *et al.* (1986) reported significant correlations between EDTA extractable copper and organic matter (r = +0.5709), and between DTPA extractable copper and organic matter (r = 0.579).

c. Effect of Soil pH on available copper

Hynes and Swift (1985) reported a decline in 0.1M HCl and 0.05M DTPA-extractable Cu as soil pH increased due to liming. Patel and Singh (1995) found that solubility of Cu decreases as soil pH increases. Cu gets strongly adsorbed by soil colloids as pH increases and precipitates as hydroxides and hydroxyl carbonate above pH 5.5. Raghapathi and Vasuki (1993) observed a highly negative correlation between available Cu and pH, meaning that with increasing pH the available Cu levels decreased. Semu and Singh (1996) reported similar results in soils of Iringa district, Tanzania, implying that Cu availability to plants is related to soil pH.

d. Effect of clay and oxides on available copper

It has been reported that clays are the retention sites of Cu (Traina and Doner, 1985). Farrah *et al.* (1980) found retention of Cu to be in the order of montmorillonite>illite>kaolinite. Soil clay mineralogy greatly influences the amount of Cu retained. It can be stated that clay content and its composition play an important role in the retention and distribution of copper added to soils.

Unlike many other metallic ions, Cu^{2+} can be "specifically" adsorbed by Al, Fe and Mn oxides. Specific adsorption refers to adsorption in the presence of excess quantities of Ca^{2+} or some other electronically bonded metalic ions that would otherwise be capable of preventing significant Cu^{2+} adsorption by simple ion exchange (McBride, 1981). Amorphous Fe and Al hydroxides as well as crystalline oxyhydroxides readily adsorb Cu^{2+} despite the presence of excess alkali metal ions (Forbes *et al.*, 1976). With the possible exception of Pb^{2+}, Cu^{2+} is the most strongly adsorbed of all the divalent transition and heavy metals on Fe and Al oxides and oxyhydroxides. Like Fe and Al oxides, Mn oxides specifically adsorb Cu^{2+}, with the level of adsorption increasing as a function of soil pH. The affinity of synthetic Mn oxides for Cu^{2+} is even stronger than that of Fe or Al oxides (McKenzie, 1980).

2.2.2.5 Copper content in plants

Optimum copper contents in plants differ with plant species, plant parts, stage of maturity and soil conditions, and generally they are in the range of 2 – 22 mg kg^{-1} (Reuther and Labanauskas, 1966). Bowen (1979) reported that in most plants the range of copper concentration is from 5 – 15 mg kg^{-1} and in crop plants, the usual range is 5 – 20 mg kg^{-1} (Jarvis, 1981).

The critical deficiency level of copper in vegetative parts is generally in the range of 3 – 5 $\mu g\ g^{-1}$ dry weight. Depending on the plant species, plant organ, development stage, and nitrogen supply, this range can be larger (Marschner, 1990). Jones and Eck

(1973) reported the critical level of copper in maize to be 5 mg kg^{-1}. For most crop species, the critical toxicity level of copper in the leaves is considered to be above 20 to 30 mg kg^{-1} dry weight (Marschner, 1990).

2.2.2.6 Response of crop plants to copper

Most crops have been found to respond to copper addition in deficient soils. Nilson, (1973) observed that copper application in addition to nitrogen and phosphorous enabled wheat and barley to head and produce high yields. Kamasho (1980) reported that copper at 5 kg ha^{-1} substantially increased both dry matter and grain yields of wheat in Mbeya district.

Berger (1965), as cited by Murphy and Walsh (1972), reported high yield increases in potatoes, carrots, oats, red beets, cabbage, onions, field beans and sweet corn upon addition of 28 kg Cu ha^{-1}. Murphy and Walsh (1972) reported medium copper responses by sweet corn, maize, barley and cabbage while oats, onions, lettuce, spinach, carrots and wheat gave high response to Cu. Working with maize, wheat and soyabeans, Makarim and Cox (1983) reported soyabean yield increases due to copper at three sites out of seven sites. Maize did not respond in all sites tested, which had an average of 0.5 mg kg of extractable Cu in soils.

2.2.3 Zinc

2.2.3.1 Sources of zinc in soils

The source of zinc in soils is the soil parent material. The minerals contributing to total zinc in soils are zincite (ZnO), sphalerite (ZnS), sauconite ($ZnSiO_3$) and smithsonite ($ZnCO_3$) (Lindsay, 1972).

2.2.3.2 Total zinc in soils

Total Zn in soils is very variable depending on the nature of the parent material, soil type and clay content. On average it ranges from 10 – 300 mg kg^{-1} (Krauskopf, 1972). The mean total Zn in surface soils has been reported as ranging from 17 – 125 (Kabata – Pendias and Pendias, 1992). Aubert and Pinta (1977) reported that total zinc content of basic eruptive rocks (basalt and gabbro) ranged from 70 – 130 mg kg^{-1}, acid eruptive rocks (granite and rhyolite) contained 50 – 60 mg kg^{-1}, while metamorphic rocks (schist) and certain sedimentary rocks (clays) had about 30 mg kg^{-1}. In loessic loams and glacial clays, Zn content varied from 30 – 40 mg kg^{-1} and in carbonated rocks and sandstones, it was 20 and 16 mg kg^{-1}, respectively.

2.2.3.3 Available zinc

Soil available zinc is usually very low. Available zinc levels ranging from 0.5 to 0.9 mg kg^{-1} are very common especially in cultivated soils (Wear and Sommer, 1948; Sillanpaa, 1982). In Tanzania DTPA – extractable Zn levels of 1.9 – 7.9 mg kg^{-1} have been reported in volcanic soils of Mbeya (Kamasho, 1980). In Tabora, soils of rice growing areas were reported by Msolla *et al.* (1994) to have 0.50 – 1.10 mg Zn

kg^{-1} in deficient soils and 1.15 – 2.70 mg Zn kg^{-1} in non deficient soils. The distribution pattern of available zinc in the profile differs widely. Alston and McConaghy (1965), cited by Lindsay (1972), reported that EDTA extractable zinc decreased sharply with depth in the profile. Kanehiro and Sherman (1967) observed that in most of the 19 series of Hawaiian soils, the highest concentration of available zinc was in surface soils and decreased with soil profile depth.

In contrast, studies conducted in Tanga and Tukuyu (Ngaiza, 1977) and Mbeya (Kamasho, 1980) in Tanzania, indicated that there was no specific distribution pattern of available zinc in the profiles studied. Lindsay and Norvel, (1978) reported the critical level of Zn in the soil to be in the range of 0.5 – 1.0 mg kg^{-1}. In some soils of Taiwan the critical level of soil Zn has been found to range from 0.1 – 2 mg kg^{-1} (Chen, 2001).

2.2.3.4 Factors affecting zinc availability in soils

a. Interaction of zinc with other nutrients

High concentrations of Fe, Mn, Mg, P; Ca, and HCO_3 ions, especially under high moisture conditions, have been reported to affect zinc availability (Mikkelsen and Kuo, 1977). High levels of P in soils with low available zinc decreased zinc uptake (Barrow, 1987; Xie and Mackenzie, 1988; Tisdale *et al.*, 1990). In soils rich in hydrous oxides, and P, Zn availability was low due to retention of phosphate by hydrous oxides (Bolland *et al.*, 1977). Loneragan *et al.* (1979) reported three factors which may contribute to P-induced Zn deficiency in plants: (i) dilution of Zn in plants by the increase in growth caused by P fertilizer, (ii) inhibition of Zn uptake by cations added with phosphorous fertilizers and (iii) phosphorus induced zinc adsorption in soil due to hydroxides and oxides of iron and aluminium and to $CaCO_3$. Under high moisture conditions hydrated oxides of Fe and Mn, which have high surface area, prevail. These have very strong adsorptive capacity for zinc, hence under such conditions availability of zinc is reduced (Adriano *et al.*, 1971; Giordano *et al.*, 1974; Hasra *et al.*, 1987).

