ASSESSMENT OF ZINC STATUS IN SOILS AND TEA RESPONSE TO ADDED ZINC IN SELECTED ESTATES IN MUFINDI DISTRICT, TANZANIA

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ABSTRACT

A study was conducted in Mufindi district to determine the status of zinc and the response of tea to zinc application. Soil zinc status was assessed by using a sequential extraction procedure and DTPA extractant. Leaf zinc status was assessed by using a wet oxidation procedure. Five levels of zinc: 0, 2.5, 5.0, 7.5 and 10 kg Zn/ha as zinc oxide (80% zinc) applied both on the foliage and on soil were used to test the effect of zinc application on tea yield.

The zinc fractionation study indicated that of the total soil zinc, 4.2% was exchangeable, 1.1% was associated with carbonates, 18.1% with organic matter, 23.5% with oxides and 49.9% with the residual fraction. Thus the largest proportion of zinc was associated with the residual fraction. The DTPA extractable zinc ranged from 0.70-3.46 and from 0.70-5.20 mg/kg in the cultivated and virgin soils, respectively. Leaf zinc concentration ranged from 11.76-32.64 mg/kg. This range indicated that some estates were deficient in zinc. Foliar application of zinc at a rate of 2.5 kg Zn/ha significantly ($P<0.05$) increased tea yields by upto 32%. Soil application of zinc decreased yields slightly. The decrease was probably due to unfavourable interaction between zinc and other cations, especially magnesium.

The critical zinc deficiency level was estimated to be 1.7 mg DTPA zinc/kg. Soils with DTPA zinc of less than 1.7 mg/kg are likely to respond to zinc application. More than half (55%) of the estates covered in this study are deficient in zinc. Foliar application of zinc oxide at a rate of 2.5 kg Zn/ha is recommended to correct zinc deficiency.

DECLARATION

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

Signature..........

Michael S.C. Mhosole

Date....5/9/95.

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DEDICATION

Dedicated to my beloved parents-the late Silyamgoda Chambasingo Mhosole and Ester Kilekamakambi Mtasiwa; the late Dominicus Lunyungu and Barnaba Benson Haule; my sisters and brothers who kindly contributed to my education.

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CHAPTER ONE

INTRODUCTION

Tea (*Camellia sinensis* L.) is a beverage cash crop, the economic yield being the tender succulent shoot of two leaves and a bud. In Tanzania the history of tea dates back to 1904 when it was first grown by German settlers at Amani in east Usambara mountains and Kyimbila Mission in Rungwe district. From there it spread to other parts of the country. Todate tea is an important cash crop in Lushoto, Bukoba, Rungwe, Njombe and Mufindi districts (Ndamugoba, 1990).

In terms of importance tea ranks third after coffee and cotton. It contributes 6% of the foreign exchange earnings by cash crops and 4% of the country's foreign exchange earnings (Ministry of Agriculture, 1992). Mufindi district is a major tea producer in Tanzania. Of the 20 million kg of made tea produced in the country in 1990, 9 million kg (45%) were produced in Mufindi district. The total area under tea in the district was 3152 hectares. More than ten thousand people are employed in tea production in the district thus relieving the problem of unemployment in the district.

The best soils for tea growth are those which are deep, acidic and high in water holding capacity. It can however thrive in a wide range of soils provided the soil reaction is acidic. The optimum pH range for tea growth is 5.0-5.6 (Othieno, 1992). The removal of nutrients from the soil by a tea crop is very high due to young shoots harvested being highly concentrated in nutrients. In order to maintain high yields therefore, high rates of inorganic fertilizers are used. Rates in the range of 250-300 kg N/ha/year (1000-1200 kg/ha of NPK 25:5:5) are used by large scale estates owned by Brooke Bond (T) Limited and Mufindi Tea Company. Currently, yields in these estates are in the range of 2500-3000 kg of made tea/ha/year (Carr and Stephen, 1992). Application of such high rates of nitrogen, phosphorus and potassium year after year results in mining of large quantities of other nutrients including zinc. High levels of nitrogen and phosphorus have been observed to induce zinc deficiency (Tisdale *et al.*, 1990). Since zinc is not included in the fertilizer formulation, its content in the soil may have decreased to deficiency levels.

Information on zinc nutrition of tea in Tanzania and Mufindi, in particular, is very scanty because no detailed research has been carried out before. The situation is, however, different in the neighbouring Kenya and Malawi where extensive research on the nutrient has been carried out and zinc application on tea is a routine practice. Zinc experiments conducted in Kenya have indicated yield responses by upto 30% (Tea Research Institute of East Africa (TRIEA), 1973) as a result of foliar sprays of zinc oxide, applied twice per year each at a rate of 3 kg Zn/ha. In Malawi three applications per year each at 1.25 kg ZnO/ha on the tea foliage are recommended to correct zinc deficiency (Tea Research Foundation of Central Africa (TRFCA), 1994).

Studying the effect of fertilizer application on the leaf nutrient content of clone 6/8 at Ngwazi Tea Research Unit, Mufindi, Burgess (1992) observed zinc concentration in the mature leaf to range between 8-9.5 mg/kg. This value falls below the critical level of 10 mg Zn/kg reported by Wanyoko and Njuguna (1983). Zinc deficiency may therefore be a major yield limiting factor in Mufindi tea growing area, hence the need to assess the magnitude and extent of the problem. The study was therefore conducted with the following objectives:

(i) To determine the status and distribution of zinc in the tea growing soils of Mufindi.

(ii) To investigate the effect of zinc application on tea yield in Mufindi.

CHAPTER TWO

LITERATURE REVIEW

2.1 Total content of zinc in soils

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

The total zinc 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 (Krauskopf, 1972). Thus Aubert and Pinta (1977) reported that total zinc content in basic eruptive rocks (basalt and gabbro) ranged from 70-130 mg/kg, acid eruptive rocks (granite and rhyolite) contained 50-60 mg/kg, while metamorphic rocks (schist) and certain sedimentary rocks (clays) had about 30 mg/kg. In loessic loams and glacial clays, it varied from 30-40 mg/kg and in carbonated rocks and sandstones, it was 20 and 16 mg/kg, respectively. Pendias (1984) reported that zinc was uniformly distributed in magmatic rocks; being high in mafic rocks (80-120 mg/kg) and low in acid rocks (40-60 mg/kg).

Total zinc content, however, does not always reflect the availability of the same to plants. Determining total and available zinc in soils from different climatic zones, Singh and Abrol (1986) found that in a tropical agroclimatic zone, total zinc was 62 mg/kg while available zinc was 0.35 mg/kg. In the tropical semi-arid climatic zones, total zinc was 253 mg/kg while available zinc was 0.53 mg/kg. Thus factors more than total zinc, control zinc availability in soils. These factors are discussed in the following section.

2.2 Factors affecting zinc availability in soils

Many factors affect zinc availability in soils such as soil pH, phosphate, nitrogen, soil type, climate, organic matter, zinc content, clay fraction and antagonistic effects.

2.2.1 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 explained to be due to the speciation changes in the solubility of Zn^{2+} with changes in pH. Lindsay and Norvell (1978) presented the theoretical relationship of soil zinc and pH as follows:

Soil-Zn + $2H^{+}$ = Zn^{2+} $\log K^0 = 5.8$, where K^0 is the

equilibrium constant. The equation can also be expressed as: $\log Zn^{2+} = 5.8 - 2pH$.
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). Jeffery and Uren (1983) found Zn^{2+} concentration to be highly pH-dependent; as the pH of the soil solution increased from 4.4-7.5, the total Zn^{2+} concentration in soil solution decreased by about 100 fold (from 1.8 to 1.2×10^{-2} mg/kg).

Generally most pH-induced zinc deficiencies to most crops occur within the pH range of 6.0-8.0 (Singh and Abrol, 1986; Soper *et al.*, 1989).

2.2.2 High phosphate levels in the soil

Large applications of phosphorus fertilizers in the soils low in available zinc decrease zinc uptake (Barrow, 1987; Pasricha *et al.*, 1987; Xie and Mackenzie, 1988; Tisdale *et al.*, 1990). The P effect on zinc uptake varies with soils and crops, zinc and P levels and other factors. In soils rich in hydrous oxides and phosphorus, zinc availability is low due to being retained by phosphated hydrous oxides (Stanton and Burger, 1967; Bolland *et al.*, 1977). Loneragan *et al.* (1979) advanced three factors which account for the P-induced zinc deficiency in plants: (a) dilution of zinc in plants by the increase in growth induced by phosphorus fertilizers (b) inhibition of zinc uptake by cations (Ca^{2+} in particular) added with phosphorus fertilizers and (c) phosphorus enhanced zinc adsorption in the soil to hydroxides and oxides of iron and aluminium and to $CaCO_3$. They further reported that high content of sesquioxides in acid soils is one of the major reasons for P-induced zinc deficiency on plants growing in such soils due to P enhanced zinc adsorption by sesquioxides.

2.2.3 Effect of nitrogen

The effect of nitrogen on zinc 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 $(NH_4)_2SO_4$, have the greatest effect on zinc 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 the N carriers exerted the greatest effect on zinc uptake. Ammonium sulphate, which decreased soil pH, increased zinc availability. Another effect of nitrogenous fertilizers is the increase in plant growth rate with subsequent dilution of zinc in the plant. Under marginal supply of zinc therefore, increased supply of nitrogen induces zinc deficiency. In subterranean clover, increased supply of nitrogen increased the severity of zinc deficiency (Ozzane, 1955). This is attributed to zinc being retained in the roots as zinc protein complex. The retention of zinc in the roots led to severe zinc deficiency in the tops.

2.2.4 Soil type

The available zinc in soils varies with soil type. Quite often, sandy soils are low in available zinc and hence deficient. This is because quartz minerals from which sandy soils are derived, are low in total zinc content (Lindsay, 1972; Katyal *et al*., 1982). Similarly, in peats and mucks (Histosols) available zinc is low. These soils contain organic matter of greater than 18% depending on clay content. The availability of zinc in these soils is low due to low content of zinc in the surface organic layer and the inaccessibility to most plant roots of the mineral form of zinc in the subsoil (Lucas and Knezek, 1972). The humic fraction of the organic matter has high capacity of binding zinc and thus decreasing its availability (Stevenson and Ardakani, 1972). In high rainfall areas where acidic conditions prevail, zinc released by weathering is lost from the root zone by leaching at a relatively fast rate thus decreasing the amount of zinc available to plants (Sharma and Motiramani, 1969). Acidic soils which are generally high in Fe^{3+} due to high weathering, have high Zn^{2+} sorption due to Zn^{2+} diffusing into the goethite lattice with subsequent fixation through isomorphous substitution of lattice Fe^{3+} by Zn^{2+} (Ankomah, 1992).

2.2.5 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 soils. Experiments in rice conducted in temperate climate showed a decrease in zinc response with increase in soil temperature (Sharma and Motiramani, 1969). This may be due to the native soil zinc being more available to the rice plants as soil temperatures increased. Similarly, P-induced zinc deficiency due to high P fertilization has been observed in cool weather but not in hot weather (Martin *et al.*, 1965). In India Randhawa and Nayyar (1982) found zinc deficiencies to be more severe in cold weather and absent in hot weather. Thus cool weather tends to limit, while hot weather enhances zinc uptake. Soil moisture effects on zinc availability are related to the soil pH and carbonic acid. Excessive soil moisture, such as in flooded or waterlogged soil conditions, increases the pH of the soil to around neutral level which is not an optimum pH for zinc availability. Similarly, high concentration of CO_2 resulting from anaerobic condition in the soil leads to production of carbonic acid which, in reacting with Zn^{2+}, forms $ZnCO_3$ which is less soluble (Forno *et al.*,1975).

2.2.6 Organic matter

Organic matter has a big influence on the availability of zinc in soils. Organic matter reacts with zinc to form organic matter-zinc complexes of different strengths depending on the type of organic matter fraction involved in the reaction. Generally, zinc associated with the soluble fraction of the organic matter, such as the organic and amino acids, is readily available whereas that associated with the humic acids is less available (Stevenson and Ardakani, 1972). Several studies have indicated the relationship between soil organic matter and diethylenetriaminepentaacetic acid (DPTA) available zinc to be positively correlated. For instance, Follet and Lindsay (1970) reported a high and positive (r=0.76) correlation between organic matter and DTPA extractable zinc in some Colorado soils. Similarly, a high and positive correlation (r=0.893) between organic matter and DTPA extractable zinc has been observed in some basement complex soils of the tropical, dry rainforest of southwestern Nigeria (Fagbami *et al.*, 1985).

2.2.7 Clay fraction

Clay fraction plays a vital role in the availability of zinc since it provides negatively charged sites where zinc can be adsorbed and prevented from leaching. Different types of clay minerals have different zinc adsorption capacities. Assessing zinc fixation capacities of different clay minerals separated from tropical soils, Rahmatullah *et al.* (1985) found that about 57% of the applied zinc was unextractable by 0.005M DTPA and hence considered as fixed. Of the clays studied, biedellite fixed 70%, vermiculite 59%, montmorillonite 55% and hydrous mica impregnated with kaolinite and vermiculite 40%, of the added zinc. Thus the type of clay in a given soil will have a great influence on the availability of native as well as the applied zinc in such a soil.

2.2.8 Antagonistic effects

Presence of other ions in high concentration in soils highly affects zinc availability. Thus 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). 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 antagonism has been observed to occur during both absorption and translocation processes. Giordano *et al.* (1974) observed the order of interference on zinc absorption to be Fe=Cu>>Mg>Mn>Ca and on zinc translocation to be Fe=Cu>>Ca>Mn. The antagonistic relationship between Fe and Zn may be attributed to the competition of Fe^{2+} and Zn^{2+} at adsorption sites of the root (Sakal *et al.*, 1984). Studying the relationship between Zn and Mg, Katyal and Ponnamperuma (1974) observed that Mg was higher in zinc deficient than in healthy plants, and soil application of Zn depressed the amount of Mg in the plants. This was explained as a result of the closeness of ionic radii of Zn^{2+} and Mg^{2+} which influence the uptake of these cations. But Mg^{2+} enhances the translocation of Zn^{2+} (Adriano *et al.*, 1971; Giordano *et al.*, 1974).

2.2.9 Differential responses of plant species and genotypes to zinc

Plant species and genotypes differ greatly in their ability to obtain zinc from soils. Varieties coming from the same species can differ markedly in their susceptibility to zinc deficiency (Lucas and Knezek, 1972). Tea has been reported (Wilson, 1992) to have low ability of utilizing soil zinc. This may imply that zinc deficiency in tea can be encountered even in soils high in total zinc. Generally, the critical level of zinc in the third leaf of a tea shoot is 30 mg Zn/kg (Bonheure and Wilson, 1992).

2.3 Functions of zinc in plants

Zinc is responsible for a number of functions both structural and regulatory. Structurally, zinc is important for the stability of cytoplasmic ribosomes (Katyal and Sharma, 1979). In regulation it plays important roles in many enzyme catalysed reactions in the plant. For instance in the transformation of carbohydrates, zinc regulates the consumption of sugars, increases the source of energy for production of chlorophyll, aids in formation of auxins and enhances the ability of plants to absorb water (Lindsay, 1972; Mengel and Kirkby, 1975; Marschner, 1986)

2.4 Diagnosing zinc deficiency

Zinc deficiency can be diagnosed through visual observations, soil and plant tests. Deficiencies of zinc in plants can lead to development of abnormalities which can be visually seen; these include decreased internode length, restricted development of new leaves, brownish appearance, small, distorted and necrotic leaves (Bell *et al.*, 1990).

Visual symptoms of zinc deficiency in tea include formation of two or more small buds from a single axil to make a "rosette", elongation of leaves and twisting to a sickle cell shape, reduced internode length and leaf size (Bonheure and Wilson, 1992).

2.4.1 Plant tissue tests

Plant analysis is a vital tool in diagnosing causes of decreased growth and yield performances of crop plants. The quantity of nutrient measured reflects the status of nutrient in the soil because the quantity found in the plant has indeed been in the soil in forms available to plants. This is the main advantage of plant tests over soil tests. The interpretation of plant analysis results is, however not easy as it needs the knowledge of the composition of a given plant species corresponding to the optimum growth and yield; but plant composition can vary widely especially in the range of luxury consumption without having measurable or visual effects on growth and yield of plants. Generally zinc content of healthy plants ranges from 20-100 mg/kg varying with plant species depending on ability of extracting zinc from the soil (Brar *et al.*, 1980). The ability of tea to make use of soil zinc is low (Bonheure and Wilson, 1992) and critical concentration of zinc is about 10 mg/kg in the mature leaf (Wanyoko and Njuguna, 1983) and 30 mg/kg in the young (third) leaf of a tea shoot (Bonheure and Wilson, 1992).

2.4.2 Soil tests

A soil test is a technique which, in combination with plant analysis, offers a better means of estimating nutrient availability in soils and fertilizer needs (Singh and Takkar, 1981). An ideal soil test is that one which can estimate as nearly as possible the critical level of an extractable nutrient above which, plants are not deficient and below which plants are deficient. The test should also be able to detect levels at which toxicity may occur (Gangwar and Chandra, 1975). However, soil testing for micronutrients is complex due to low plant requirements of these nutrients. Therefore slight contamination of a sample or modification of sampling and analytical procedures seriously affect soil test results (Lindsay and Cox, 1985).

Different extractants are in use for estimating available zinc in soils. Generally, they fall in three groups: (a) Water and neutral salts, namely; distilled water and $MgCl_2$ (Stewart and Berger, 1965), (b) Inorganic acids, such as HCl (Hibbard, 1940) and (c) Buffered chelating agents: ethylenediaminetetraacetic acid (EDTA) and DTPA (Viro, 1955; Jensen and Lamm, 1961). The best extractant for any particular soil is the one which extracts nutrients from the same pool as the plants do. The power of a given extractant and the form of zinc in the soil which is extracted by the extractant largely account for the differences in the amounts extracted by a range of extractants from a soil. Comparing the extracting power of three etractants, viz: 0.05N HCl +0.25N H_2SO_4, 0.1N HCl and EDTA-$(NH_4)_2CO_3$ for extracting available zinc, Coffman and Miller (1973) found 0.05N HCl+0.25N H_2SO_4 to extract 70% as much zinc as 0.1N HCl and about 25% more than that extracted by EDTA-$(NH_4)_2CO_3$. This may imply that 0.05N HCl+0.25N H_2SO_4 and 0.1N HCl extracted zinc from the same pool.

DTPA was chosen in this study because in several studies conducted in Tanzania, such as Mbeya district by Kamasho and Singh, (1982) and in Tabora region by Msolla *et al.* (1994), it has been found to extract amounts of zinc which correlate well with the zinc uptake. Similarly, although DTPA was first designed for calcareous soils, it has been reported to be a suitable extractant to a wide range of soil types including acid soils (Baker and Amacher, 1982).

2.4.2.1 Extraction with DTPA

DTPA extractant is composed of 0.005 Molar DTPA, 0.01 Molar calcium chloride, and 0.1 Molar triethanolamine, adjusted to pH 7.3. The addition of 0.1M $CaCl_2$ and maintaining the pH at 7.3 is made to prevent dissolution of $CaCO_3$ in calcareous soils through attaining equilibrium between the extractant and $CaCO_3$ (Singh and Takkar, 1981).

The superiority of DTPA over other extractants has been observed by several researchers. For example in soils of Mbeya district, Kamasho and Singh (1982) found DTPA extractable zinc to correlate better with the uptake of the nutrient by wheat than EDTA and 0.1N HCl extractable zinc. They established the critical deficiency value for wheat growth in Mbeya soils to be 3.7 mg/kg. In soils of Tabora region, Msolla *et al.* (1994) found DTPA extractable zinc to correlate significantly ($r=0.82$, $P<0.01$) with zinc uptake by rice plants. They established the critical deficiency value for rice in Tabora region to be 1.1 mg/kg.

2.5 Zinc pools in soils

Soil zinc exists in several fractions. Fractionation studies have generally classified zinc fractions in soils into exchangeable, carbonate, organic, oxide and residual (Neilsen *et al.*, 1986; Hasra *et al.*, 1987). A large proportion of the total zinc has been found to occur in the relatively inactive form as a constituent of primary minerals. For example about 46-92% of soil zinc in some British Columbian soils was found to be in inactive form in primary minerals which is not readily available to plants. Only 0.5-29.7% of the total soil zinc was in exchangeable form considered to be readily available to plants (Neilsen *et al.*, 1986). Studying the distribution of zinc fractions in soils, Hasra *et al.* (1987) observed that exchangeable zinc, on average did not exceed 1.1% of the total zinc. The distribution of total soil zinc amongst different fractions is related to various soil properties. Exchangeable zinc tends to increase with the decrease in soil pH. This has been explained in terms of the increase in solubility of soil zinc minerals (Lindsay, 1972) and to the adsorption-desorption reactions (Brummer *et al.*, 1983). On the other hand, organic matter zinc tends to increase with increase in pH and organic matter (Iyengar *et al.*, 1981). The oxide zinc tends to increase with amount of adsorbed phosphorus and clay-sized minerals (Bollard *et al.*, 1977; Kalbasi and Racz, 1978). Thus high total zinc in soils does not imply high availability to plants.

2.6 Correction of zinc deficiency in tea

Zinc deficiency in tea is usually corrected by applying zinc on the foliage. Soil zinc application is not popular because tea has low ability of utilizing soil zinc (Bonheure and Wilson, 1992). Responses following zinc applications have been reported in several countries. For example, in Kenya yield responses of upto 30% have been obtained due to foliar ZnO applications twice per year each at a rate of 3 kg Zn/ha (TRIEA, 1973). In Malawi experiments have indicated responses by upto 15.5% due to four foliar applications per year each at a rate of 1.25 kg ZnO/ha (TRFCA, 1994). In Sri Lanka, four foliar applications per year each at a rate of 5.5 kg $ZnSO_4$/ha are recommended to correct zinc deficiency (Wickremasinge and Krishnapillai, 1986) as cited by Bonheure and Wilson (1992). Of the two sources of zinc used in correcting zinc deficiency in tea, zinc oxide is more preferred due to its high analysis and low salt injury (TRFCA, 1994).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

3.1.1 Soils

Forty composite (0-40 cm) soil samples were collected from cultivated and virgin land of twenty tea estates. The study area was divided into two zones based on agroecology.

3.1.1.1 Zone one

This zone falls under agroecological zone three (Samki and Dewan, 1981) and is characterized by steeply dissected topography, low shrubs and humid forest with annual rainfall amounting to 1300-1600 mm. Soils were collected from ten estates, namely; Kifyulilo, Livalonge, Kidope, Luiga, Luisenga, Kilima, Idetero, Udumuka, Ihomasa and Kasanga. Udumuka, Ihomasa and Kasanga are smallholder whereas the rest are large scale farms.

3.1.1.2 Zone two

A larger part of this zone falls under agroecological zone fourteen characterized by flat to undulating topography, scattered shrubs and trees. The annual rainfall amounts to about 900-950 mm. Soils were collected from ten estates: Ngwazi, Lugoda, Matugutu, Ifupira, Lupeme, Maganga, Itona, Sawala, Lufuna and Mninga. The last three are smallholder whereas the rest are large scale farms.

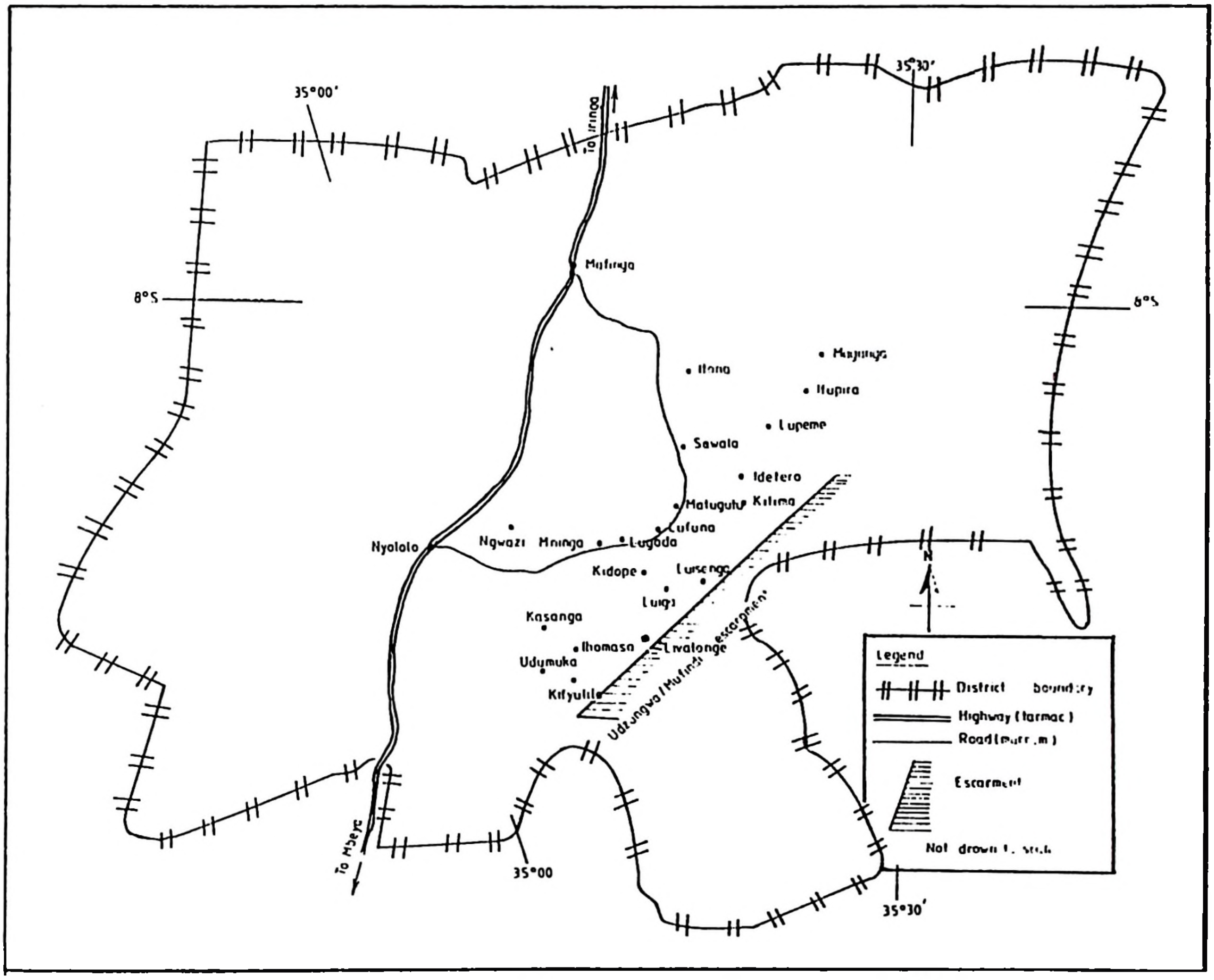

Figure 1. Sketch map of Mufindi district showing location of study estates.

3.1.2 Test crop

Tea (*Camellia sinensis* L.) was used as a test crop. Clones used in the study were 207, K35, 22A and Seed.

3.1.3 Fertilizers

Zinc oxide (80%) was used in the field experiments and both foliar application and soil incorporation were tested to assess the effect of zinc on tea yield. On Livalonge and Ngwazi estates, N, P and K were applied at a rate of 188 kg N, 17 kg P and 31 kg K/ha. At Udumuka the rate of application was 63, 6 and 10 kg/ha of N, P and K, respectively. Compound (NPK 25:5:5) fertilizer was used to supply these nutrients. This formulation is preferred because it provides three nutrients in a single application. This minimizes the application costs.

3.2 Methodology

3.2.1 Soil classification

Two profiles were dug at Udumuka and Ngwazi. These were sampled, characterized and classified following standard procedures (FAO, 1977; FAO-UNESCO, 1989; USDA, 1990). The soils were classified to subgroup level according to USDA Soil Taxonomy system and down to level 2 of the FAO-UNESCO soil classification system as follows:

Ngwazi:

	-USDA:	Order: Ultisols
		Suborder: Humults
		Greatgroup: Kanhaplohumults
		Subgroup: Ustic Kanhaplohumults
	-FAO-UNESCO:	Order: Acrisols
		Suborder: Humic Acrisols

Udumuka:

	-USDA:	Order: Mollisols
		Suborder: Udolls
		Greatgroup: Paleudolls
		Subgroup: Typic Paleudolls
	-FAO-UNESCO:	Order: Phaeozems
		Suborder: Luvic Phaeozems (PHI)

3.2.2 Sampling and sample preparation

3.2.2.1 Soil

Soil samples (0-40 cm) were collected using an auger, composited, air dried and ground to pass through 2 mm sieve prior to all analyses. The sampling depth of 0-40 cm was chosen based on the ploughing and planting depths of tea which is slightly more than 40 cm. Also most feeder roots of a tea bush tend to concentrate down to that depth (Wilson, 1992).