The effect of nitrogen on Zn availability in plants has been reported to be mainly on its effect on soil pH. Viets *et al.* (1957) observed that those N-fertilizers with an acidifying effect, such as $(NH_4)_2$ SO_4, have the greatest effect on Zn uptake and growth of plants. In a study to compare various nitrogen sources, namely ammonium sulphate, ammonium nitrate, and calcium nitrate, it was observed (Lindsay, 1972) that pH changes accompanying the use of N carriers exerted the greatest effect on Zn uptake. Ammonium sulphate, which decreased soil pH most, increased Zn availability most.

b. Clay fraction

Different types of clay minerals have different zinc adsorption capacities. Clays plays a vital role in the availability of zinc since they provides negatively charged sites where zinc can be adsorbed and be prevented from leaching. Follet *et al.* (1981) reported that montmorillonitic clay can adsorb zinc in excess of its CEC, particularly at near neutral or alkaline pH levels. Therefore, it can be concluded that the type of clay in a given soil will have great influence on the availability of native as well as added zinc in such soils.

c. Climate

Climate plays a major role on the availability of zinc in soils. Temperature and moisture are the main components of climate, which affect zinc availability in the soils. Castro (1970) observed in India that micronutrient deficiencies were most severe in cold weather and absent in warm weather on marginally deficient soils. Excessive soil moisture, such as in flooded or water logged soil conditions, increases the pH of the soil to around neutral and thus reduces Zn availability to plants. Martin *et al.* (1965) found that applying high levels of P to soils of low available Zn induces Zn deficiency in cool weather but not during hot weather.

d. Soil type

Distribution of soil Zn varies with soil type. Quite often, sandy soils are low in available Zn and hence Zn deficient, since quartz is generally low in total Zn content (Lindsay, 1972; Katyal *et al.*, 1982). Sharma and Motiramani (1969) reported that in high rainfall areas, where acidic conditions prevail, weathered minerals release Zn that is subsequently removed by leaching. Thus, Zn deficiencies in acid soils are generally associated with low soil Zn content.

Zinc concentrations in volcanic soils differ widely. Walker and Gessel (1991) found that Zn concentrations in volcanic soils were not low to indicate definite deficiency.

In some volcanic soils zinc was low. Bajwa (1984) associated clay type in volcanic ash soil with widespread Zn deficiency on certain important wetland rice soils, and found Zn deficiency to be prevalent in volcanic ash derived soils having amorphous and smectitic clays. Other clay minerals such as chlorite, vermiculite, kaolinite, halloysite and hydrous mica did not appear to be related to Zn deficiency on these soils.

e. Organic matter

Organic matter has a big influence on the availability of Zn in soils. Organic matter reacts with Zn to form organic matter-zinc complexes of different strengths depending on the type of organic matter fraction involved in the reaction. Generally Zn associated with the soluble fractions of organic matter, such as organic acids and amino acids, is readily available whereas that associated with the humic acids is less available (Stevenson and Ardakani, 1972).

Soluble organic ligands may also influence Zn adsorption by changing the concentration of the Zn species that is preferentially adsorbed, or by changing the number of sites available for adsorption (Barrow, 1986). Adsorption of organic anions can increase the negative charge on surfaces (Barrow, 1985) and hence increase Zn adsorption. On the other hand, the presence of organic ligands in solution may decrease Zn adsorption by competing for the adsorption surfaces with Zn.

f. Soil pH

Soil pH plays a big role in regulating the availability of many cations/nutrients in soils, including zinc (Viets *et al.* 1957; Misra *et al.*, 1976; Saeed and Fox, 1979; Kamasho, 1980; Barrow, 1987). Zinc availability is negatively correlated with pH (Jahirudidin *et al.*, 1985; Xie and Mackenzie, 1988). This has been attributed to changes in ionic species with changes in pH. Increase in pH reduces the solubility of Zn^{2+} by formation of insoluble compounds such as $Zn(OH)_2$ and $ZnCO_3$, hence decreasing the amount of Zn^{2+} in the soil solution (Sims, 1986; Tisdale *et al.*, 1990). The availability of Zn in the soil is increased as the soil becomes more acid (Lucas and Davis, 1961).

2.2.3.5 Zinc in plants

Zinc is a micronutrient whose normal concentration range in plants is 25 to 150 mg kg^{-1}. Deficiency symptoms develop when the levels fall below 25 mg kg^{-1} (Bear, 1954). In leaves, the critical deficiency levels are below 15 – 20 μg Zn g^{-1} dry weight (Marschner. 1990). Corn and beans are sensitive to Zn deficiency. Grain and seed yield are depressed to a greater extent by Zn deficiency than the total dry matter production. perhaps because zinc seems to play a specific role in fertilization. Pollen grains have a very high zinc content, and during fertilization most of the zinc is incorporated into the developing seed (Polar, 1975).

When zinc supply is large, zinc toxicity can readily be induced in non tolerant plants. Quite often zinc toxicity leads to chlorosis of young leaves, which may, at least in part be, an induced Fe deficiency since hydrated Zn^{2+} and Fe^{2+} have similar ionic radii. The critical toxicity levels of zinc in leaves of most crop plants are more than 400 – 500 mg kg^{-1} dry weight (Marschner, 1990).

2.2.3.6 Response of crop plants to zinc

Numerous workers have reported response of crops to zinc addition. Semoka *et al.* (1981) reported a significant increase in yield of flue-cured tobacco when zinc was applied to soils of Iringa district containing less than 1 ppm EDTA extractable zinc. Kamasho (1980) observed a yield response of wheat, lucerne and maize to addition of 10 kg Zn ha^{-1} on some soils of Mbeya district.

Viets *et al.* (1954) reported maize to be highly sensitive to zinc levels while cereals such as wheat, oats, barley and rye are rather insensitive to zinc. Contrary to the above results, Hilton and Zubriski (1985) reported that there were no response to zinc fertilization by maize and sunflower even when the extractable zinc was below 0.5 mg kg^{-1} DTPA - $(NH_4)_2CO_3$ extractable zinc. Singh *et al.* (1987) working with soils which contained < 0.5 mg Zn kg^{-1} soil, obtained a significant response to zinc in only one trial out of 23 trials using wheat, barley, peas, alfalfa and maize as test crops. This means that most of crops were insensitive to Zn application.

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 < 2.8 mg kg^{-1} doubled acid extractable zinc.

CHAPTER THREE

3.0 MATERIALS AND METHODS

A site, which had not been previously treated with phosphatic, boron, copper or zinc fertiliser for the past ten years, was selected for pot and field experiments. The soil was classified as Pathic Haplustand (Semoka, 2000).

3.1 Soil sampling

A bulk soil sample for use in pot experiments and for routine soil analysis were collected, from an area of about 0.2 ha to a depth of 20 cm. Four subsamples, were collected from the area each representing a designated block in the field. They were air-dried and ground to pass through a 6 mm sieve and then, thoroughly mixed to give a composite medium for the pot experiment study. A portion of this soil was ground to pass through a 2 mm sieve and used for physical and chemical analysis.

3.2 Laboratory analysis

3.2.1 Soil analysis

Soil pH was determined in a 1:2.5 soil:water suspension using a pH meter (MacLean, 1982). Extractable P was determined according to the Bray 1 method (Bray and Kurtz, 1945) and colour was developed by the ascorbic acid method of Murphy and Riley (1962). Organic carbon was determined by the Walkey and Black method (Nelson and Sommer, 1982). Total N was determined by macro-Kjeldah digestion followed by distillation (Bremner and Mulvaney, 1982). Particle size distribution was determined by the hydrometer method (Gee and Bauder, 1986). The cation exchange capacity was determined by the ammonium acetate saturation method (Rhoades, 1982). Exchangeable Ca and Mg in the ammonium acetate filtrate were determined by atomic absorption spectrophotometry while exchangeable K and Na were determined by flame spectrophotometry. Exchangeable Al was determined by the KCl method described by MacLean (1982). The DTPA extractable Cu, Fe, Mn and Zn were determined by atomic absorption spectrophotometry (Lindsay and Norvell, 1978). Boron was determined by the hot water extraction method (Moberg, 2000).

3.3 Pot experiments

The first pot experiment was conducted in order to screen the most limiting micronutrients in the soil. Four kilogramme portions of soil sieved through a 6 mm sieve were weighed into six-litre plastic pots. Ten treatment combinations as shown in Table 1 were assigned. Nitrogen and P were applied as basal nutrients in order to make sure that these nutrients, which were deficient in the soil, did not limit yields. The treatments were replicated three times and arranged in a randomized complete block design.