3.2.2.2 Leaf samples

Leaf (third leaf) samples of clones 207, K35, 22A and Seed were collected, oven dried at 65^{0}C and ground to pass through one mm sieve using a Tecator 1093 Cyclotec sample mill prior to analysis.

3.2.2.3 NPK 25:5:5 fertilizer

A sample of compound NPK 25:5:5, a commonly used fertilizer in tea was analysed for Ca, Mg, Zn and Cu content. The method used for analysis is indicated in section 3.2.4.

3.2.3 Field experiments

Three field experiments were laid out at Ngwazi (clone K35), Udumuka (clone 207) and Livalonge (clone 22A) estates on mature tea planted in 1970s. The management practice on Ngwazi and Livalonge estates is good. The amount of N, P and K applied range from 250-300 kg N, 22-26 kg P and 42-50 kg K/ha/year applied as NPK 25:5:5. Weeds are optimally controlled using herbicides and the tea is irrigated during the dry season. On the other hand the management on Udumuka estate is poor. The amount of N, P and K applied as NPK 25:5:5, range from 0-63, 0-6 and 0-10 kg/ha/year, respectively. Weed control is poor, effected mostly by slashing and the tea is not irrigated during the dry season.

Five levels of zinc: 0, 2.5, 5.0, 7.5 and 10 kg Zn/ha as zinc oxide were tested in a randomized complete block design with five replicates. On Ngwazi and Udumuka trials, zinc was applied both on the foliage and in the soil. A plot of 40 bushes spaced at 1.2 m x 0.9 m (= 38.4 m^2) was divided into two equal halves each separated by two guard rows. On one half of the plot, zinc was sprayed on the foliage whereas on the second half zinc was applied in the soil. On the Livalonge experiment zinc was applied on the foliage only. Foliar application of zinc was effected by using knapsack sprayers. About five litres of water was used to suspend zinc oxide before spraying evenly on the leaves of the experimental plot. Occasional agitation of the knapsack sprayer was done during spraying to ensure that zinc did not settle down in the sprayer and hence affect even distribution of zinc on the leaves. Soil application of zinc was done by broadcasting zinc oxide evenly within the experimental plot. To ensure even distribution, zinc oxide portions for soil application were thoroughly mixed with about one kg of sand. Both the foliar and soil treatments of zinc were applied in late November 1993. Yield recording started two months later and continued to the end of March 1994. Yield data in kg green leaf per plot were converted to kg made tea by using appropriate conversion factors. The factors were based on plot size, plant population per hectare and 22.5% turn over to made tea for every kg of green leaf harvested. Leaf (third leaf) samples were obtained from all plots while soil samples were collected from soil applied treatments only in late March 1994.

3.2.4 Sample analysis

3.2.4.1 Routine analysis

The samples collected (sections 3.2.1, 3.2.2 and 3.2.3) were analysed for different attributes as follows:

Parameter	Method of analysis	Reference
(i) Particle size analysis	Hydrometer method	Juo (1979)
(ii) pH	Using pH meter (in 1:2.5 soil/water & 1M KCl suspension- for soil classification only)	McLean (1982)
(iii) Organic carbon %OM = %OCx1.72	Walkley-Black method	Nelson and Sommers (1982)
(iv) Total N	Semi-macro Kjeldahl	Bremner and Mulvaney (1982)
(v) Available P	Bray and Kutz-1	Olsen and Sommers (1982)

(vi) Exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}	In neutral 1M NH_4OAc extract and determined by atomic absorption spectrophotometry (AAS)	Thomas (1982)
(vii) Cation exchange capacity (CEC)	Saturation with 1M NH_4OAc extract followed by ethanol and acidified 1M KCl. Adsorbed NH_4^+ determined by Kjeldahl distillation - titration method	Rhoades (1982)
(viii) Exchangeable acidity (Al^{3+} and H^+)	Extracted with 1M KCl and determined by titration with 0.1N NaOH and 0.1N HCl	Thomas (1982)
(ix) Total Zn, Cu, Fe and Mn in soils	Digestion using H_2O_2 -HNO_3-$HClO_4$- HF mixture and determined by AAS	Baker and Amacher (1982)

(x) Available Zn and Cu	DTPA extraction followed by determination using AAS	Lindsay and Norvell (1978)
(xi) N in leaves	Semi-macro Kjeldahl	Bremner and Mulvaney (1982)
(xii) P in leaves	Digestion using H_2O_2-HNO_3-H_2SO_4-$HClO_4$-HF mixture and determined spectrophotometrica-lly at 882 nm	Juo (1979)
(xiii) Total K, Mg, Ca, Cu, Zn, Fe and Mn in leaves	Digestion using H_2O_2-HNO_3-$HClO_4$-HF mixture and then determined by AAS	Juo (1979)
(xiv) Total Ca, Mg, Zn and Cu in (NPK 25:5:5) fertilizer	H_2SO_4- digestion then determined by AAS	Anderson and Ingram (1993)

3.2.4.2 Zinc fractionation

Zinc fractions in soils were determined using a sequential extraction method as outlined by Tessier *et al.* (1979) as follows:

-Exchangeable fraction: 1 g of soil + 10 mls of 1 M $MgCl_2$ at pH 7. The mixture was shaken for 1 hour

(h) at room temperature then centrifuged at 10 000 rpm for 30 minutes (min.). Zinc was determined in the supernatant using Atomic Absorption Spectrophotometer (AAS).

-Carbonate fraction: residue+10 mls of 0.6 M CH_3OONa + 1M CH_3COOH at pH 5. The mixture was shaken for 5 h at room temperature then centrifuged at 10 000 rpm for 30 min. Zinc was determined in the supernatant using AAS.

-Oxide fraction: residue + 20 mls of 0.04 M $NH_2OH.HCl$ adjusted to pH 2 using acetic acid. The mixture was then heated at 96^{0}C in a water bath for 6 h and shaken for 1 h, centrifuged at 10 000 rpm for 30 min.. Zinc was determined in the supernatant using AAS.

-Organic fraction: residue + 11 mls of H_2O_2 adjusted to pH 2 using 0.02 M HNO_3. The mixture was heated at 85^{0}C in a water bath for 3 h, cooled and then 20 mls of 3.2 M CH_3COONH_4 were added. The mixture was shaken for 30 min., centrifuged at 10 000 rpm for 30 min.. Zinc was determined in supernatant by AAS.

-Residue fraction: residue + 2 mls of $HClO_4$+10 mls of HF. The mixture was heated at 100-150^{0}C to near dryness then 2 mls of $HClO_4$ + 10 mls of HF were added again and heated at 100-150^{0}C to dryness. The dried materials were then solubilized by using 12 N HCl before diluting to 100 mls with distilled water. Zinc was determined using AAS.

Between each successive extraction the residue was washed with 8 mls of distilled water and centrifuged for 30 min. and the supernatant discarded. The main advantage of H_2O_2-HNO_3-$HClO_4$-HF digestion is its ability to solubilise even the most resistant minerals (Baker and Amacher, 1982).

3.2.5 Zinc status in Mufindi tea growing areas

The status of zinc in the study area was assessed using data on total, extractable, and leaf zinc obtained from the twenty estates. The data obtained from zinc experiments were used to recommend the rate of zinc application.

3.2.6 Statistical analysis

Simple correlation coefficients were calculated between various soil properties. The analysis of variance as outlined by Snedecor and Cochran (1989) was used to assess treatment effects in field experiments based on the model:

$$Yij = U + Ti + Bj + Eij$$

where: Yij = Yield

U = General mean

Ti = Treatment effect

Bj = Block effect

Eij = Random error

Means were separated using Duncan's New Multiple Range Test.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Physico-chemical properties of soils

4.1.1 Physical properties

The physical properties of the soils are presented in Tables 1 and 2 and Appendix Figure 1. The texture of the soils is predominantly sandy clay loam grading to clay in the subsurface horizon. The surface soils are very friable when moist, porous, and of moderate to strong subangular blocky structure with high water holding capacity. High to medium amount of water is available throughout the profile to the depth of 100+ cm. Tea being a deep rooted crop does make use of this water especially during the dry season. The soil profile data (Appendix 1) indicate the soils to be very deep, deeper than 190 cm. This implies that the soils are highly weathered.

4.1.2 Chemical properties

4.1.2.1 Soil pH

The pH of soils varied from 4.5-5.6 and 5.1-6.0 in cultivated and virgin soils, respectively. This range is within the optimum pH range for tea growth (Othieno, 1992). The annual application of nitrogenous (NPK 25:5:5) fertilizers over many years has tended to decrease the pH in the cultivated soils.

4.1.2.2 Total nitrogen

The total nitrogen varied from 0.1-0.6 with a mean of 0.3% in the cultivated soils and 0.1-0.7% with a mean of 0.4% in the virgin soils of zone one. In zone two, it varied from 0.2-0.4 with a mean of 0.3% in the cultivated soils and 0.2-0.6 with a mean of 0.3% in the virgin soils. The higher nitrogen content in soils of zone one as compared to those of zone two could be due to differences in vegetation and hence organic matter production. The vegetation of zone one is comprised of thick humid forest while that of zone two is comprised of grasslands with scattered shrubs.

The status of nitrogen in these soils is in the medium range on the basis of rating set by Landon (1984, pp 138). The lower nitrogen content in cultivated as compared to virgin soils is attributed mainly to the substantial removal of soil nitrogen by the tea plant. In every 1000 kg of made tea produced, 40 kg of nitrogen are removed from the soil (Bonheure and Wilson, 1992).

4.1.2.3 Organic matter

The organic matter content of soils varied from 5.0-12.0 with a mean of 9.5% in the cultivated soils and 5.9-15.7 with a mean of 11.1% in the virgin soils of zone one. In zone two, it varied from 5.7-11.4 with a mean of 8.3%

in the cultivated soils and 4.1-11.7 with a mean of 8.5% in the virgin soils.

Generally, the organic matter content in these soils was very high. This may be due to the cool weather which prevails in the area. This type of weather has an effect of decreasing the rate of decomposition of organic materials. The observed higher organic matter content in zone one than in zone two could mainly be due to differences in vegetation types of these zones and the temperature regimes that control decomposition rates.

4.1.2.4 Available P

The available P in soils varied from 6.5-104.0 with a mean of 38.5 mg P/kg in the cultivated soils and 4.1-47.4 with a mean of 18.9 mg P/kg in the virgin soils of zone one. In zone two, it varied from 1.09-93.4 with a mean of 35.6 mg P/kg in the cultivated soils and 1.0-31.9 with a mean of 8.7 mg P/kg in the virgin soils.

According to Landon (1984, p 136), the status of P in the cultivated soils was high whereas in virgin soils was low to medium. The P content in cultivated soils was higher than in virgin soils mainly due to high rates of P fertilizers used in the cultivated soils. The removal of soil P by a tea crop is about 3.7 kg P per every 1000 kg of made tea produced (Bonheure and Wilson, 1992). Similarly, the loss of applied P in soils through leaching is virtually non existent because of its low mobility. The observed lower P status in soils of zone two may be due to differences in organic matter content and/or in parent material from which these soils were derived. The high available P in these soils may be a major reason for the reported non significant yield response following P application on tea (NTRP Progress Report, 1992).

4.1.2.5 Cation exchange capacity (CEC)

The CEC of soils varied from 25.4-48.8 with a mean of 36.0 me/100g soil in the cultivated soils and 26.4-52.5 with a mean of 38.0 me/100g soil in the virgin soils of zone one. In zone two, it varied from 16.3-37.6 with a mean of 26.4 me/100g soil in the cultivated soils and 17.0-40.2 with a mean of 26.8 me/100g soil in the virgin soils.

The CECs of these soils are in the medium range on the basis set by Landon (1984, pp 120). The higher values of CEC observed in virgin than in cultivated soils may be due to virgin soils having higher organic matter content than cultivated soils. Organic matter has been observed to have a great influence on modifying the CEC of soils. In a study conducted in Panama it was observed that organic matter contributed 10-85% of the total CEC (Martin, 1970).

4.1.2.6 Exchangeable cations

The total exchangeable cations of soils varied from 5.27-33.39 with a mean of 13.48 me/100g soil in the cultivated soils and 6.52-26.57 with a mean of 15.94 me/100g soil in the virgin soils of zone one. In zone two, the total exchangeable cations varied from 3.68-19.89 with a mean of 11.93 me/100g soil in the cultivated soils and 12.5-19.08 with a mean of 14.36 me/100g soil in virgin soils. On the average, the exchangeable cations are high in virgin than cultivated soils. This may be attributed to removal of the cations from the cultivated soil through harvesting tender succulent tea shoots which are highly concentrated with nutrients (Bonheure and Wilson, 1992).

Calcium and potassium contributed a bigger proportion of the total exchangeable cations. The exchangeable magnesium was very low. According to Embleton (1973) soils containing 0.5-1.0 me Mg/100g soil are rated as deficient in magnesium. The average content of magnesium in these soils is within this range. This implies that these soils are deficient in magnesium.

Table 1: **Some physico-chemical properties of soils studied in zone 1**

Estate	Kifyulilo		Livalonge		Kidope		Luiga		Luisenga	
	*c	v	c	v	c	v	c	v	c	v
Particle size analysis										
% sand	49	49	65	70	65	56	50	52	77	77
silt	15	13	11	10	13	17	12	13	10	9
clay	36	38	24	20	22	27	38	35	13	14
Texture USDA*	SC	SC	SCL	SCL	SCL	SCL	SC	SC	SL	SL
pH 1:2.5 (H_2O)	5.4	5.6	5.1	5.8	4.9	5.6	4.5	5.4	4.8	5.1
O.C (%)	5.4	6.0	5.5	9.1	6.1	7.2	6.6	8.1	5.5	7.6
O.M (%)	9.3	10.4	9.5	15.7	10.6	12.5	11.4	14.0	9.5	13.2
Total N(%)	0.3	0.3	0.2	0.6	0.4	0.4	0.4	0.5	0.6	0.6
Bray-1P (mg/kg)	15.7	21.8	24.7	15.3	29.0	8.6	84.6	26.6	18.8	21.9
CEC (me/100 g soil)	26.0	39.3	25.7	40.7	48.8	52.5	47.7	51.5	43.6	32.1
Exchangeable bases (me/100 g soil)										
Ca^{2+}	4.19	5.46	4.29	12.18	4.30	7.50	2.17	8.86	1.10	3.15
Mg^{2+}	0.17	0.83	0.24	0.18	0.07	1.12	0.07	1.02	0.07	0.59
K^+	0.15	11.20	4.40	10.52	8.45	6.87	10.29	9.65	3.96	1.80
Na^+	0.15	0.11	0.14	0.14	0.26	0.14	0.17	0.17	0.14	0.67
Total bases (me/100 g soil)	14.51	17.60	9.07	23.02	13.08	15.63	12.70	19.70	5.27	6.52
B.S.(%)	56.00	45.00	35.00	57.00	27.00	30.00	27.00	38.00	12.00	20.00
Exch. acidity (me/100 g soil)										
Total	2.10	2.84	2.14	1.55	6.45	4.28	8.39	2.21	5.52	6.79
H^+	0.21	2.84	1.14	1.55	2.15	4.28	3.97	1.32	1.99	5.69
Al^{3+}	1.89	-	1.00	-	4.30	-	4.42	0.89	3.53	1.10

Table 1: cont.

Particle size analysis	Kilima c	Kilima v	Idetero c	Idetero v	Udumuka c	Udumuka v	Ihomasa c	Ihomasa v	Kasanga c	Kasanga v
(%) sand	70	59	54	54	45	43	52	68	54	53
silt	8	10	14	16	18	19	18	9	9	9
clay	22	31	32	30	37	38	30	23	37	38
Textural classification USDA*	SCL	SCL	SCL	SCL	SC	SC	SCL	SCL	SCL	SCL
pH 1:2.5(H_20)	4.7	5.4	4.6	5.9	5.7	6.0	5.6	5.9	4.9	5.2
O.C (%)	4.7	9.1	6.9	5.4	6.4	3.5	4.7	4.8	2.9	3.4
O.M. (%)	8.1	15.7	11.9	9.3	11.1	6.1	8.1	8.3	5.0	5.9
Total N (%)	0.2	0.7	0.4	0.4	0.3	0.1	0.2	0.3	0.1	0.1
Bray-1P (mg/kg)	84.6	47.4	104.0	24.4	6.5	10.6	8.4	8.4	8.2	4.1
CEC (me/100g soil)	25.4	28.2	32.8	26.4	45.2	36.3	31.4	37.4	33.6	35.9
Exch. bases (me/100g soil)										
Ca^{2+}	2.12	10.44	3.22	5.31	9.77	4.25	6.27	4.22	1.02	3.07
Mg^{2+}	0.03	0.70	0.07	1.21	1.20	0.54	0.73	0.67	0.16	0.36
K^+	10.50	6.20	12.50	4.63	22.28	5.31	4.56	21.54	4.86	7.60
Na^+	0.16	0.31	0.28	0.14	0.14	0.14	0.15	0.14	0.13	0.16
Total bases (me/100g soil)	12.81	17.65	16.07	11.29	33.39	10.24	11.71	26.57	6.17	11.19
B.S. (%)	50.0	63.0	49.0	43.0	74.0	28.0	37.0	71.0	18.0	31.0
Exch. acidity (me/100g soil)										
Total	4.23	3.12	7.08	2.12	1.74	1.11	3.34	1.69	3.08	2.87
H^+	3.17	2.23	3.22	2.12	1.74	1.11	3.34	1.69	1.44	1.03
Al^{3+}	1.06	0.89	3.86	-	-	-	-	-	1.64	1.84

*c = cultivated;
v = virgin;
SC = sand clay
SCL = sand clay loam
SL = sandy loam

Table 2: **Some physico-chemical properties of soils studied in zone 2**

Estate	Ngwazi		Lugoda		Matugutu		Itona		Maganga	
	*c	v	c	v	c	v	c	v	c	v
Particle size analysis (%)										
sand	63	61	86	88	70	54	66	78	70	67
silt	9	9	9	7	9	15	21	10	9	12
clay	28	30	5	5	21	31	13	12	21	21
Texture (USDA)*	SCL	SCL	S	S	SCL	SCL	SL	SL	SCL	SCL
pH(H_20)1:2.5	4.9	5.5	4.7	5.4	4.7	5.5	5.1	6.0	5.4	5.7
O.C (%)	3.6	2.4	5.3	6.8	6.1	5.4	5.2	5.7	5.4	5.6
O.M. (%)	6.2	4.1	9.2	11.7	10.5	9.3	9.0	9.8	9.3	9.7
Total N(%)	0.2	0.2	0.4	0.6	0.3	0.2	0.2	0.2	0.3	0.4
Bray-1P (mg/kg)	73.3	1.0	51.9	31.9	77.2	9.6	93.4	6.9	18.8	9.4
CEC(me/100 g soil)	17.4	23.4	37.6	40.2	34.0	35.7	20.5	28.9	36.8	33.3
Exch. bases me/100g soil)										
Ca^{2+}	2.04	2.04	2.06	5.60	2.14	5.15	4.10	6.93	4.17	11.44
Mg^{2+}	0.16	0.32	0.07	0.89	0.03	0.67	0.23	1.32	0.20	0.88
K^+	6.26	9.17	5.28	8.40	1.37	8.50	7.10	4.15	15.50	6.40
Na^+	0.15	0.16	0.16	0.32	0.14	0.18	0.22	0.10	0.10	0.36
Total bases	8.61	11.69	7.57	15.21	3.68	14.50	11.65	12.50	19.89	19.08
B.S. (%)	49.00	50.00	20.00	39.00	11.00	41.00	57.00	43.00	54.00	57.00
Exch. acidity										
Total	4.48	2.45	6.80	2.03	7.08	5.00	1.76	2.08	3.31	1.32
H^+	2.85	2.45	3.30	1.34	2.79	5.00	1.35	2.08	2.06	1.32
Al^+	1.63	-	3.50	0.69	4.29	-	0.41	-	1.25	-

Table 2: cont.

Estate	Ifupira		Lupeme		Sawala		Lufuna		Muinga	
	c	v	c	v	c	v	c	v	c	v
Particle size analysis (%)										
sand	69	69	60	64	54	57	60	63	56	50
silt	14	13	15	13	13	11	14	16	11	16
clay	17	18	25	23	33	32	26	21	33	32
Texture (USDA)*	SL	SL	SCL	SCL	SCL	SCL	SCL	SCL	SCL	SCL
pH(H_2O) 1:2.5	4.9	5.0	5.5	5.7	5.1	5.2	5.6	6.0	5.4	5.7
O.C (%)	3.6	4.2	3.3	5.8	3.6	3.5	6.6	5.7	5.2	4.2
O.M. (%)	6.2	7.3	5.7	10.0	6.2	6.0	11.4	9.8	9.0	7.4
Total N (%)	0.2	0.2	0.2	0.3	0.2	0.2	0.3	0.5	0.2	0.2
Bray-1 P (mg/kg)	15.5	12.3	10.2	1.0	4.1	3.1	1.1	11.0	10.4	1.0
CEC (me/100 g soil)	20.5	16.3	24.5	20.8	18.6	23.0	35.2	29.7	18.7	17.0
Exch. bases (me/100 g soil)										
Ca^{+}	2.04	1.03	6.12	5.66	3.04	3.22	10.85	7.69	6.23	3.10
Mg^{2+}	0.06	0.29	0.16	1.09	0.20	0.36	1.10	1.01	0.72	0.72
K^{+}	9.93	6.44	10.38	9.88	4.89	9.80	1.95	4.40	8.00	9.34
Na^{+}	1.55	6.00	0.16	0.14	0.18	0.16	0.09	0.15	0.14	0.18
Total bases	13.58	13.76	16.82	16.77	8.36	13.54	13.99	13.25	15.09	13.34
B.S. (%)	66.00	84.00	69.00	81.00	45.00	59.00	40.00	45.00	81.00	78.00
Exch. acidity (me/100g soil)										
Total	6.31	3.28	2.45	3.75	2.89	2.07	4.34	2.66	3.32	1.24
H^{+}	3.87	2.00	2.45	3.75	1.89	1.45	4.34	2.66	1.87	1.24
Al^{3+}	2.44	1.28	-	-	1.00	0.62	-	-	1.45	-

*c = cultivated; v = virgin; s = sandy; SL = sandy loam; SCL = sandy clay loam

4.2 Micronutrient status of soils

The status of micronutrients in soils is presented in Tables 3 and 4. The total contents of these nutrients is higher in zone one than zone two. Differences in parent material from which these soils were derived could be a major reason for the noted differences in micronutrient content of the soils. According to Saggerson (1969), soils of zone one developed from the Usagaran rock systems which are composed of many rock types while soils of zone two developed mainly from acid granitic rocks. Acid granitic rocks are low in micronutrients content (Krauskopf, 1972).

4.2.1 Zinc

The total zinc varied from 31.4-253.8 with a mean of 125.1 mg Zn/kg in the cultivated soils and 31.7-293.2 with a mean of 150.8 mg Zn/kg in the virgin soils of zone one. In zone two it varied from 16.7-179.9 with a mean of 84.9 mg Zn/kg in the cultivated soils and 51.6-273.4 with a mean 135.8 mg Zn/kg in the virgin soils (Table 3).

The DTPA extractable zinc varied from 0.76-3.46 with a mean of 1.98 mg Zn/kg in the cultivated soils and 0.7-5.2 with a mean of 2.07 mg Zn/kg in the virgin soils of zone one. In zone two, it ranged from 0.7-3.1 with a mean of 1.44 mg Zn/kg in the cultivated soils and 1.04-4.1 with a mean of 2.44 mg Zn/kg in the virgin soils (Table 4).

Table 3a: Total micronutrient contents (mg/kg) of soils of zone one

Estates	Zn		Cu		Mn		Fe	
	c*	v	c	v	c	v	c	v
Kifyulilo	72.3	81.0	15.7	43.7	499.3	484.8	27 309.8	33 255.2
Livalonge	92.6	99.7	8.6	16.6	279.4	289.4	44 214.5	48 504.8
Kidope	31.4	31.7	6.5	10.8	209.1	265.3	52 560.6	54 447.5
Luiga	253.8	293.2	6.5	6.6	417.3	488.9	31 524.5	30 683.5
Luisenga	211.8	234.7	6.6	6.6	422.2	485.7	26 127.2	27 386.8
Kilima	185.9	292.2	6.3	7.0	404.2	553.8	31 559.6	32 150.9
Idetero	94.7	146.5	16.1	11.7	426.8	506.1	38 374.4	33 708.9
Udumuka	47.7	50.9	6.5	7.4	321.2	320.1	30 088.1	31 123.8
Ihomasa	183.0	192.4	7.4	10.5	376.6	374.6	41 622.5	37 718.3
Kasanga	78.1	85.9	4.1	8.2	266.8	365.9	24 207.9	28 273.7
Mean	125.1	150.8	8.4	12.9	362.3	413.5	34 758.9	35 725.4

Table 3b: Total micronutrient contents (mg/kg)of soils of zone two

	Zn		Cu		Mn		Fe	
Estate	c	v	c	v	c	v	c	v
Ngwazi	72.2	78.4	4.0	3.1	101.98	210.75	14 417.30	18 615.80
Lugoda	38.6	51.6	6.2	6.8	290.58	252.08	29 891.00	32 831.30
Matugutu	91.4	175.1	5.4	6.4	308.38	506.62	23 902.40	25 130.90
Itona	16.7	273.4	6.2	6.6	256.76	270.67	43 623.20	38 655.50
Maganga	66.5	66.8	4.3	4.2	196.90	199.18	26 052.95	27 355.60
Ifupira	77.4	86.3	6.1	10.3	214.18	220.52	13 056.50	14 560.50
Lupeme	62.2	121.8	6.1	18.7	485.72	608.35	22 709.00	26 001.65
Sawala	179.9	192.3	6.2	4.1	268.37	268.41	29 920.50	31 734.65
Lufuna	112.8	169.8	6.5	6.7	320.93	286.73	43 809.50	46 172.00
Mninga	131.7	142.1	6.2	6.2	197.60	237.92	32 931.20	34 163.75
Mean	84.9	135.8	5.7	7.3	24.14	306.14	28 031.38	29 486.17

* c = cultivated; v = virgin

Table 4a: DTPA extractable micronutrients (mg/kg) of soils of zone one

	Zn		Cu		Mn		Fe	
Estate	c	v	c	v	c	v	c	v
Kifyulilo	0.76	1.30	0.63	0.98	3.33	3.56	56.59	60.80
Livalonge	1.64	3.50	0.17	0.55	2.57	2.44	64.32	82.07
Kidope	1.30	1.40	0.13	0.22	4.30	7.28	55.80	64.42
Luiga	1.90	2.50	0.07	0.13	1.66	0.87	68.36	66.42
Luisenga	2.50	1.20	0.07	0.13	2.38	2.10	60.97	82.40
Kilima	1.80	5.20	0.08	0.26	3.60	3.80	74.27	75.15
Idetero	3.40	2.62	0.24	0.66	3.00	2.97	75.25	75.55
Udumuka	2.20	1.70	0.43	0.32	0.87	0.42	72.21	73.31
Ihomasa	3.46	1.52	0.21	0.31	0.84	1.26	54.34	50.61
Kasanga	0.80	0.80	0.12	0.31	5.50	6.13	65.43	71.54
Mean	1.98	2.17	0.22	0.39	2.81	3.08	64.75	70.11

Table 4b: DTPA extractable micronutrients (mg/kg) of soils of zone one

	Zn		Cu		Mn		Fe	
Estate	c	v	c	v	c	v	c	v
Ngwazi	1.04	1.20	0.12	0.10	0.61	2.27	57.37	59.77
Lugoda	2.20	2.80	0.06	0.14	2.06	4.06	53.56	62.10
Matugutu	1.10	4.10	0.32	0.32	2.57	4.25	55.04	59.14
Itona	1.46	2.50	0.31	0.14	1.64	3.70	67.98	64.15
Maganga	0.80	3.84	0.13	0.52	2.50	7.28	61.54	66.96
Ifupira	1.20	1.26	0.31	0.61	2.45	2.50	45.41	48.56
Lupeme	3.10	3.72	0.31	0.41	3.54	5.30	59.75	53.44
Sawala	1.80	2.50	0.21	0.12	3.10	3.31	58.36	59.14
Lufuna	1.04	1.40	0.11	0.88	2.43	2.14	62.08	65.94
Mninga	0.70	1.04	0.12	0.10	2.49	2.89	69.43	76.44
Mean	1.44	2.44	0.17	0.33	2.34	3.77	59.05	61.56

Both total and DTPA extractable zinc was higher in virgin than in cultivated soils. This could be attributed to large removal of nutrients in the cultivated soils by the crop. The tender young shoot of two leaves and a bud which is harvested is highly concentrated with nutrients (Bonheure and Wilson, 1992). Thus the depletion of soil nutrients is higher in cultivated soils than in virgin soils.