Triple super phosphate (46% P_2O_5) was used as source of phosphorus while sulphate of ammonia ($(NH_4)_2SO_4$) (21% N) was used as source of nitrogen. Sodium pentaborate

Table1. Treatments used in the pot experiment

Treatment combination	Micronutrients used
$P_0\ N_0\ B_0\ Cu_0\ Zn_0$	Absolute control
$P_{160}\ N_{240}\ B_0\ Cu_0\ Zn_0$	Micronutrient control
$P_{160}\ N_{240}\ B_0\ Cu_0\ Zn_{10}$	Zinc alone
$P_{160}\ N_{240}\ B_2\ Cu_0\ Zn_0$	Boron alone
$P_{160}\ N_{240}\ B_0\ Cu_5\ Zn_{10}$	Copper and zinc
$P_{160}\ N_{240}\ B_0\ Cu_5\ Zn_0$	Copper alone
$P_{160}\ N_{240}\ B_2\ Cu_5\ Zn_0$	Boron and copper
$P_{160}\ N_{240}\ B_2\ Cu_0\ Zn_{10}$	Boron and zinc
$P_{160}\ N_{240}\ B_2\ Cu_5\ Zn_{10}$	All micronutrients with low P rate
$P_{320}\ N_{240}\ B_2\ Cu_5\ Zn_{10}$	All micronutrients with high P rate

Subscript values are nutrient rates in mg kg^{-1}

decahydrate ($Na_2B_{10}O_{16}.10H_2O$) (17.5% B), copper sulphate ($CuSO_4.5H_2O$) (25.4% Cu), and zinc sulphate ($ZnSO_4.H_2O$) (36.4% Zn) were used as sources of B, Cu and Zn, respectively.

All fertilizer sources for N, P, B, Cu and Zn were applied by mixing the fertilizers thoroughly with the four kg of soil before filling the pots and sowing of seeds. Two rates of P, 160 mg and 320 mg kg^{-1}, were used. Rates of 2 mg kg^{-1}, 5 mg kg^{-1}, and 10 mg kg^{-1} were respectively applied for B, Cu and Zn. The B, Cu and Zn were used in order to ensure that these nutrients did not limit plant growth. Before sowing maize seeds the potted soils were watered using 1,190 ml distilled water per pot, equivalent to 90% of the field capacity, and allowed to equilibrate for one day. Four maize seeds of hybrid variety UH 615 were planted per pot. The soils in the pots were maintained at approximately field capacity during the whole experiment period by watering using distilled water.

Thinning was done one week after seedling emergence, leaving two plants per pot. Two weeks after sowing the first N split dose was applied at the rate of 120 mg N kg^{-1} to each pot except the absolute control pot. The second half of N split was applied 28 days after sowing, at the same rate. Plant shoots were harvested at 42 days after planting by cutting the stems at about 1 cm above the soil surface. The plants were thoroughly cleaned using a wet napkin paper and dried at 65 °C to a constant weight. Then dry matter yields were determined by weighing. Nutrient uptake values were calculated by multiplying concentrations values by its dry matter yield. The plant samples were cut into small pieces and ground to pass through 0.5 mm sieve for plant analysis (section 3.4).

The second pot study was conducted in order to determine the optimum rate of copper, which would maximize yields, having observed copper to be the most limiting. The same procedures given above were followed for the second pot experiment. Rates of 320 mg P kg^{-1} and 240 mg N kg^{-1} were used in order to make sure that these nutrients did not limit the plant growth. Different levels of Cu, at 5, 7.5, 10, 15, or 20 mg Cu kg^{-1}, were used.

3.4 Plant analyses

Plant materials were analysed for N, P, B, Cu and Zn. Total nitrogen was determined by the micro-Kjeldahl method. Plant B was obtained by the dry-ash method (Nyomora *et al*, 1996) as follows: Ground plant samples (1.5 g) were mixed with 0.3 g CaO powder, placed in crucibles, covered to prevent contamination from B that might be vaporised from the furnace wall, and ashed at 525°C in a muffle furnace for 3 hours. The ash was dissolved in 20 ml of 2M HCl, then 20 ml of distilled water were added and the suspension filtered, the solutions were stored in plastic vials. Auto pipette was used to transfer 1ml of the filtrate to dry 50 ml plastic vials, then 2 ml of buffer solution and 2 ml of azomethine-H reagent was added and mixed well and allow to stand for 45 minutes to develop colour. Then B was analysed using a spectrophotometer. For the other elements 1.5 g of each sample was ashed in a muffle furnace at 525° C for 3 hours, and the ash was dissolved in 6N HCl, filtered and aliquots made up to 50 ml with deionized water. The different elements were determined from the aliquot as follows: P by the ascorbic acid method of Murphy and Riley (1962); Cu and Zn by atomic absorption spectrophotometry (Lindsay and Norvell, 1978).

3.5 Field experiment

3.5.1 Location of the study site

The site was within the Mpangala Primary School farm. The area is located between latitudes of 8°59′ and 9°00′ S and longitudes 33°57′ and 33°58′ E at an elevation of 2,250 m.a.s.l. The annual mean rainfall ranges from 1,000 – 1,400 mm and the mean annual air temperature is 15.3°C (the minimum annual air temperature is 8.9 °C while the maximum temperature is 21.6 °C).

3.5.2 Experimental design, field plan and treatments

A randomised complete block design was used in this experiment with 10 treatments as shown in Table 2, and the treatments were replicated four times. The dimensions of each plot were 5.1 m x 4.5 m, with interblock and interplot spacing of 1 m and 0.5 m, respectively. A 2 m pathway was maintained around the entire experimental area. Seeds were sown at the spacing of 75 cm x 30 cm.

Table 2. Treatments used in the field experiment

Treatment combination	Micronutrients used
$P_0 N_0 B_0 Cu_0 Zn_0$	Absolute control
$P_{80} N_{120} B_0 Cu_0 Zn_0$	Micronutrient control
$P_{80} N_{120} B_0 Cu_0 Zn_5$	Zinc alone
$P_{80} N_{120} B_1 Cu_0 Zn_0$	Boron alone
$P_{80} N_{120} B_0 Cu_{2.5} Zn_5$	Copper and zinc
$P_{80} N_{120} B_0 Cu_{2.5} Zn_0$	Copper alone
$P_{80} N_{120} B_1 Cu_{2.5} Zn_0$	Boron and copper
$P_{80} N_{120} B_1 Cu_0 Zn_5$	Boron and zinc
$P_{80} N_{120} B_1 Cu_{2.5} Zn_5$	All micronutrients with low P rate
$P_{160} N_{120} B_1 Cu_{2.5} Zn_5$	All micronutrients with high P rate

Subscript values are nutrient rates in kg ha^{-1}.

NB: Half rates in field experiment as opposed to pot experiments was used because when field fertilizer rates converted into application rate in pot experiment, the fertilizer becomes very low and bring no significant effect to the plant. Therefore doubling the field fertilizer rates into pot experiment, results into the significant effect to the plant.

The application of TSP, SA, B, Cu and Zn at the rates of 80 kg P ha^{-1}, 120 kg N ha^{-1}, 1 kg B ha^{-1}, 2.5 kg Cu ha^{-1}, and 5 kg Zn ha^{-1}, respectively, was done manually by spreading the fertilizers evenly on the soil surface, followed by throughly mixing them into the soil using a hoe. Planting was done on 14th November, 2001 together with application of the first ¼ split of 30 kg N ha^{-1}as $(NH_4)_2SO_4$. The maize variety used was UH 615. Three maize seeds were planted per hill. Seedlings were then thinned to one plant per hill two weeks after seedling emergence. The second $(NH_4)_2SO_4$ split of 40 kg N ha^{-1} was applied four weeks after planting when the maize seedlings attained the height of 10 – 15 cm. The third split of 30 kg N ha^{-1} was applied nine weeks after planting when the seedlings attained about 20 – 30 cm and the fourth split of 20 kg N ha^{-1} at 15 weeks after planting when maize was about to flower. Frequent weeding was done so that the experimental plots were almost free of weeds for most of the plant growth period.

Plant sampling was done at 20 weeks after sowing by taking three ear leaves per row from each of inner 4 rows out of 6 rows, giving a total of 12 leaves per plot. These plants were sampled when almost 50 percent of maize plants had tasselled. The samples were oven dried at 65°C to constant weight and cut to small pieces and ground to pass through 0.5 mm sieve. Determination of P, N, B, Cu, and Zn in the plant materials was done using the procedures outlined in section 3.4.

Maize grain was harvested at 286 days after planting. A guard row was left around each plot so that only the inner 4 rows were harvested. Cobs were shelled, grain weighed and the moisture content of the grain determined using a moisture meter. The grain yields were reported in tonnes ha^{-1} at 12.5% moisture.

3.6 Data analysis

All the data were subjected to analysis of variance. Duncan's New Multiple Range Test was used for the separation of means. The statistical model used for data analysis was as described by Snedcor and Cochran (1989):

$Y_{ij} = \mu + T_i + \beta_j + E_{ij}$ for $i = 1, 2,..b$

$j = 1, 2,..t$

where;

Y_{ij} = Observation for each of the treatments

μ = Overall mean

T_i = Effects due to treatments

β_j = Effects due to the block

E_{ij} = Variation within treatments and blocks (i.e. error term).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Physical and chemical Properties of soils of the experimental site

Some of the physical and chemical properties of Mpangala soil are shown in Table 3. The pH of Mpangala soil, at 5.93, was rated as being medium (Landon, 1991). The optimum soil pH range for maize production is between 6 to 7 (Purseglove, 1988). The pH of 5.93 could be considered as optimum for crop production, when other soil and plant factors are not limiting.

Organic carbon in Mpangala soil was found to be 2.23%. This value was rated as high (Landon, 1991). The high organic carbon could be accounted for by the fact that volcanic ash soils normally have high content of organic carbon. Nitrogen content in the soil was 0.13%. Landon (1991) categorized soil total N values of 0.1 - 0.2% as low. Therefore, total N in Mpangala soil was rated as low.

Bray 1 (available) P content of the soil was 4.41 mg kg^{-1}. Landon (1991) categorized extractable P (Bray 1 method) in soils as follows; high (>50); medium (15 - 50) and low (<15). Therefore, available P of 4.41 mg kg^{-1} by the Bray 1 method was ranked as very low, implying that the soil was deficient in P.

Table 3. Some physical-chemical characteristics of the experimental soil

Parameter	Value	Rating	Reference
pH in water	5.93	Medium	Landon (1991)
Organic carbon (%)	2.23	High	Landon (1991)
Bray 1 P (mg kg^{-1})	4.41	Deficient	Landon (1991)
Total N (%)	0.13	Low	Landon (1991)
CEC {cmol (+) kg^{-1}}	19.8	Medium	Landon (1991)
Exchangeable Ca {cmol (+) kg^{-1}}	4.09	Medium	Landon (1991)
Exchangeable Mg {cmol (+) kg^{-1}}	1.69	Medium	Landon (1991)
Exchangeable K {cmol (+) kg^{-1}}	1.13	High	Landon (1991)
Exchangeable Na {cmol (+) kg^{-1}}	0.66	Low	Landon (1991)
Exchangeable Al {cmol (+) kg^{-1}}	1.00	-	-
Exchangeable H {cmol (+) kg^{-1}}	0.35	-	-
Aluminium saturation (%)	5.05	-	-
Calcium saturation (%)	20.7	-	-
Hot water soluble B (mg kg^{-1})	0.52	Medium	Golov and Bakhova (1996)
DTPA Cu (mg kg^{-1})	0.14	Deficient	Lindsay and Norvel (1978)
DTPA Zn (mg kg^{-1})	0.86	Marginal	Lindsay and Norvel (1978)
DTPA Fe (mg kg^{-1})	50.54	Very high	Lindsay and Norvel (1978)
DTPA Mn (mg kg^{-1})	17.32	Very high	Tandon (1995 a)
Particle size analysis		-	-
% Sand	49		
% Silt	15		
% Clay	36		
Textural class	Sandy clay	-	FAO (1977)

The DTPA extractable Cu was found to be 0.14 mg kg^{-1}. According to Lindsay and Norvell (1978) and Tandon (1995 b), the critical level of DTPA Cu in the soil is 0.2 mg kg^{-1}. Therefore, DTPA extractable Cu of 0.14 mg kg^{-1} in the soil is deficient since it is below the soil critical level. The DTPA extractable Zn observed in the soil was 0.86 mg Zn kg^{-1}. Lindsay and Norvell (1978) suggested levels of 0.5 – 1.0 mg kg^{-1} to be the critical levels for Zn. Therefore the concentration of 0.86 mg Zn kg^{-1} was rated as marginal. The B concentration found in Mpangala soil was 0.52 mg B kg^{-1} by hot water extraction. Cox and Kamprath (1972) proposed the B critical range to be between 0.2 – 1.0 mg kg^{-1}. Golov and Bakhova (1996), using the hot water soluble boron method, gave the following scale: < 0.33 mg B kg^{-1} to be low, 0.34 – 0.70 mg B kg^{-1} to be medium, and above 0.71 mg B kg^{-1} to be high. On the basis of these categories the level of 0.52 mg B kg^{-1} for Mpangala soil falls in the medium range.

4.2 Glasshouse pot experiments

4.2.1 Response of maize to boron, copper and zinc

The effects of boron, copper and zinc on the dry matter (DM) yields of maize shoots are shown in Table 4. The DM yield ranged from 7.93 – 68.50 g pot^{-1}. All treatments gave significantly ($P=0.05$) higher dry matter than that of the absolute control. The addition of P and N into the soil increased dry matter yield from 7.93 g pot^{-1} to 49.77 g pot^{-1}. When Zn was applied, dry matter yield increased slightly but not significantly over the micronutrient control.

Table 4. Effects of B, Cu and Zn application on maize dry matter yield in a pot experiment

Treatment	Dry matter yield, (g pot^{-1})
P_0 N_0 B_0 Cu_0 Zn_0 (Absolute control)	7.93d
P_{160} N_{240} B_0 Cu_0 Zn_0 (Micronutrient control)	49.77c
P_{160} N_{240} B_0 Cu_0 Zn_{10}	53.30bc
P_{160} N_{240} B_2 Cu_0 Zn_0	51.67c
P_{160} N_{240} B_0 Cu_5 Zn_0	57.90b
P_{160} N_{240} B_2 Cu_0 Zn_{10}	51.37c
P_{160} N_{240} B_0 Cu_5 Zn_{10}	50.73c
P_{160} N_{240} B_2 Cu_5 Zn_0	51.27c
P_{160} N_{240} B_2 Cu_5 Zn_{10}	57.83b
P_{320} N_{240} B_2 Cu_5 Zn_{10}	68.50a
CV%	6.66

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

The addition of B did not increase dry matter yields significantly. A dramatic effect on dry matter yields was observed in the Cu treatment, which significantly increased DM yields to 57.9 g pot^{-1}. Application of B in combination with Zn, Cu in combination with Zn, or B in combination with Cu, did not increase dry matter yield, significantly. Increasing P to the rate of 320 mg P kg^{-1} together with B, Cu, and Zn, increased DM yield significantly to 68.50 g pot^{-1}.

The lowest yields in the absolute control reflect the inherently low levels of N and P in the soil, as shown in Table 4. Hence addition of N and P caused yields to increase. The slight increases in dry matter yields over the micronutrient control when Zn was added signify only a small contribution of Zn to dry matter yields. Similarly B did not increase DM yields significantly (P=0.05) relative to the micronutrient control. These results imply that Zn and B were not yet limiting yields in this soil. However, Zn may be a more limiting nutrient than B. This may be because the B level in the soil was medium while Zn was marginal (Table 3).

Very dramatic effect of Cu in increasing the dry matter yields suggests that Cu is a limiting nutrient in the Mpangala soil, and hence the significant (P=0.05) increase in yields upon its use. The soil analysis data (Table 3) supports this conclusion. The non-significant increase of dry matter yields over the micronutrient control as a result of use of B in combination with Zn, Cu in combination with Zn, or B in combination with Cu, could probably be due to antagonistic interactions of these nutrients. Graham *et al.* (1987) reported an antagonistic interaction of B with Zn. They observed B uptake by barley to be lower when Zn was added. Kauser *et al.* (1976)

reported that Cu uptake by the plants was suppressed when Zn was added. Chaudhry and Sharif (1975) found Cu to depress the Zn concentration in the shoots of rice plants. Thus, such antagonisms may have operated in the present study.