The correlations of zinc to various soil properties are presented in Table 5. Total zinc was not significantly related to most soil properties except clay and organic matter. Total zinc in cultivated soils correlated to the soil clay content. On the other hand, total zinc in virgin soils correlated to the soil organic matter content. These findings imply that in the cultivated soils a larger proportion of zinc is associated with the clay fraction, whereas in virgin soils it is mainly associated with the organic matter fraction. Similar observations have been reported by Neilsen *et al.* (1986) in orchard soils of British Columbia, Canada.

DTPA extractable zinc in the cultivated soils was not significantly correlated with the soil properties determined. The negative relationship between the extractable zinc with organic matter, clay and pH in the

Table 5: Correlation coefficients for amounts of total and extractable Zn to selected soil properties

	Cultivated land						Virgin land					
	Total Zn	pH	Clay	OM	CEC	Bray-1 P	Total Zn	pH	Clay	OM	CEC	Bray-1 P
(i) Zone 1												
Total Zn		-0.232	0.806*	0.090	-0.164	-0.378		-0.482	0.102	0.743*	0.153	-0.123
DTPA extractable Zn	0.375	0.004	-0.241	-0.461	-0.194	-0.295	0.737*	-0.424	-0.286	0.742*	-0.034	-0.012
(ii) Zone 2												
Total Zn		0.232	0.806*	0.090	-0.164	-0.602		-0.437	-0.141	0.639*	0.059	-0.244
DTPA extractable Zn	0.475	-0.004	-0.191	-0.461	-0.194	-0.091	0.524*	-0.090	-0.098	0.542*	-0.568	-0.144

* - Significant at $P < 0.05$

cultivated soils, although insignificant, may imply that these parameters influence to some extent the availability of zinc in these soils. Negative correlations between available zinc and organic matter, clay and pH have been observed elsewhere (Stevenson and Ardakani, 1972; Jeffery and Uren, 1983; Rahmatullah *et al.*, 1985). In virgin soils, on the other hand, the DTPA extractable zinc was significantly ($r=0.542$ and $r=0.742$; $P<0.05$) correlated with the organic matter content. This appears to confirm that organic matter influences the availability of zinc. Positive and significant relationship between DTPA extractable zinc and organic matter have also been observed by Follet and Lindsay (1970) and Fagbami *et al.* (1985).

4.2.2 Copper

The total copper varied from 4.1-16.1 with a mean of 8.4 mg Cu/kg in the cultivated soils and 7.4-43.7 with a mean of 12.9 mg Cu/kg in the virgin soils of zone one. In zone two, it varied from 4.0-6.5 with a mean of 5.7 mg Cu/kg in the cultivated soils and 3.1-18.7 with a mean of 7.3 mg Cu/kg in the virgin soils (Table 3).

DTPA extractable copper varied from 0.07-0.63 with a mean of 0.22 mg Cu/kg in the cultivated soils and 0.26-0.98 mg Cu/kg with a mean of 0.39 mg Cu/kg in the virgin soils of zone one. In zone two, it varied from 0.06-0.32 with a mean of 0.17 mg Cu/kg in the cultivated soils and 0.10-0.88 with a mean of 0.33 mg Cu/kg in the virgin soils. According to Sims and Johnston (1991), the critical level of copper in soils ranges from 0.1 to 2.5 mg/kg. Based on this range, the status of copper in some soils was low thus copper may limit tea yield.

4.2.3 Iron

The total iron varied from 24 207.6-52 560.6 with a mean of 34 758.9 mg Fe/kg in the cultivated soils and from 27 386.8-54 447.5 with a mean of 35 725.4 mg Fe/kg in the virgin soils of zone one. In zone two, it varied from 13 056.5-43 809.5 with a mean of 28 031.4 mg Fe/kg in the cultivated soils and from 14 560.5-46 172.0 with a mean of 29 486.2 mg Fe/kg in the virgin soils (Table 3).

DTPA extractable iron varied from 55.80-75.25 with a mean of 64.75 mg Fe/kg in the cultivated soils and from 50.61-82.07 with a mean of 70.11 mg Fe/kg in the virgin soils of zone one. In zone two, it varied from 7.74-69.43 with a mean of 59.05 mg Fe/kg in the cultivated soils and from 9.81-76.44 with a mean of 61.56 mg Fe/kg in the virgin soils (Table 4). The iron content in these soils is very high, such high content may limit the availability of zinc. In a study to assess the sorption capacity of goethite (Ankomah, 1992) observed that goethite has a high capacity of retaining zinc. He found that a synthetic goethite of 15.8 m^2/g could remove 91% of zinc from the solution (from 1.07 x 10^{-1} to 9.5 x 10^{-3} m Mol Zn/l).

4.2.4 Manganese

Total manganese varied from 209.1-499.3 with a mean of 362.3 mg Mn/kg in the cultivated soils and from 265.3-553.8 with a mean of 413.5 mg Mn/kg in the virgin soils of zone one. In zone two, it varied from 102.0-320.9 with a mean of 264.2 mg Mn/kg in the cultivated soils and from 210.8-608.4 with a mean of 306.2 mg Mn/kg in the virgin soils (Table 3).

DTPA extractable manganese varied from 0.84-4.30 with a mean of 2.81 mg Mn/kg in the cultivated soils and from 0.42-7.28 with a mean of 3.08 mg Mn/kg in the virgin soils of zone one. In zone two, it varied from 0.61-3.54 with a mean of 2.34 mg Mn/kg in the cultivated soils and from 2.14-7.28 with a mean of 3.77 mg Mn/kg in the virgin soils (Table 4). The total and available manganese in these soils is fairy high thus deficiencies are not expected.

4.2.5 Levels of selected elements in NPK fertilizer

The mean content of Ca, Mg, Zn and Cu in the (NPK 25:5:5) fertilizer was 192, 3545, 1.14 and 0.88 mg/kg, respectively (Appendix Table 2). The amount of zinc and copper added into the soil through fertilizer application is very small compared to the amounts removed by the tea crop. For instance, the average yield of tea receiving 1200 kg NPK/ha/year is 3000 kg of made tea per hectare/year. This amount of fertilizer supplies 2 kg Ca, 4 kg Mg, 2 g Zn and 1 g Cu/ha/year. On the other hand, 3000 kg of made tea remove 6 kg Ca, 6 kg Mg, 75 g Zn and 54 g Cu/ha/year. The removal of zinc and copper by the tea crop is far above the amount added through NPK fertilization. Thus continued use of NPK 25:5:5 fertilizer will not help to solve the nutritional problems of these nutrients in these soils.

4.3 Zinc fractionation

The distribution of soil zinc amongst different fractions is presented in Table 6 and shown in Figure 2. The fractionation studies revealed that of the total zinc, 4.2% was exchangeable, 1.1% was associated with carbonate 18.1% with organic matter, 23.5% with oxides and 49.9% with the residual fraction of the soil. Thus the largest proportion of soil zinc was associated with the oxides and residual fraction of the soils.

These findings conform well with those reported by Alhaji and Singh (1993). Studying the partitioning and distribution of zinc in selected cultivated soils in Norway, they observed 31 and 47% of the total soil zinc to

Table 6: Distribution of zinc fractons in soils from tea growing areas of Mufindi district

Soil sample	Zinc fractions												
	Total	Exchangeable	(%)	Carbonate	(%)	Organic	(%)	Oxide	(%)	Residual	(%)	Sum of fractions	(%)
Udumuka cultiv.	47.74	1.17	2.45	0.82	1.72	4.62	9.68	13.55	28.38	26.58	55.68	46.74	97.91
Udumuka virgin	50.89	1.12	2.20	0.55	1.08	0.56	1.10	10.99	21.60	35.67	70.09	48.89	96.07
Livalonge cultiv.	92.58	3.29	3.55	0.17	0.18	24.21	26.25	6.68	7.19	56.83	61.38	91.57	98.91
Livalonge virgin	99.72	4.55	4.56	0.17	0.17	18.37	18.42	18.40	18.45	52.87	53.02	97.74	98.01
Kifyulilo cultiv.	72.30	2.14	2.96	1.08	1.49	20.29	28.06	8.67	11.99	38.28	52.95	70.22	97.54
Ngwazi cultiv.	72.16	21.40	29.66	2.05	2.84	3.97	5.5	2.14	2.97	41.34	57.29	71.74	99.42
Ngwazi virgin	78.41	4.11	5.24	0.41	0.52	2.07	2.64	6.26	7.98	63.57	81.07	76.46	97.51
*MP1-1 (Udumuka)	145.48	1.17	0.80	0.57	0.39	21.23	14.59	13.55	9.31	89.19	61.31	125.31	86.14
MP1-2	88.40	3.10	3.51	3.55	4.02	13.38	15.14	24.78	28.3	40.15	45.42	81.58	92.29
MP1-3	65.30	2.08	3.19	1.14	1.75	10.22	15.65	4.27	6.54	46.62	71.39	63.21	96.80
MP1-4	55.66	1.02	1.83	3.05	5.56	13.12	23.57	8.17	14.68	30.30	54.44	54.66	98.20
MP1-5	53.09	1.00	1.88	0.45	0.85	12.90	24.30	2.02	3.80	35.50	66.87	51.83	97.63
Ngwazi 18	199.41	4.09	2.05	1.05	0.53	52.44	26.30	9.50	47.64	41.34	20.73	193.92	97.25
Ngwazi 24	163.78	2.05	1.25	0.44	0.27	12.04	7.35	106.22	64.86	41.34	25.24	162.09	98.97
Udumuka 24	243.22	2.26	0.93	1.26	0.52	88.68	36.46	123.32	50.70	26.58	10.93	242.10	99.54
Udumuka 48	254.08	2.34	1.31	1.26	0.50	87.00	34.24	132.89	52.30	26.18	10.30	250.67	98.66
Mean	111.39	3.62	4.21	1.13	1.40	24.07	18.07	36.06	23.53	43.27	49.88	108.06	96.93

*MP = profile number 1; 1 = 0-20 cm; 2 = 40-60 cm; 3= 70-90 cm; 4 = 100-120 cm; 5 = 140-160 cm

18, 24, 48 = plots with 10 kg Zn/ha soil application

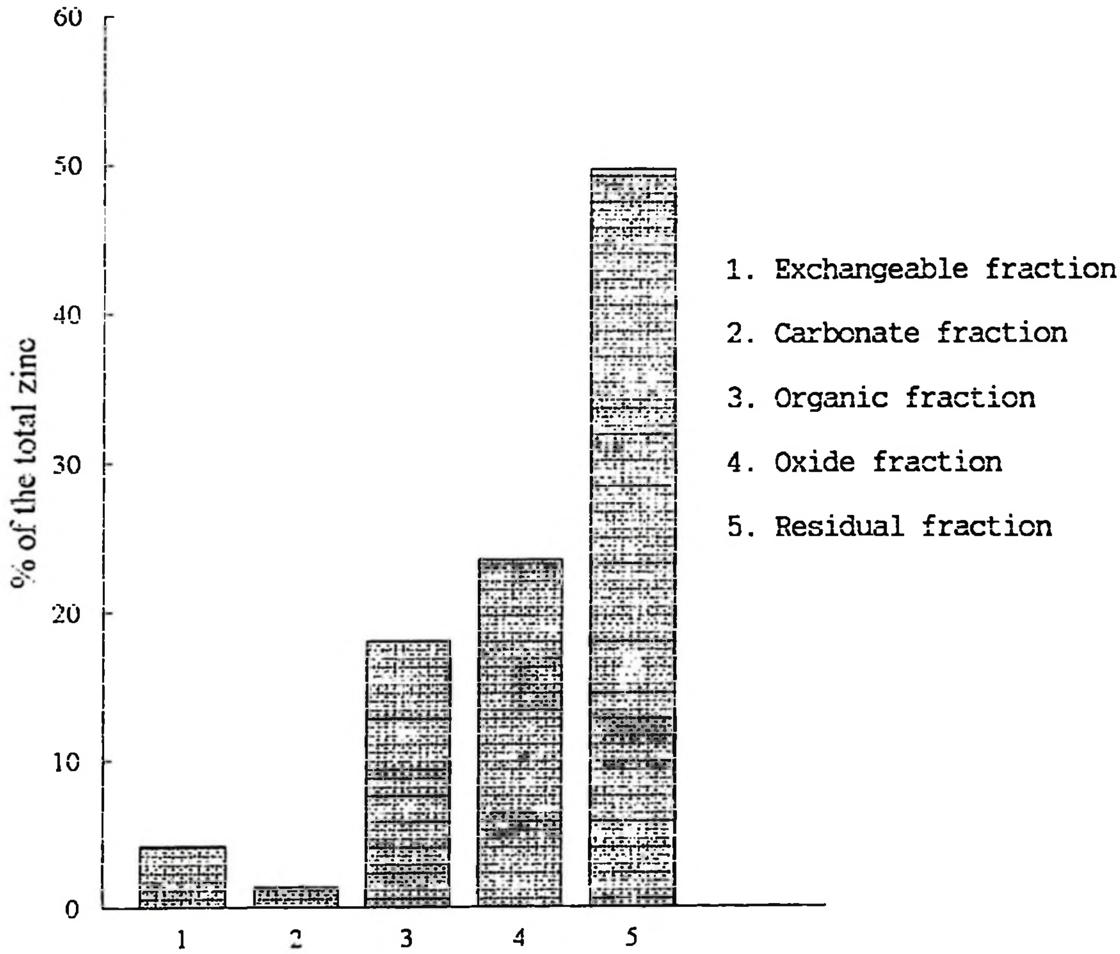

Figure 2. Distribution of zinc in different soil constituents.