The lack of dry matter yield increase for the treatment which received B, Cu and Zn together, whereas yields were higher when only Cu was used, signify that the main contributor for high dry matter yields, after N and P, was copper, and not B or Zn. A positive response of crops to copper has been reported elsewhere in Tanzania. Mkangwa (1992), working with soils from Iringa district, found that maize DM yields were increased by use of 5 kg Cu ha^{-1} in a number of soils. Kamasho (1980) in Mbeya district, Tanzania, observed that copper increased DM yields of wheat substantially.

The still higher (P=0.05) dry matter yields when P at the rate of 320 mg kg^{-1} was used (in combination with the micronutrients) implies that the rate of 160 mg P kg^{-1} was not adequate in the Mpangala soil. This implies a high capacity for P fixation in this soil. Szilas (2002) found the Mpangala soil to have a P adsorption maximum of 1017 mg P kg^{-1}, which is much higher than the P rate used in the present studies.

4.2.2 Concentration and uptake of copper in maize shoots

The concentrations of Cu and its uptake by the maize shoots are shown in Table 5. Copper concentrations in maize shoots ranged from 1.2 – 4.5 mg kg^{-1}. Copper uptake in the absolute control was very low, but P and N increased Cu uptake significantly (P=0.05) over the absolute control treatment. Application of Zn or B did not increase

Cu uptake significantly (P=0.05) when compared to the micronutrient control, while Cu application increased Cu uptake significantly when compared to the micronutrient control. The Cu uptake in the treatments with B + Zn or B + Cu did not differ significantly with the Cu alone treatment. Application of Cu + Zn increased Cu uptake over the micronutrient control but the increase was smaller than that for the Cu alone treatment. Higher and significant copper uptake was observed in the treatment which received 160 mg P kg^{-1} in combination with all micronutrients than the rest of the treatments. Copper uptake in the treatment which received 320 mg P kg^{-1} in combination with all micronutrients, was significantly lower than that in the treatment with 160 mg P kg^{-1} in combination with all micronutrients.

Table 5. Concentration and uptake of B, Cu and Zn in maize plant as influenced by their addition to the soil

Treatment	B (mg kg^{-1})	B uptake (mg pot^{-1})	Cu (mg kg^{-1})	Cu uptake (mg pot^{-1})	Zn (mg kg^{-1})	Zn uptake (mg pot^{-1})
$P_0 N_0 B_0 Cu_0 Zn_0$	18.1bc	145.3e	1.2e	9.8e	10.8d	85.7c
$P_{160} N_{240} B_0 Cu_0 Zn_0$	15.5cd	770.6d	1.5e	76.0d	11.7cd	581.9b
$P_{160} N_{240} B_0 Cu_0 Zn_{10}$	14.4cd	772.6d	1.7e	91.2d	18.7a	998.7a
$P_{160} N_{240} B_2 Cu_0 Zn_0$	25.1a	1296ab	1.6e	81.3d	10.8d	557.8b
$P_{160} N_{240} B_0 Cu_5 Zn_0$	12.7d	747.7d	3.4bc	197.2b	11.0d	634.7b
$P_{160} N_{240} B_2 Cu_0 Zn_{10}$	21.4ab	1091bc	3.9b	200.5b	18.9a	974.0a
$P_{160} N_{240} B_0 Cu_5 Zn_{10}$	14.6cd	739.2d	2.9cd	144.9c	14.3bc	724.5b
$P_{160} N_{240} B_2 Cu_5 Zn_0$	17.9bc	917.8cd	3.7b	191.8b	12.8cd	653.6b
$P_{160} N_{240} B_2 Cu_5 Zn_{10}$	20.9b	1214ab	4.5a	257.7a	16.6ab	965.1a
$P_{320} N_{240} B_2 Cu_5 Zn_{10}$	20.0b	1369a	2.5d	169.0bc	14.5bc	993.3a
CV%	12.0	15.2	11.9	13.4	10.8	13.8

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

Jones and Eck (1973) reported the critical level of Cu in maize shoots as 7 mg Cu kg^{-1} at 30 – 45 days of growth. Therefore Mpangala soil is very deficient in Cu content, since the values obtained from the analyzed plant samples were below the critical level. The low Cu uptake from the absolute control treatment reflects the low Cu content in the soil as shown in Table 3. Addition of P and N to the soil, increased plant Cu uptake. The increase in Cu uptake signifies that these nutrients (P and N) were low in the soil and hence their addition increased the Cu uptake. The significant increase in Cu uptake from the Cu treatment signifies that Cu was one of the limiting nutrients in this soil and it was in this treatment where significantly high dry matter yields was obtained.

Copper uptake in the treatments with B + Cu and B + Zn did not change significantly over the Cu alone treatment. This indicates that other factors were probably associated with these results. The uptake of Cu seems to be reduced by Zn application. Lower uptake of copper was observed in the Cu treatment in combination with Zn than in the alone Cu treatment. The highest Cu uptake was found in the treatment which received 160 mg P kg^{-1} plus all micronutrients. When the P rate was doubled the uptake of Cu decreased. The decrease in Cu uptake could be attributed to the high P rate (320 mg P kg^{-1}) that could have interfered with the low level of added Cu. Bingham (1963) observed similar results of decrease in plant Cu uptake as the P rate was increased.

4.2.3 Concentration and uptake of zinc in maize shoots

Zinc concentrations and uptake by maize shoots are presented in Table 5. Zinc content in maize shoots ranged from 10.8 – 18.9 mg kg^{-1}. The lowest Zn uptake was found in the absolute control treatment. In the micronutrient control treatment Zn uptake increased ($p=0.05$) significantly over the absolute control treatment. The highest Zn uptake was observed in the Zn treatments. Boron and Cu increase increase Zn uptake over the micronutrient control. When Zn was combined with B, dry matter yield was increased significantly over the micronutrient control. However, the increase in dry matter yield did not differ significantly from the treatment that received only Zn.

Zinc concentration values in maize shoots were below the critical range of 25 – 60 mg kg^{-1} as established by Tisdale *et al.* (1993). Soil analysis data for Zn indicated that Mpangala soil had marginal level of Zn. Addition of N and P in the soil did not significantly increase Zn concentrations in maize shoots significantly probably due to dilution effect as a result of the increase in dry matter. Significantly ($p=0.05$) higher Zn uptake as a result of N and P reflects the same reason as discussed in section 4.2.2 that N and P in the soil were low and hence addition of these nutrients increased Zn uptake. The significant Zn uptake from the Zn treatment is attributed to an increase in available Zn due to use of Zn fertilizer. The increase in Zn uptake for the treatment with Zn + B, which was also comparable to the Zn treatment, signify Zn uptake is not hindered by the presence of B. The lowest uptake was found in the treatment to which Cu was combined with Zn. This suggests that there may be antagonistic interaction between Cu and Zn as discussed in section 4.2.1. Kauser *et al.* (1976)

working with other cereal crops also reported reductions of Cu uptake when Zn was applied. The high and significant Zn uptake for both treatments with 160 mg P kg^{-1} and 320 mg P kg^{-1} could be caused by the large increase in dry matter yield.

4.2.4 Concentration and uptake of B in maize shoots

The concentrations and uptake of B in maize shoots are shown in Table 5. Boron concentrations ranged from 12.7 – 25.1 mg kg^{-1}. Phosphorus and nitrogen were found to increase B uptake significantly (p=0.05) over the absolute control treatment. Application of Zn and Cu did not increase B uptake over the micronutrient control while B application increased B uptake significantly over the absolute control. Application of B in combination with Zn, and B in combination with Cu did not differ significantly in their dry matter yields. However, these two treatments were significantly different from the micronutrient control. The high and significant B uptake over all treatments was observed in the treatment with 320 mg P kg^{-1}, although this treatment did not differ significantly from the treatment that received 160 mg P kg^{-1}.

Maize shoot concentration values were above the B critical range of 8 – 10 mg B kg^{-1} as reported by Melsted *et al.* (1969) and Lockman (1972). Therefore, Mpangala soil has adequate B content. The increase in B uptake as a result of N and P application bears the same reason that N and P are low in this soil as discussed in section 4.2.2. Both Cu and Zn did not change B uptake probably due to lack of interaction between these nutrients with B. The significant increase in B uptake for the B treatment reflects an increase in available B in the soil solution. Uptake of B was found to be significantly higher for the treatment that received 320 mg P kg^{-1}, than the other treatments, indicating that the high rate of P increased the uptake of B.

4.2.5 Concentration and uptake of N and P in maize shoots

Concentrations and uptake of N and P in maize shoots are shown in Table 6. Nitrogen concentration values ranged from 0.79 – 1.60 %, while P concentration in maize shoots ranged from 0.12 – 0.16%. Significant (p=0.05) N uptake was found only in the treatment which received 320 mg P kg^{-1}, indicating that doubling the P rate improved N utilization. There was no significant difference in N uptake in the rest of the treatments which received N, because they received a constant rate of 240 mg N kg^{-1}. The P uptake increased significantly in the treatment which received 320 mg P kg^{-1}, which had also high dry matter yields. There was no significant difference between the rest of treatments which received P, because they received a constant rate of 160 mg P kg^{-1}.

Okalebo *et al.* (1993) reported that nitrogen concentrations between 3.5 – 5% were considered adequate for maize at 30 – 45 days of growth. The N concentration values in maize plants in the present study indicated that the soil was deficient in N. Szilas (2002) reported that N application to Mpangala soil increased N uptake substantially although none of the levels reached the sufficiency level despite a relatively high level of 120 kg N ha^{-1}, indicating that the efficiency of N was low either due to leaching or other nutrient constraints, which then limited N uptake. The P concentration values obtained are below the sufficiency range of 0.25 – 0.4% as reported by Jones and Eck (1973). The low P concentration in maize shoots reflects the low P in soil solution due to the high P adsorption capacity of Mpangala soil (Szilas, 2002).

Table 6. Concentrations and uptake of N and P in maize plants as influenced by different levels of B, Cu and Zn in the soil in the pot experiment

Treatment	N (%)	N uptake (mg pot^{-1})	P (%)	P uptake (mg pot^{-1})
$P_0 N_0 B_0 Cu_0 Zn_0$	0.79d	6.3d	0.12b	1.0e
$P_{160} N_{240} B_0 Cu_0 Zn_0$	1.56ab	77.6bc	0.14ab	7.1bcd
$P_{160} N_{240} B_0 Cu_0 Zn_{10}$	1.52abc	81.1bc	0.15ab	8.0bcd
$P_{160} N_{240} B_2 Cu_0 Zn_0$	1.53abc	79.2bc	0.12b	6.3d
$P_{160} N_{240} B_0 Cu_5 Zn_0$	1.42c	82.0bc	0.14ab	8.3bc
$P_{160} N_{240} B_2 Cu_0 Zn_{10}$	1.60a	82.3bc	0.15ab	7.3bcd
$P_{160} N_{240} B_0 Cu_5 Zn_{10}$	1.45bc	73.9c	0.14ab	6.8cd
$P_{160} N_{240} B_2 Cu_5 Zn_0$	1.56abc	79.7bc	0.13ab	6.7cd
$P_{160} N_{240} B_2 Cu_5 Zn_{10}$	1.52bc	87.9b	0.15a	8.7b
$P_{320} N_{240} B_2 Cu_5 Zn_{10}$	1.45bc	99.5a	0.16a	10.7a
CV%	4.91	7.6	10.67	13.5

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

4.3 Estimation of optimum copper level for maize production in Mpangala soil

4.3.1 Response of maize dry matter yield to different levels of copper

Dry matter yield values for maize as a result of different Cu levels are presented in Table 7. The dry matter yield ranged from 6.7 – 48.4 g pot^{-1}. Dry matter yields did not differ significantly (p=0.05) between the level of 5 mg Cu kg^{-1} and 15 mg Cu kg^{-1}. The highest dry matter yield was obtained from the treatment that received 20 mg Cu kg^{-1}. Dry matter yield results depict that, when N fertilizer was applied alone, the increase yield was slight, whereas when P was applied alone, the increase in yield was greater than with N alone.

The greater increase in dry matter yield in the P treatment over the N treatment indicated that P was the most limiting macronutrient. A significant increase in dry matter yields with 5 mg Cu kg^{-1} over the P treatment indicated that Cu was also a limiting nutrient in Mpangala soil. The rates of 5 – 15 mg Cu kg^{-1} did not change dry matter yields significantly. The highest and significant dry matter yield observed in the treatment, which received 20 mg Cu kg^{-1} suggests that, this treatment improved Cu supply further leading to high Cu uptake.

Table 7. Dry matter yields, copper concentrations and uptake, and DTPA Cu concentrations in soil as a result of varying copper levels

Treatment	DM yield (g pot^{-1})	Plant Cu (mg kg^{-1})	Plant Cu uptake (µg pot^{-1})	DTPA extractable Cu in soil (mg kg^{-1})
P_0N_{240} Cu_0	6.7d	2.9c	19.2c	0.12d
$P_{320}N_0$ Cu_0	13.6c	3.3c	44.5c	0.18d
$P_{320}N_{240}Cu_5$	38.9b	5.2b	204.7b	1.24c
$P_{320}N_{240}$ $Cu_{7.5}$	36.7b	7.3a	268.2b	1.65c
$P_{320}N_{240}$ Cu_{10}	39.4b	7.5a	294.9b	3.79b
$P_{320}N_{240}$ Cu_{15}	40.0b	7.5a	303.1b	3.92b
P_{320} N_{240} Cu_{20}	48.4a	9.2a	448.0a	4.85a
CV%	10.8	17.4	25.3	18.5

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

4.3.2 Concentration and uptake of Cu in maize shoots

The concentrations and uptake of Cu in maize shoots are shown in Table 7. Concentration values obtained ranged from 2.9 – 9.2 mg kg^{-1}. When application rates of Cu increased, Cu concentrations in maize shoots increased. However, there was no significant ($p=0.05$) increase between the rates of 7.5 – 20 mg kg^{-1} indicating that the sufficient Cu level was within the given range. The result also showed that there is a relationship between copper uptake by maize plant and the increase in soil extractable copper.

Most of the concentration values were above the critical range of 7 mg kg^{-1} which is the lower value of the sufficiency range for maize at 30 – 45 days of age as reported by Jones and Eck (1973). These results indicate that rates between 7.5 – 20 mg kg^{-1} (15 – 40 kg ha^{-1}) are required to supply sufficient levels of Cu. However, the rate of 20 mg kg^{-1}, is required for Mpangala soil for optimization of maize yields because it gave the highest and significant dry matter yield. This rate of Cu is relatively high, suggesting that this soil has high Cu fixation. The concentration of plant Cu was also probably affected by high rate of P used. Spencer (1966) found that a high rate of 350 mg P kg^{-1} decreased the Cu content of leaves and roots at all Cu levels applied from 0 to 250 mg kg^{-1}. Spenser also found that very high rates of Cu were not very effective in increasing Cu content of leaves. The increase in copper uptake due to increase of the soil copper levels could probably be attributed to the increase in copper concentration in soil solution. Copper uptake was high for the treatment that received 20 mg kg^{-1}, and it was in this treatment that the highest dry matter yield was obtained.

4.3.3 Concentration and uptake of B and Zn in maize shoots

The concentrations and uptake of B and Zn in maize shoots are shown in Table 8. The B concentrations ranged from 5.6 – 12.1 mg B kg^{-1}. The results further show that copper levels of 5 – 10 mg kg^{-1} did not increase the B concentrations significantly. However, levels of 15 – 20 mg Cu kg^{-1} significantly increased B concentration in maize shoots. Zinc concentrations ranged from 6.8 – 15.7 mg Zn kg^{-1}.

Most of the B concentration values were within the critical range of 8 – 10 mg B kg^{-1} reported by Melsted *et al.* (1969) and Lockman (1972). This implies that B in Mpangala soil is not limiting crop yields at present. The soil analysis data (Table 3) also confirmed the level of B to be medium. The lowest B uptake was observed in N and P treatments, and this shows that either N or P had no significant effect on B uptake unless they were applied in combination. The uptake of B within the levels of 5 – 15 mg Cu kg^{-1} did not change significantly. Significantly higher ($p=0.05$) B uptake was found in the treatment which received 15 mg Cu kg^{-1}. The highest and significant uptake of B over the all the treatments was found in the treatment which received 20 mg Cu kg^{-1}. These trends suggest that sufficient levels of Cu had a positive effect on B uptake.