The correlation coefficients for the amounts of total zinc and amounts of zinc in various fractions is presented in Table 7. Total zinc was not significantly related to exchangeable zinc but highly related to organic zinc ($r=0.903$; $P<0.001$) and oxide zinc ($r=0.903$; $P<0.001$). The fact that exchangeable zinc is not significantly related to total zinc supports the commonly held view that total zinc does not contribute to the available pool in the short term (Neilsen *et al.*, 1986).

The correlation coefficients for amounts of zinc in various fractions vs selected soil properties are shown in Table 8. Significant ($P<0.05$) correlations were observed between pH and exchangeable zinc, organic matter and organic zinc, available P and oxide zinc, and carbonate zinc and clay. The exchangeable zinc increased as the pH decreased ($r=-0.518$; $P<0.05$); organic zinc increased as the organic matter increased ($r=0.516$; $P<0.05$); oxide zinc increased as the extractable P increased ($r=0.519$; $P<0.05$) and carbonate zinc increased as the clay content increased ($r=0.606$; $P<0.05$). The increase in exchangeable zinc with decrease in pH is attributed to increased solubility of zinc with decrease in pH. Similar results have been observed by Jahirudidin *et al.* (1985) and Xie and Mackenzie (1988).

Table 7: Correlation coefficients between different zinc fractions

	Zinc fraction					
	Total Zn	Exchangeable Zn	Carbonate Zn	Organic Zn	Oxide Zn	Residual Zn
Exchangeable Zn	- 0.063					
Carbonate Zn	- 0.088	0.212				
Organic Zn	0.903^{***}	-0.120	0.017			
Oxide Zn	0.931^{***}	-0.121	-0.025	0.830^{*}		
Residual	0.089	-0.013	-0.352	-0.301	-0.364	
Sum of fraction Zn	0.998^{***}	0.051	-0.078	0.912^{**}	0.945^{***}	-0.140

*, **, *** - significant at P < 0.05, P<0.01 and P < 0.001

Table 8 : Correlation coefficients for amounts of Zn in various fractions and selected soil properties

	Zinc fraction					
	Total Zn	Exchang. Zn	Carbonate Zn	organic Zn	oxide Zn	Residual Zn
pH	-0.276	-0.518^{*}	0.066	-0.049	-0.273	-0.136
Org. matter (%)	0.369	-0.004	-0.386	0.516^{*}	0.289	-0.02
Bray-1 P	0.396	0.102	-0.134	0.111	0.519^{*}	-0.057
Clay (%)	-0.337	-0.244	0.605^{*}	-0.141	-0.195	-0.448
DTPA zinc	0.336	0.013	-0.533^{*}	0.271	0.265	0.027

* Significant at P < 0.05

The high affinity of organic matter for zinc is responsible for the positive and significant correlation between them. Increase in soil organic matter therefore provides more reaction sites where zinc from the soil solution can be held.

The relationship of extractable P and oxide zinc was such that as P increased the oxide zinc increased ($r=0.519$; $P<0.05$). This may be attributed to similarity of adsorption sites on oxides for P and Zn (Bolland *et al.*, 1977). The DTPA extractable zinc did not correlate significantly to most zinc fractions except carbonate zinc. Carbonate zinc was negatively and significantly correlated to DTPA extractable zinc. However, in acid soils, carbonates are not expected. Thus the carbonate zinc obtained in this study may have been attributed to problems associated with analytical procedure. The reagents used dissolve other soil phases such as poorly crystalline hydroxy phases as well as specifically adsorbed trace metals (Miller *et al.*, 1986b).

4.4 Leaf nutrient content

The leaf nutrient content of clone 207 and Seed are presented in Table 9. With the exception of iron, potassium and manganese, the content of nitrogen, phosphorus, calcium, magnesium, copper and zinc were below the levels considered to be adequate (Appendix Table 3).

The content of nitrogen in leaves of seed varied from 2.56-5.39 with a mean of 3.94% in zone one. In zone two, it varied from 2.41-5.05 with a mean of 3.72%. In leaves of clone 207, the content of nitrogen varied from 3.03-4.66 with a mean of 3.94% in zone one whereas in zone two, it varied from 2.50-4.43 with a mean of 3.63%. According to Bonheure and Wilson (1992) leaf nitrogen content of less than 3% is considered as deficient, less than 4% as subnormal, more than 4% as adequate and more than 5% as excess (Appendix Table 3). Based on this criterion, the leaf nitrogen content in most estates was not adequate. The lower content of N in small as compared to large scale estates was attributed to little input of fertilizers in the small scale estates.

The content of phosphorus in the leaves in both large and small scale estates, zones and clones, were well below the critical level of 0.4% (Bonheure and Wilson, 1992). These results are surprising because experiments conducted in these areas indicated insignificant yield response to phosphate application (NTRP Progress Report; 1992). Further, this study has found the status of soil P to be quite high. This suggests a review of the critical level of this nutrient in tea growing in this area.

The average content of magnesium in seed varied from 0.06% in zone one to 0.09% in zone two. In clone 207, it varied from 0.06% in zone one to 0.08% in zone two. The mean leaf calcium content in seed was 0.04% in zone two and 0.06% in zone one. In clone 207, it varied from 0.04% in zone one to 0.06% in zone two. According to Bonheure and Wilson (1992) the observed leaf contents of calcium and magnesium fall below the sufficiency levels of 0.15 and 0.1% respectively. The deficiency of these nutrients on crops growing in these soils may be due to low contents of these nutrients in the soils. Similarly, the problem might have been aggravated by high levels of iron and manganese that might have interfered with the uptake of calcium and magnesium. High levels of manganese and iron have been observed to induce calcium and magnesium deficiency (Marschner, 1986, pp 286). The copper and zinc levels in both zones and clones were below the critical sufficiency levels. High levels of iron and manganese may be the major contributing factor to low availability and hence deficiency of copper and zinc.

Table 9: **Nutrient content in the third leaf of tea shoots of two extensively grown clones in Mufindi district**

	Seed								
	N	P	K	Mg	Ca	Cu	Zn	Fe	Mn
Estate	(%)					(mg/kg)			
Kifyulilo	5.39	0.19	2.63	0.07	0.04	8.09	15.94	214.00	183.12
Livalonge	4.64	0.29	2.75	0.11	0.08	4.08	22.04	239.60	310.00
Kidope	3.44	0.23	2.65	0.10	0.04	6.22	27.92	370.40	409.80
Luiga	3.76	0.12	1.50	0.12	0.08	4.17	15.94	360.40	407.84
Luisenga	4.43	0.17	1.67	0.03	0.06	4.18	11.76	244.00	448.92
Kilima	3.70	0.29	2.38	0.09	0.06	4.14	24.40	244.00	346.72
Idetero	3.62	0.12	2.67	0.03	0.02	6.53	15.94	234.40	539.36
Udumuka	nd	nd	nd	nd	nd	nd	nd	nd	nd
Ihomasa	2.56	0.17	1.88	0.12	0.06	5.22	22.20	261.60	409.24
Kasanga	nd	nd	nd	nd	nd	nd	nd	nd	nd
Mean	3.94	0.21	2.39	0.09	0.06	5.34	19.52	261.8	381.88
Ngwazi	nd	nd	nd	nd	nd	nd	nd	nd	nd
Lugoda	3.75	0.10	2.10	0.02	0.02	6.12	25.28	150.00	214.40
Matugutu	3.73	0.35	2.33	0.03	0.02	5.30	23.52	260.50	276.30
Itona	3.46	0.19	2.08	0.10	0.04	4.07	22.64	152.72	226.62
Maganga	3.76	0.12	1.68	0.04	0.04	4.23	15.94	275.50	353.04
Ifupira	5.05	0.41	2.91	0.05	0.02	6.23	23.52	250.00	1000.00
Lupeme	3.87	0.17	2.08	0.11	0.06	6.25	23.52	275.10	348.48
Sawala	nd	nd	nd	nd	nd	nd	nd	nd	nd
Lufuna	2.41	0.25	2.29	0.08	0.08	5.27	23.96	252.8	260.94
Mninga	nd	nd	nd	nd	nd	nd	nd	nd	nd
Mean	3.72	0.23	2.21	0.06	0.04	5.35	22.63	230.95	382.83

nd= not determined

Table 9 : cont.

	207								
	N	P	K	Mg	Ca	Cu	Zn	Fe	Mn
Estate			(%)				(mg/kg)		
Kifyulilo	3.94	0.12	2.14	0.05	0.04	12.52	26.38	250.10	356.88
Livalonge	4.01	0.21	2.81	0.03	0.04	8.84	22.20	274.80	460.92
Kidope	4.11	0.17	2.35	0.08	0.04	6.12	11.76	260.00	404.00
Luiga	4.28	0.12	1.99	0.08	0.02	6.11	15.94	274.80	478.64
Luisenga	4.66	0.39	2.55	0.03	0.02	8.88	27.04	335.20	452.80
Kilima	4.28	0.23	2.60	0.03	0.04	8.28	22.20	350.00	401.00
Idetero	3.75	0.23	1.73	0.08	0.04	8.60	11.76	235.20	312.20
Udumuka	3.43	0.12	1.77	0.02	0.04	8.35	22.64	274.80	444.96
Ihomasa	3.03	0.17	2.44	0.12	0.10	6.11	17.58	240.50	367.17
Kasanga	3.93	0.19	1.73	0.03	0.04	7.44	24.44	240.00	312.40
Mean	3.94	0.20	2.21	0.06	0.04	8.13	20.19	273.59	399.10
Ngwazi	4.24	0.23	2.81	0.05	0.04	6.60	22.64	235.20	412.20
Lugoda	3.78	0.19	2.35	0.15	0.10	4.00	15.94	250.00	361.78
Matugutu	4.05	0.17	2.66	0.07	0.06	4.63	11.76	265.15	314.78
Itona	3.56	0.58	2.03	0.08	0.02	8.16	23.08	252.80	377.60
Maganga	3.75	0.19	1.97	0.02	0.04	4.08	22.64	280.15	303.99
Ifupira	3.91	0.12	1.72	0.05	0.04	4.18	17.58	174.80	439.04
Lupeme	4.43	0.17	1.73	0.10	0.08	4.00	16.55	284.50	320.40
Sawala	2.95	0.10	2.67	0.14	0.11	4.27	24.44	280.40	450.50
Lufuna	2.50	0.10	2.24	0.08	0.08	4.18	22.64	260.60	492.00
Mninga	3.14	0.21	2.29	0.03	0.04	6.50	32.64	290.10	338.80
Mean	3.63	0.21	2.25	0.08	0.06	5.06	19.99	257.37	381.05

The relationships of leaf nutrient content with soil properties is presented in Table 10. Leaf zinc was not significantly correlated to any soil property. The observed positive relationship of organic matter and total zinc to leaf zinc, though not significant, may imply that these parameters play some role in zinc availability. The insignificant relationship between leaf zinc and DTPA extractable zinc may imply that DTPA is an inferior extractant in assessing zinc availability in these soils.

The relationship of leaf zinc with nitrogen and phosphorus was such that as leaf nitrogen and/or phosphorus and soil content increased, the leaf zinc decreased. High supply of nitrogen and phosphorus induces vigorous plant growth. Under marginal supply of zinc, vigorous plant growth decreases the concentration of zinc in the leaves due to dilution effect (Loneragan *et al*., 1979; Kumar *et al*., 1985).

Table 10: **Correlation coefficients of leaf nutrients content to selected soil and leaf properties**

	Zone 1					
	Clone 207			Seed		
	Leaf nutrient content					
Property	Zn	N	P	Zn	N	P
Total Zn	0.073	-0.203	-0.276	0.128	-0.290	0.167
DTPA Zn	-0.403	-0.474	0.348	0.097	-0.020	0.028
Bray-1 P	-0.532	0.199	0.011	-0.307	0.318	0.419
Total soil N	-0.157	0.199	0.010	-0.115	0.496	0.225
CEC	-0.332	-0.068	-0.196	0.208	-0.282	-0.429
Clay	-0.103	-0.457	-0.817**	0.474	-0.443	-0.641
OM	-0.103	-0.210	-0.162	0.178	0.334	0.172
Leaf Zn		-0.361	-0.329		-0.623	-0.315
	Zone 2					
Total Zn	0.320	-0.572	-0.619	0.026	-0.232	-0.071
DTPA Zn	-0.341	0.368	0.032	0.451	0.118	0.033
Bray-1 P	-0.256	0.442	0.703*	0.162	0.412	0.410
Total soil N	-0.312	0.119	0.020	-0.025	0.364	0.142
CEC	-0.028	-0.068	-0.196	-0.692	-0.372	0.133
Clay	-0.458	-0.317	-0.374	-0.266	-0.284	-0.095
OM	0.103	0.471	0.103	-0.068	0.751	0.366
Leaf Zn		-0.572	-0.214		-0.041	-0.245

* ** Significant at $P < 0.05$ and $P < 0.01$, respectively

4.5 Effect of zinc application on tea

4.5.1 Foliar application

4.5.1.1 Effect on yield

The effect of foliar zinc application on tea at Ngwazi, Livalonge and Udumuka is presented in Table 11 and shown in Figure 3. At Ngwazi and Livalonge tea responded significantly ($P<0.05$) to foliar application of zinc. At Udumuka the response was not significant. Yield responses of upto 31.1, 31.6 and 9.3% were obtained at Ngwazi (clone K35), Livalonge (clone 22A) and Udumuka (clone 207), respectively. At each site 2.5 kg Zn/ha gave the highest yield response. Rates of 7.5 kg Zn/ha and higher decreased yield significantly at Livalonge. Ngwazi, which had 1.04 mg/kg DTPA extractable zinc, gave the most consistent response. Livalonge with 1.64 mg/kg DTPA extractable zinc gave response only at the first rate. Udumuka with 2.2 mg/kg DTPA extractable zinc did not respond to zinc application. This suggested that soils with less than 1.7 mg/kg DTPA extractable zinc were deficient in zinc whereas those with more than 1.7 mg Zn/kg were not deficient. Based on this definition, 55% of the estates in Mufindi are deficient in zinc.