Table 8. Boron and zinc concentrations, uptake and DTPA soil extractable zinc values as a result of varying copper levels

Treatment	B (mg kg^{-1})	B uptake (µg pot^{-1})	Zn (mg kg^{-1})	Zn uptake (µg pot^{-1})	DTPA Zn (mg kg^{-1})
P_0N_{240} Cu_0	12.2a	80.9d	15.7a	103.4c	0.58bc
$P_{320}N_0$ Cu_0	9.3abc	125.7d	6.8c	91.6c	0.93a
$P_{320}N_{240}Cu_5$	7.4bc	283.1bc	9.1b	354.1ab	0.56c
$P_{320}N_{240}$ $Cu_{7.5}$	6.2bc	225.0cd	9.4b	344.5ab	0.56c
$P_{320}N_{240}$ Cu_{10}	5.6c	221.9cd	8.7bc	344.1ab	0.58bc
$P_{320}N_{240}$ Cu_{15}	9.6ab	382.5b	8.1bc	322.5b	0.65b
P_{320} N_{240} Cu_{20}	11.6a	564.6a	8.6bc	414.9a	0.59bc
CV%	21.7	29.0	11.5	13.6	6.45

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

Zinc concentrations obtained were below the critical range of 25 - 60 mg Zn kg^{-1} reported by Tisdale *et al.* (1993). The results suggest that Zn is also deficient in Mpangala soil despite its non-significant effect in dry matter yield as observed in the first pot experiment. The results also depict that the decrease in Zn concentration appear to be caused by P rather than Cu. The uptake data indicate the depression to be due to a dilution effect rather than an unfavourable interaction between the two nutrients. Msolla (1994) found that Cu depressed Zn concentration in the tops of rice plants. This effect appears to result from the depressing effect of Cu on Zn translocation. The same may be true for maize crop. Kauser *et al.* (1976) also observed antagonistic effects of Cu on Zn in other cereal crops.

The lowest Zn uptake was observed in N and P treatments, signifying that either N or P did not increase uptake of Zn. The uptake of Zn within the treatments which received Cu levels from 5 – 15 mg kg^{-1} did not change significantly but Zn uptake in these treatments was significantly different from that in the N and P treatments. The treatment which received 20 mg kg^{-1} gave slightly higher Zn uptake.

4.3.4 Concentration and uptake of N and P in maize shoots

The concentrations and uptake of N and P in maize plants are shown in Table 9. The N concentration values ranged from 0.80 – 2.71%. When copper levels increased beyond 5 mg kg^{-1}, N uptake decreased slightly. Phosphorus concentrations ranged from 0.11 – 0.24%. The P uptake for the P treatment increased significantly ($p=0.05$) over the N treatment. This implies that as the P level was increased from 160 mg P

kg^{-1} to 320 mg P kg^{-1}, N needed to be increased so as to reach the N sufficiency range as given above. Martini and Luzuriaga (1989) reported that organic matter in volcanic soils decomposes slowly leading to slow N mineralization. Thus adding N fertilizer is necessary for optimum agricultural production.

The P concentration values obtained were approaching the critical range of 0.25 – 0.4% as reported by Jones and Eck (1973). The concentration values for P in the plants were not significantly different between the lowest and highest Cu levels because P was applied at a constant rate. Szilas (2002) reported that lack of significant P response in Mpangala soil could either be explained by sufficiently high levels of plant available soil P, or other soil fertility constraints. Szilas (2002) also suggested that the lack of significant P response could be due to the high soil P fixation capacity. He observed the maximum P adsorption capacity for Mpangala soil to be 1017 mg P kg^{-1}. The increase in P uptake for the 5 mg Cu kg^{-1} treatment over the P alone treatment suggest that the presence of N influenced P uptake. Significant P uptake was found in the treatment with the highest copper supply and it was in this treatment that the highest DM yield was obtained.

Table 9. Nitrogen and phosphorus concentrations and uptake in maize shoots as affected by N, P and Cu

Treatment	N (%)	N uptake (mg pot^{-1})	P (%)	P uptake (mg pot^{-1})
$P_0 N_{240} Cu_0$	2.71a	18.1c	0.11b	0.7b
$P_{320} N_0 Cu_0$	0.80d	10.7c	0.16ab	2.3c
$P_{320} N_{240} Cu_5$	2.37ab	91.0a	0.22a	8.7b
$P_{320} N_{240} Cu_{7.5}$	2.18b	78.8b	0.24a	7.8b
$P_{320} N_{240} Cu_{10}$	2.09bc	82.4ab	0.22a	8.7b
$P_{320} N_{240} Cu_{15}$	2.15b	85.5ab	0.21a	8.2b
$P_{320} N_{240} Cu_{20}$	1.69c	81.8ab	0.20a	9.8a
CV%	12.55	7.6	7.51	8.2

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

4.4 Field experiment

4.4.1 Maize grain yields

Data for maize grain yields are presented in Table 10. Maize grain yields ranged between 1.76 and 5.84 t ha^{-1}. Grain yield for the Cu treatment of 5.84 t ha^{-1} was significantly higher ($P < 0.05$) than the absolute control and the rest of the treatments. The lowest grain yield was obtained in the absolute control treatment. The P + N treatment increased grain yield significantly over the absolute control. Grain yield for the Zn treatment, B + Zn treatment, Cu + Zn treatment and B treatment did not change significantly over the micronutrient control. The highest and significant grain yield over all treatments was obtained in the Cu alone treatment. Boron + Cu treatment and the treatment with 160 kg P ha^{-1} produced high grain yields next to the Cu treatment. The treatment with 80 kg P ha^{-1} with all micronutrients did not differ significantly in yield over the Zn treatment.

The significantly higher grain yield increases for the micronutrient control over the absolute control imply that Mpangala soil had low levels of N and P. When Zn was applied alone, grain yield increased slightly over the micronutrient control. When Zn was applied together with Cu, grain yield was not improved above the treatment control, in addition, there was no significant difference in grain yield when Zn was applied in combination with either B or Cu. However, when B and Cu were applied in combination there was a significant increase in yield above the micronutrient control but the yield was slightly lower than that from Cu alone treatment. These data suggest that there was antagonistic interaction between Zn and Cu. Kauser *et al.*

(1976) working with cereal crops observed antagonistic interactions between Cu and Zn. When B was applied alone, the grain yield did not change significantly as compared to the treatments in which B was applied together with Zn and the treatment in which Cu was applied with Zn.

The results obtained from this study suggest that maize grain yields were mostly influenced by Cu, followed by P. The grain yield results obtained are in agreement with those obtained in the pot experiments (sections 4.2 and 4.3). According to United Republic of Tanzania (1995), the production level for maize, which is a major food crop, is very low. Currently the average potential yields are between 4.0 and 8.0 t ha^{-1}. The maize grain yield level of 5.84 t ha^{-1} obtained from the Cu treatment and the yield of 5.35 t ha^{-1} for both B with Cu treatment and the treatment with 160 kg ha^{-1} were within the current maize average yield for Tanzania. Higher maize yields beyond the 5.84 t ha^{-1} may be obtained at Mpangala if the Cu supply and other agronomic conditions are optimized. Copper level of at least 10 kg ha^{-1} are suggested. on the basis of the second pot experiment as the level which can optimize maize yields under the currently adopted nutrient application rates.

Table 10. Effects of added B, Cu and Zn on maize grain yields

Treatment	Grain yields (t ha^{-1})
P_0 N_0 B_0 Cu_0 Zn_0 (Absolute control)	1.76d
P_{80} N_{120} B_0 Cu_0 Zn_0 (Micronutrient control)	4.06c
P_{80} N_{120} B_0 Cu_0 Zn_5	4.47bc
P_{80} N_{120} B_1 Cu_0 Zn_0	4.33c
P_{80} N_{120} B_0 $Cu_{2.5}$ Zn_0	5.84a
P_{80} N_{120} B_1 Cu_0 Zn_5	4.40c
P_{80} N_{120} B_0 $Cu_{2.5}$ Zn_5	4.17c
P_{80} N_{120} B_1 $Cu_{2.5}$ Zn_0	5.35ab
P_{80} N_{120} B_1 $Cu_{2.5}$ Zn_5	4.87bc
P_{160} N_{120} B_2 $Cu_{2.5}$ Zn_5	5.35ab
CV%	12.84

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

4.4.2 Nutrient concentrations in maize leaves

4.4.2.1 Concentrations of boron

The concentrations of B in maize leaves are given in Table 11. The concentrations of B ranged from 5.6 – 8.7 mg kg^{-1}. There was no significant difference in plant B concentrations in all treatments. These values were within the sufficient range of 5 – 25 given by Tisdale *et al.* (1993). Therefore B is not a deficient micronutrient in Mpangala soil. These results are similar with those obtained in the pot experiments as discussed in sections 4.2.4 and 4.3.3.

4.4.2.2 Concentrations of copper

The concentrations of Cu in maize leaves are given in Table 11. The concentrations of Cu ranged from 0.45 – 1. 44 mg kg^{-1}. The absolute control, micronutrient control, Zn treatment, B treatment and Cu + Zn treatment did not differ significantly in Cu concentrations. The Cu treatment, B + Cu treatment and B + Zn treatment had significantly ($p=0.05$) higher Cu concentrations than the absolute control. Values for these treatments were around 1.0 mg kg^{-1}.

Table 11. Concentrations of P, N, B, Cu and Zn in the maize plants from the field experiment

Treatment	N (%)	P (%)	B(mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})
$P_0 N_0 B_0 Cu_0 Zn_0$	1.37c	0.10b	8.7a	0.45d	4.25a
$P_{80} N_{120} B_0 Cu_0 Zn_0$	2.19ab	0.13ab	6.9a	0.52cd	4.65a
$P_{80} N_{120} B_0 Cu_0 Zn_5$	2.08ab	0.12ab	6.5a	0.77cd	5.33a
$P_{80} N_{120} B_1 Cu_0 Zn_0$	2.25a	0.11ab	7.1a	0.74cd	5.19a
$P_{80} N_{120} B_0 Cu_{2.5} Zn_0$	1.93b	0.12ab	6.7a	1.01abc	4.72a
$P_{80} N_{120} B_1 Cu_0 Zn_5$	2.09ab	0.13ab	7.8a	1.06abc	4.82a
$P_{80} N_{120} B_0 Cu_{2.5} Zn_5$	2.15ab	0.10b	5.9a	0.89bcd	4.74a
$P_{80} N_{120} B_1 Cu_{2.5} Zn_0$	2.13ab	0.12ab	6.7a	1.41ab	5.30a
$P_{80} N_{120} B_1 Cu_{2.5} Zn_5$	2.07ab	0.13ab	6.4a	1.43a	5.12a
$P_{160} N_{120} B_1 Cu_{2.5} Zn_5$	2.12ab	0.15a	5.6a	1.44a	5.53a
CV %	8.0	20.9	27.3	34.5	17.6

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

Maize plants treated with Cu showed concentrations of Cu lower than critical values while the grain yield was significantly high, probably this indicates that the copper requirement for grain formation is higher than that for the maize shoot growth. This trend of high grain yield in Cu treatment was similar to that obtained for maize dry matter yield during the first pot experiment. The Cu concentrations in plants from treatments with 80 and 160 kg P ha^{-1} were significantly higher than all treatments that received no Cu, with Cu values of around 1.4 mg kg^{-1}. These treatments responded to Cu, and had maize yield of 4.89 – 5.35 t ha^{-1} suggesting that Cu in itself was severely limiting.

The plant Cu concentration values were very low when compared to the critical concentration value of 5 mg kg^{-1} given by Jones and Eck (1973). Despite the very low concentration values of Cu in maize leaves, grain yield was obtained. For example in the absolute control treatment which had plant concentration of 0.45 mg Cu kg^{-1}, 1.76 t ha^{-1} of grain yield was obtained. Makarim and Cox (1983) also observed low levels of Cu in maize plants. They found the critical Cu concentration in whole corn plants to be 1.8 mg kg^{-1}, but even plants with 1.5 mg kg^{-1} did not show Cu deficiency symptoms. However, in general the results indicated that the Cu level applied was low and that higher rates are required.

4.4.2.3 Concentrations of zinc

The concentrations of Zn in maize leaves are given in Table 11. The concentrations ranged from 4.25 – 5.53 mg kg^{-1}. There was no statistical difference in Zn concentration in maize leaves among the treatments. The concentration values obtained were below the adequate range of 10 – 100 mg kg^{-1} of most field crops and pastures as established by Chapman (1973). Although the Zn concentration values were below the critical range, maize plants survived to maturity and did not show Zn deficiency symptoms. This could probably be due to the plant genetic factor of the maize variety used which enabled the plants to withstand Zn deficiency, in addition to the fact that the Zn levels in Mpangala soil were presently only marginal and not clear cut deficient (Table 3). Sofaya and Gupta (1979) obtained similar results in their study on differential susceptibility of corn cultivars to Zn deficient soils. They observed that Zn concentrations in one of the least Zn susceptible corn cultivars (Amber) had as low as 6.3 mg kg^{-1} in its leaves. Other factors that could also be associated with low Zn concentration in maize leaves include soil Zn adsorption. The level of applied Zn in the soil could have been adsorbed by Mn (McBride, 1981) and hence made unavailable to plants. Therefore, these results suggest that Zn supply in Mpangala soil was marginal and for sustainable crop production Zn application is required.

4.4.2.4 Concentration of nitrogen and phosphorus

Concentrations of N and P in maize leaves are given in Table 11. The N concentration values ranged from 1.37 – 2.25%, while the P concentrations ranged from 0.10 – 0.15%. The N concentration in the leaves was lowest in the absolute control. However, the N in the plants increased significantly ($p=0.05$) when N and P were applied together. The Cu treatment had slightly lower N concentration than the treatment control probably due to a dilution effect since the former treatment produced the highest yields. There were no significant differences in the rest of the treatments. The results also suggest that higher rates of N are still required in Mpangala soil.

The N concentration values obtained were below the critical range of 3 – 4 % given by Tisdale *et al.* (1993), and the P concentration values obtained were also below the critical range of 0.25 – 0.4% as reported by Jones and Eck (1973). The only high and significant P concentration in plant leaves was found in 160 kg P ha^{-1}, but the concentration was also below the critical range. The results indicate that P is a limiting macronutrient at Mpangala, and the rates applied were not yet adequate. This indicates the need for higher P rates.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

On the basis of the present findings, the following conclusions can be drawn:

1. Boron content in Mpangala soil was medium, and was sufficient for normal plant growth. Copper was found to be deficient in the soil, and plant data also confirmed copper deficiency. Zinc appeared to be marginal, and Zn concentrations in the maize plants were below the critical concentration range.

2. The study clearly demonstrated that Mpangala volcanic soil has severe copper deficiency probably due to the strong copper fixation capacity, and therefore the low maize yield from Mpangala soil was partly attributed to the copper deficiency. Thus application of copper fertilizer improved maize yields appreciably. The study also observed that the rates of 120 Kg N ha^{-1} and 80 kg P ha^{-1} were on the lower side and did not maximize maize crop growth and yields.

3. A pot experiment estimated the rate of 20 mg Cu kg^{-1} to be optimum in Mpangala soil. This rate was found to correct copper deficiency; however, yield may still be limited by the other nutrients such as zinc, which appears to be marginal. Such deficiency may not show up severely until after one or more additional harvesting cycles.

5.2 Recommendations

Taking into consideration the findings in this study, the following are recommended:

1. The rate of 160 kg P ha^{-1} is recommended for the immediate objective of increasing yields. However, higher rates of P are still required in Mpangala soil. Also, further research should also be conducted to evaluate higher N rates than the current rate of 120 kg ha^{-1} so as to balance the N and P nutrient levels in the soil after optimization of Cu and Zn.

2. Further research on the chemistry and adsorption of Cu, Zn, and B in Mpangala volcanic soil should be carried out to identify the adsorption or retention characteristics of this soil, because management of nutrients seems to be very challenging under these circumstances.

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