Table 11: Effect of zinc application on yield of tea

Rate kg Zn/ha	Mean yield (kg ha^{-1})				
	Foliar application			Soil application	
	Livalonge	Ngwazi	Udumuka	Ngwazi	Udumuka
0.0	1 696b**	1 382c*	712a*	1 382a*	712a**
2.5	2 232a	1 812a	778a	1 226a	692a
5.0	2 136a	1 779a	648a	1 320a	648a
7.5	1 840b	1 535b	635a	1 170a	572b
10.0	1 833b	1 809a	643a	1 319a	548b
CV	13%	10%	11%	9%	14%
LSD	152	130	ns	ns	70

Means in the same column followed by the same letter are not significnatly different from each other according to Duncan's Multiple Range Test

* : (P<0.05)

**: (P<0.1)

Table 12: Effect of foliar zinc application on leaf nutrient content of tea

Rate kg Zn/ha	N	P	K	Mg	Ca	Cu	Zn	Mn	Fe
					Ngwazi (clone K 35)				
	-------- % ----------					------ mg/kg -------			
0.0	4.30	0.14	1.89	0.10	0.06	7.52	19.38	355.66	230.85
2.5	4.58	0.21	1.98	0.12	0.06	5.80	30.10	407.38	229.50
5.0	4.12	0.15	2.02	0.11	0.07	6.22	33.84	447.94	231.15
7.5	4.82	0.18	1.59	0.08	0.06	6.39	39.74	409.87	232.25
10.0	4.54	0.19	2.16	0.14	0.06	5.42	43.96	425.31	228.75
Mean	4.47	0.17	1.92	0.11	0.06	6.27	33.40	408.23	230.50
Sign.	ns	ns	ns	ns	ns	ns	**	*	ns
					Udumuka (clone 207)				
0.0	3.42	0.27	1.72	0.07	0.06	8.66	28.01	365.38	250.15
2.5	3.20	0.28	1.71	0.08	0.05	7.53	33.70	392.43	255.50
5.0	3.12	0.26	1.66	0.06	0.05	7.38	38.88	399.90	257.17
7.5	3.21	0.35	1.64	0.06	0.07	7.20	41.32	414.19	265.82
10.0	3.51	0.33	1.59	0.06	0.04	7.08	40.02	426.82	268.71
Mean	3.29	0.30	1.66	0.07	0.05	7.57	36.39	399.74	259.47
Sign.	ns	ns	ns	ns	***	ns	***	ns	*
					Livalonge (clone 22A)				
0.0	3.79	0.10	1.89	0.05	0.07	9.19	26.85	363.04	235.61
2.5	3.85	0.13	1.95	0.05	0.06	9.15	31.32	393.40	237.30
5.0	3.89	0.21	2.09	0.07	0.07	8.52	35.56	397.13	265.33
7.5	3.71	0.21	1.81	0.06	0.06	7.81	37.20	401.90	268.57
10.0	3.52	0.12	1.84	0.06	0.06	7.80	40.90	409.13	275.11
Mean	3.75	0.15	1.92	0.06	0.06	8.49	34.37	392.92	256.38
Sign.	ns	*	ns	ns	ns	***	***	ns	***

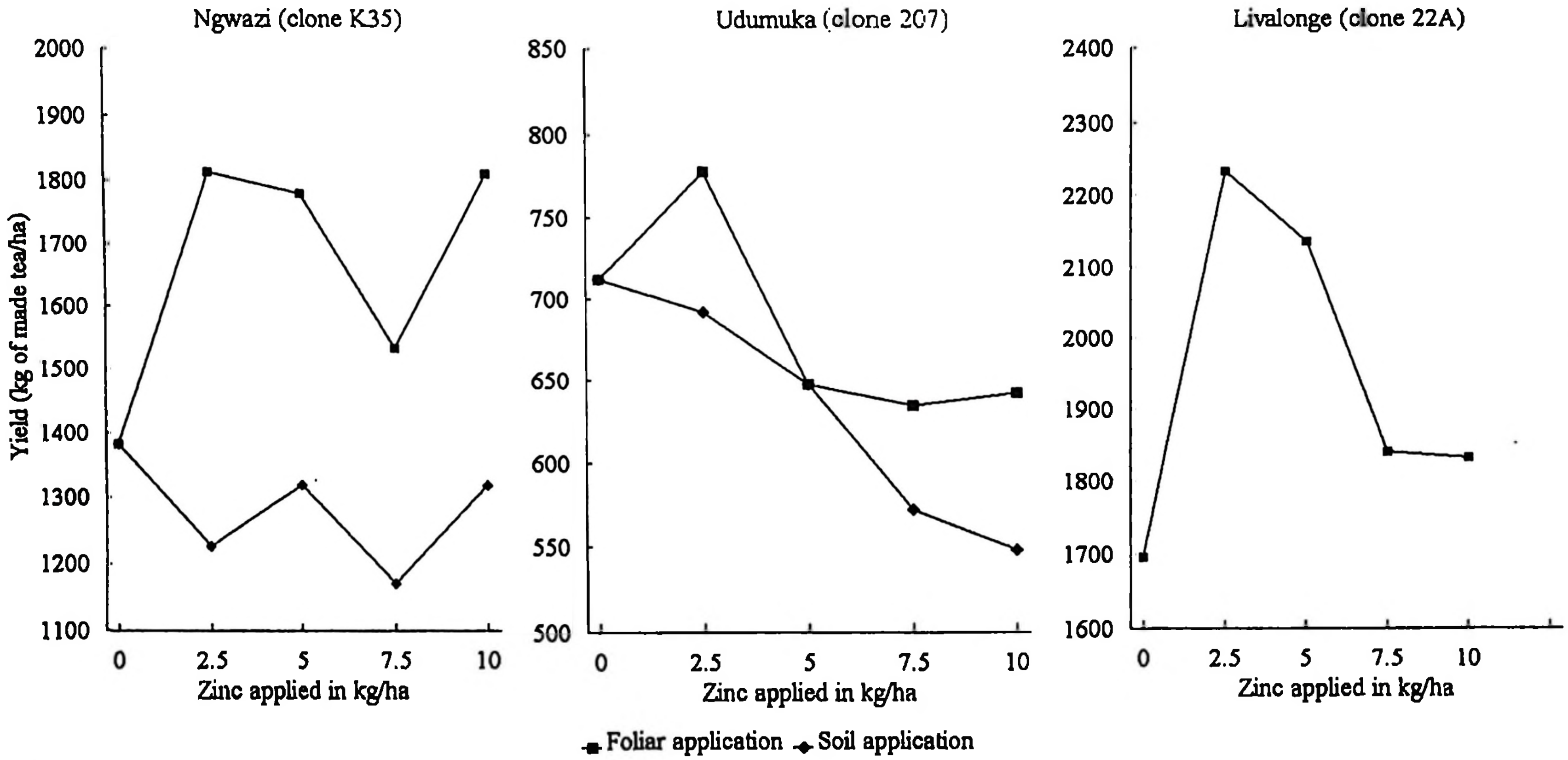

Figure 3. Effect of zinc application on tea yield.

4.5.1.2 Leaf nutrient content

The leaf nutrient contents as affected by foliar application of zinc is presented in Table 12. Foliar application of zinc increased the content of zinc in the leaves. At Ngwazi (clone K35), leaf zinc increased from 19.38 mg/kg in the control to 43.96 mg/kg at 10 kg Zn/ha; at Livalonge (clone 22A); it increased from 26.85 mg/kg in the control to 40.90 mg/kg at 10 kg Zn/ha; at Udumuka (clone 207); it increased from 28.01 mg/kg in the control to 40.02 mg/kg at 10 kg Zn/ha. The data indicate that leaf zinc concentration was suboptimal at Ngwazi thus confirming the response obtained on zinc application. At Livalonge the leaf zinc concentration in the control was within the optimum range suggesting that only little additional zinc may be required. Thus although rates of less than 5.0 kg Zn/ha increased yields, higher rates decreased yields probably due to nutrient imbalance. At Udumuka, the leaf zinc data and the lack of response to applied zinc suggest that zinc is not the main yield limiting nutrient in this site.

Other nutrients affected by foliar application of zinc were calcium, manganese, iron, phosphorus and copper. Calcium leaf content decreased significantly at Udumuka whereas at Ngwazi and Livalonge it did not change significantly. Manganese increased significantly at Ngwazi while at Udumuka and Livalonge the increase was not significant. Iron increased significantly at Udumuka and Livalonge but at Ngwazi the increase was not significant. The content of phosphorus increased significantly at Livalonge. At Udumuka and Ngwazi the increase was insignificant. Copper content decreased significantly at Livalonge but at Udumuka and Ngwazi the decrease was insignificant.

4.5.2 Soil application

4.5.2.1 Effect on yield

The effect of soil application of zinc on tea yield is presented in Table 11 and Figure 3. Soil application of zinc decreased yields slightly, the decrease being significant (P=0.1) at Udumuka but insignificant at Ngwazi. The lack of response to zinc is due to a severe decrease in magnesium (Table 13, column 5). Further discussion is presented in section 4.5.2.2.

4.5.2.2 Leaf nutrient content

The contents of zinc in the leaves as affected by soil zinc application is presented in Table 13. The content of zinc in the leaves decreased significantly (P<0.001) with soil application of zinc. This implies that soil application of zinc decreased its uptake and aggravated the nutritional problem of zinc particularly at Ngwazi. The decrease in uptake of zinc was probably due to root injury and/or decrease in the mobility of zinc. Decreased mobility of zinc with increasing rate of soil zinc application has also been observed in maize (Prabhakaran and Gaurav, 1977).

The concentration of magnesium in the leaves decreased with increasing rate of soil zinc application. At Ngwazi, magnesium concentration in leaves decreased from 0.10% in the control to 0.02% at 10 kg Zn/ha with a mean of 0.05%. When zinc was applied foliarly, magnesium concentration in leaves was not affected by zinc rate and the overall mean was 0.11% (Table 12). The same trend was observed at Udumuka. These results indicate that soil application of zinc caused magnesium deficiency particularly at Ngwazi due to unfavavourable interactions. Thus magnesium became the most limiting nutrient and hence prevented response to zinc. The same results of decreased magnesium uptake with soil zinc application have been observed in rice by Katyal and Ponnamperuma (1974). They explained the decline in magnesium concentration in the plant with soil application of zinc as due to closeness of ionic radii of zinc and magnesium which affect the uptake of one another. Magnesium and zinc have a common role in the formation of RNA polymerase important in formation of DNA. Thus deficiency of one affects the uptake and utilization of the other. Similarly, magnesium is important in the formation of energy rich compound-adenine triphosphate (ATP):

$$ADP + Pi \xrightarrow{Mg} ATP,$$

where, Pi is inorganic phosphate. Energy is necessary in the process of nutrients uptake.

The DTPA extractable zinc measured after harvest (Table 13, last column) increased slightly with the increase in the rate of applied zinc. This implied that most of the applied zinc was not readily available. This was attributed to high content of hydrous oxides of iron, aluminium and manganese in these soils which fix zinc.

Table 13: Effect of soil zinc application on leaf nutrient content of tea

Rate kg Zn/ha	N	P	K	Mg	Ca	Cu	Zn	Mn	Fe	DTPA extr. Zn
	------ % -------					----- mg/kg -------				
Ngwazi (clone K35)										
0.0	4.30	0.14	1.89	0.10	0.06	7.52	19.38	355.60	230.85	1.07
2.5	4.52	0.16	1.82	0.03	0.05	7.90	15.55	333.11	232.51	1.11
5.0	4.40	0.19	1.91	0.03	0.05	8.12	14.22	326.69	236.17	1.37
7.5	4.96	0.21	1.91	0.09	0.06	9.23	13.50	305.92	250.82	1.31
10.0	4.34	0.18	1.89	0.02	0.04	12.33	11.20	286.04	255.71	1.30
Mean	4.44	0.18	1.88	0.05	0.05	9.02	14.77	321.47	241.21	1.23
Sign.	ns	ns	ns	***	ns	*	***	***	***	ns
Udumuka (clone 207)										
0.0	3.42	0.27	1.72	0.07	0.06	8.66	28.01	365.38	250.15	1.04
2.5	3.40	0.03	1.82	0.04	0.06	9.60	25.15	342.41	254.11	1.45
5.0	3.34	0.29	1.71	0.03	0.09	9.67	24.32	331.10	259.29	1.49
7.5	3.50	0.29	1.81	0.03	0.11	11.80	24.01	325.84	261.92	1.96
10.0	3.54	0.23	1.74	0.03	0.05	14.26	22.90	318.00	265.25	1.85
Mean	3.44	0.22	1.76	0.04	0.07	10.80	24.88	336.55	258.14	1.56
Sign.	ns	ns	ns	*	***	***	***	**	*	ns

*, **, *** = significant at $P < 0.05$, $P < 0.01$ and $P < 0.001$

ns = not significant

The results from this study showed that soils with DTPA extractable levels of less than 1.7 mg Zn/kg can be considered as deficient in zinc. This is based on the fact that at Udumuka soil with DTPA extractable level of 2.2 mg /kg did not respond to foliar zinc application. Soil zinc application in this site significantly ($P<0.1$) decreased yield by up to 23%. At Livalonge with a DTPA zinc of 1.64 mg/kg the highest yield was obtained at 2.5 kg Zn/ha rate of foliar zinc application. Rate of 7.5 kg Zn/ha and higher decreased yield significantly. At Ngwazi with 1.04 mg Zn/kg the response to foliar zinc application was more consistent over the whole range of zinc rates. On the other hand soil application in this site did not decrease yield significantly. About 55% of the soils analysed had DTPA extractable zinc less than 1.7 mg/kg. This means that 55% of the estates are deficient in zinc.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

(a) The total zinc content in Mufindi tea growing soils is high but the available zinc ranges from low to high.

(b) A larger proportion of zinc is associated with the residual fractions of the soil.

(c) Soils containing less than 1.7 mg DTPA zinc/kg are likely to respond to foliar zinc application.

(d) Calcium, magnesium and copper were found to be marginal and soil application of zinc appeared to cause magnesium deficiency and prevented yield response to zinc.

5.2 Recommendations

(a) Foliar application of zinc at a rate of 2.5 kg Zn/ha is recommended to correct zinc deficiency in well managed tea estates in Mufindi.

(b) Further research is proposed to determine:

(i) The frequency of foliar application of zinc.

(ii) The effect of foliar zinc application during the cold season.

(iii) The major cause of reduction in tea yield with soil application of zinc especially the role of magnesium and calcium.

role of magnesium and calcium.

(iv) The best extractant for available zinc.

(v) The effect of copper supply on tea yield.

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APPENDICES

1.0 Soil profile data

1.1 Profile number: MP1

Date of description and sampling: 08.03.1994

Authors: B.M. Msanya, J.J. Msaky, D.N. Kimaro and M.S.C. Mhosole

Region: Iringa

District: Mufindi

Location: Udumuka, 1 km from Kifyulilo Tea Research Station

Coordinates: E 35° 07′ 26" / S 08° 41′ 25.7"

Elevation: 1870 m asl

Soil climate: Udic SMR, mesic STR

Landform: Dissected plateau with strongly dissected ridges;

Macrorelief: rolling to hilly; 0-2% linear slope;

Position on slope: Summit

Parent material: Granitic rocks

Surface characteristics: no rock outcrops; no stoniness; no erosion

Natural drainage class: well drained; high infiltration

Vegetation/land use: Tea cultivation

Remarks: The area is dominated by strongly dissected ridges with rolling to hilly topography characterised by very deep soils developed on granitic rocks.

Ap 0-25/35 cm: Black [5 YR 2.5/1] moist; sand clay; friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; many fine few medium pores; many fine and very fine roots; abrupt wavy boundary.

Bt1 25/35-63 cm: Yellowish red [5 YR 4/6] moist; sand to clay; friable moist, sticky and plastic wet; strong coarse and medium breaking to fine subangular blocks; common fine few medium pores; many coarse and medium strong irregular and angular clay nodules; few coarse and medium many fine roots; diffuse smooth boundary.

Bt2 63-95 cm: Yellowish red [5 YR 5/6] moist; clay; friable moist, sticky and plastic wet; strong coarse and medium breaking to fine subangular blocks; many fine medium strong irregular and angular clay nodules; common fine few medium roots; diffuse smooth boundary.

Bt3 95-132 cm: Red [2.5 YR 4/8] moist; clay; very friable moist ; sticky and plastic wet; strong coarse and medium breaking to fine subangular blocks; many very fine and fine few medium pores; few small and large fresh and weathered angular quartz and granite fragments; few medium strong angular clay nodules; few fine and very fine roots; clear smooth boundary.

BCt 132-195 cm: Red [2.5 YR 4/8] moist; extremely gravely clay; friable moist, sticky and plastic wet; weak medium and fine subangular blocks; many fine and very fine few medium pores; many small and medium irregular, angular and round feldspar, granite and quartz; common small and medium strong round clay nodules; few fine and very fine roots.

Remarks: The profile has a very thick black sandy clay surface soil and yellowish to red friable clay subsoil. It is very deep and well drained and shows some nitic properties.

Appendix Table 1.1.1: Some physico-chemical properties of profile MP 1

Horizon Depth (cm)	Ap 0-25/35	Bt1 25/35-63	Bt2 63-95	Bt3 95-132	BCt 132-195+
Particle size analysis (%)					
Sand	75	30	20	25	38
Silt	9	3	8	12	4
Clay	16	67	72	63	58
Texture*	SL	C	C	C	C
pH					
1:2.5 H_2O	5.7	5.7	5.8	5.9	6.2
1:2.5 KCl	4.6	4.1	4.5	3.9	3.9
O.C (%)	4.6	2.6	2.6	1.7	1.7
O.M (%)	8.0	4.5	4.5	3.0	3.0
Total N (%)	0.3	0.2	0.2	0.2	0.2
Bray-1 P (mg/kg)	6.6	1.0	8.2	8.1	0
CEC (me/100g soil)	44.6	19.5	21.6	20.4	24.1
Exchangeable bases (me/100g soil)					
Ca^{2+}	5.77	4.10	3.08	1.01	2.01
Mg^{2+}	0.69	0.36	0.33	0.29	0.22
K^+	20.72	7.60	4.74	5.19	4.11
Na^+	0.32	0.11	11.12	13.40	10.91
Total bases	27.50	12.17	19.27	19.89	17.57
B.S (%)	61.66	62.44	89.34	97.31	72.99
Total micronutrients (mg/kg)					
Zn	145.48	88.40	65.30	55.66	53.09
Cu	16.29	11.29	25.68	30.36	40.12
Mn	459.15	430.23	327.35	208.88	179.57
Fe	35 952.50	51 933.80	65 849.60	48 483.20	25 026.95
DTPA extractable (mg/kg)					
Zn	2.20	0.30	0.35	0.30	0.32
Cu	0.43	0.35	0.31	0.30	0.12
Mn	3.04	0.04	0.40	0.12	0.04
Fe	78.19	57.31	19.51	12.14	21.06
Moisture retention characteristic data:					
Depth (cm)	0		50		100
Bulk density (g/cm^3)	1.18		1.32		1.38
pF^0	78.27		63.30		53.69
pF^1	72.23		48.11		51.42
$pF^{1.5}$	69.18		47.90		50.74
pF^2	68.39		47.80		50.63
$pF^{2.6}$	61.97		36.84		47.26
pF^3	45.77		34.31		34.82
$pF^{3.6}$	45.50		33.58		34.58
$pF^{4.2}$	43.93		32.12		30.07
AWC (%)	18.05		4.72		17.19

* SL = Sandy loam
C = Clay

1.2 Profile number: MP2

Date of description and sampling: 08.03.1994

Authors: B.M. Msanya, J.J. Msaky, D.N. Kimaro and M.S.C. Mhosole

Region: Iringa

District: Mufindi

Location: Ngwazi; 2 km from Ngwazi Tea Research Unit-Road from lake Ngwazi to BBT new workers camp

Coordinates: E 35^o 10′ 29.9′′ / S 08^o 31′ 18.6′′

Elevation: 1860 m asl

Soil climate: Ustic SMR, mesic/thermic STR

Landform: Peneplain, dissected ridges;

Macrorelief: undulating to rolling =8% linear slope;

Position on slope: middle

Parent material: Insitu developed material

Surface characteristics: no rock outcrops; no surface stoniness; moderate runoff; moderate sheet erosion

Natural drainage class: well drained, high infiltration

Vegetation/land use: Tea cultivation, established forest-pine and eucalyptus

Remarks: The area is dominated by dissected ridges with undulating to rolling topography characterised by very deep soils developed on granitic rocks.

Ap 0-20 cm: Dark brown [10 YR 3/3] moist; sand loam; very friable moist, slightly sticky and slightly plastic wet; weak medium subangular blocks; many very fine and fine pores; few medium many very fine and fine roots; clear smooth boundary.

Bt1 20-55 cm: Brown to dark brown [10 YR 4/3] moist; sand clay loam; very friable moist, slightly sticky and slightly plastic wet; moderate medium and fine subangular blocks; few coarse many fine and fine pores; common very fine and fine roots; diffuse smooth boundary.

Bt2 55-80 cm: Yellowish brown [10 YR 5/4] moist; sand clay loam to sand clay; very friable moist, slightly sticky and slightly plastic wet; moderate medium and fine subangular blocks; few medium and many very fine pores; common small and medium strong round clay nodules; common very fine and fine roots; diffuse smooth boundary.

Bt3 80-130 cm: Yellowish brown [10 YR 5/6] moist; sand clay; very friable moist, slightly sticky and slightly plastic wet; weak medium and fine subangular blocks; many very fine and fine pores; many small and coarse strong round and irregular clay nodules; common medium common very fine and fine roots.

Auger observation

130-190+ cm: Yellow [10 YR 7/8] moist; clay; sticky and plastic.

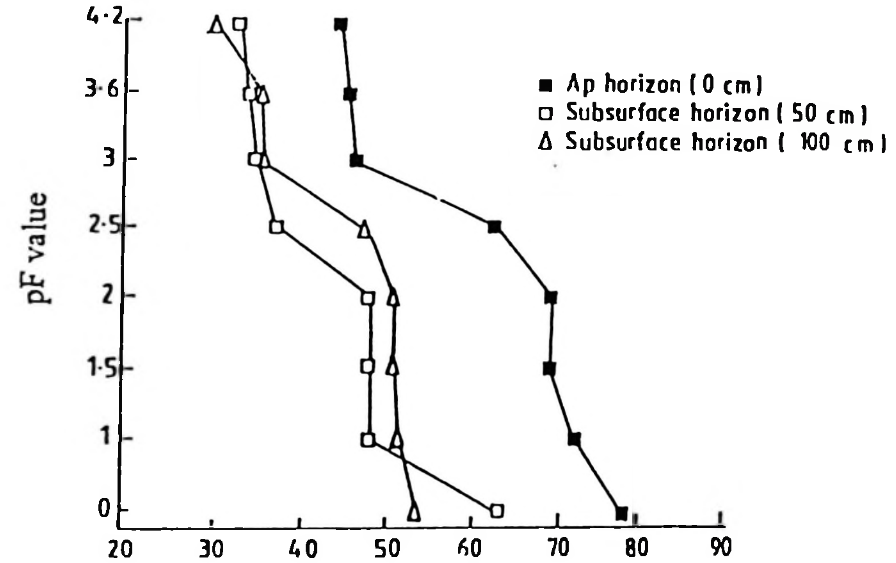
Remarks: The profile has a thick sandy clay loam surface horizon which is somewhat bleached, over a very deep, well drained, very friable sandy clay loam to sand clays.

Appendix Table 1.2.1: Some physico-chemical properties of profile MP 2

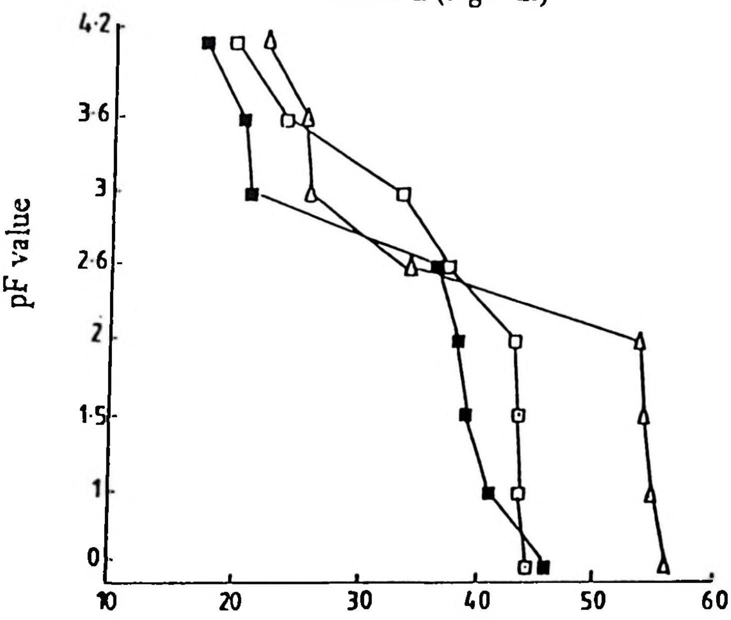
Horizon Depth (cm)	Ap 0-20	Bt1 20-55	Bt2 55-80	Bt3 80-130	Auger 130-190+
Particle size analysis (%)					
Sand	77	77	52	54	48
Silt	2	2	15	4	1
Clay	21	21	33	42	51
Texture*	SCL	SCL	SCL	SC	C
pH					
1:2.5 H_2O	5.8	5.6	5.3	5.6	5.9
1:2.5 KCl	3.6	3.5	2.9	3.9	3.9
O.C (%)	2.9	2.0	1.6	1.2	0.7
O.M (%)	5.0	3.5	2.8	2.1	1.2
Total N (%)	0.1	0.03	0.04	0.04	0.03
Bray-1 P (mg/kg)	1.1	1.0	1.1	0	0
CEC (me/100g soil)	20.4	8.7	11.0	12.2	10.3
Exchangeable bases (me/100g soil)					
Ca^{2+}	2.04	1.01	1.06	1.02	1.01
$Mg2^{+}$	0.16	0.06	0.07	0.03	0.03
K^{+}	2.56	3.77	4.77	3.38	3.80
Na^{+}	0.09	0.11	0.12	0.11	0.13
Total bases	4.85	4.95	6.02	4.54	4.97
B.S (%)	23.73	57.51	54.73	37.27	48.21
Total micronutrients (mg/kg)					
Zn	82.42	23.37	38.64	32.93	0.33
Cu	1.02	6.04	5.28	6.09	5.06
Mn	101.98	103.52	106.16	80.75	25.39
Fe	18 615.80	11 535.05	30 782.00	30 815.75	27 961.85
DTPA extractable (mg/kg)					
Zn	1.04	0.32	0.20	0.20	0.32
Cu	0.12	0.12	0.13	0.20	0.10
Mn	0.14	0.20	0.42	0.20	0.20
Fe	59.77	43.30	39.29	20.10	17.19
Moisture retention characteristic data:					
Depth (cm)	0		50		100
Bulk density (g/cm^3)	1.66		1.84		1.62
pF^{0}	46.00		44.27		56.20
pF^{1}	40.97		43.44		54.95
$pF^{1.5}$	38.83		43.31		54.08
pF^{2}	37.93		42.84		53.59
$pF^{2.6}$	36.20		37.08		33.88
pF^{3}	33.15		20.94		25.79
$pF^{3.6}$	23.57		20.22		25.17
$pF^{4.2}$	19.41		17.09		22.18
AWC (%)	16.79		19.99		11.70

* SCL = Sandy clay loam
SC = Sandy clay
C = Clay

Profile 1 (Udumuka)



Profile 2 (Ngwazi)



Moisture content (%)

Appendix Figure 1. Moisture retention characteristic curves of soils.

Appendix Table 2: Total content (mg/kg) of Ca, Mg, Zn and Cu in (NPK 25:5:5) fertilizer commonly used in tea

Replicate	Ca	Mg	Zn	Cu
1	195	3600	1.25	0.50
2	155	3650	1.25	1.00
3	175	2850	1.25	1.00
4	235	2950	1.25	0.75
5	175	3650	1.30	0.75
6	155	3950	1.25	1.00
7	220	3850	1.25	0.75
8	230	3650	1.30	1.00
9	220	3700	1.25	1.00
10	155	3600	1.25	1.00
Mean	192	3545	1.14	0.88

Appendix Table 3: Critical levels of nutrients in the third leaf a tea shoot

	N	P	K	Ca	Mg	Mn	Cu	Zn	Fe
	---------- % ----------					------ ppm -------			
Deficient	<3.0	<0.35	<1.16	<0.05	<0.05	< 50	<10	<20	< 60
Subnormal	<4.0	<0.40	<2.00	<0.10	<0.10	<100	<15	<25	<100
Excess	>5.0	>0.50	>3.00	>0.35	>0.30	>5000	>30	>50	>500

Source: Bonheure and Wilson, 1992.