THE RESPONSE OF TEA TO FOLIAR AND SOIL APPLIED COPPER: A CASE STUDY OF LUIGA AND LUGODA TEA ESTATES IN MUFINDI TEA GROWING AREAS.

BY

JOHN PATRICK MHAGAMA

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ABSTRACT.

A study was conducted in Mufindi district to determine the response of tea to copper application. Low levels of copper in the soils and in tea leaves in Mufindi which has been reported previously prompted this study to be carried out to determine the effect of foliar and soil copper application on quality and yield of tea. Five levels of copper; 0, 1.5, 3.0, 4.5 and 6.0 kg Cu/ha as copper sulphate (25% copper) applied on the foliage and 0, 2.5, 5.0, 7.5 and 10.0 kg Cu/ha applied to the soil were used to test the effect of copper application on tea quality and yield. Copper application generally improved the fermentation of tea leaves and quality of made tea. Improvement of both fermentation and quality of made tea increased with increasing foliar and soil copper application rates. The effect of foliar copper application on fermentation and quality of made tea lasted for about three months. While that of soil application was found to last longer. The highest quality score was obtained at application rate of 6.0 and 5.0 kg Cu/ha for foliar and soil application of copper, respectively. Foliar copper application generally decreased tea yield non significantly at site one and two except at application rate of 4.5 kg Cu/ha which increased tea yield non significantly at site one by 5.41 percent. The decrease in yield was probably due to difference in the size of tea plants, different pruning intensities and application rates that could have not been uniform..Soil application of copper increased tea yield by up to 26.89 and 15.45 % for site one and two, respectively. At site two application of 5.0 kg Cu/ha gave the highest response. Foliar and soil application of copper significantly ($P < 0.05$) increased leaf copper concentration in both third leaf and shoots when compared to the control. Soil

application of copper sulphate at a rate of 5.0 kg Cu/ha is recommended to correct copper deficiency at both sites.

DECLARATION

I, JOHN PATRICK MHAGAMA, do hereby declare to the Senate of Sokoine University of Agriculture (SUA) that this dissertation is a result of my own original work and has not been submitted for a degree award in any other University.

Signature...

Date...24/1/2002...........

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CHAPTER ONE

1.0 INTRODUCTION:

Tea (*Camellia sinensis* L.) is one of Tanzania's leading cash crops. It ranks the third after coffee and cotton. It contributes about 6% of foreign exchange earnings by cash crops and about 4% of the country's foreign exchange earnings (Ministry of Agriculture, 1992). Tea is a beverage crop, the economic yield being the tender succulent shoot of two leaves and a bud. In Tanzania, tea is an important cash crop in Lushoto, Bukoba, Rungwe, Njombe and Mufindi districts (Ndamugoba, 1990). Mufindi District is the major tea producing area in Tanzania, and of the 20 million kg of made tea produced in the country in 1990, nine million kg (45%) were produced in Mufindi district from 3,152 hectares under tea (Mhosole, 1995). It is estimated that more than ten thousand people are employed in tea production in the district thus relieving to a large extent the problem of unemployment in Mufindi district.

Tea grows well in deep, acidic, and high water holding capacity soils. However, tea can thrive in a wide range of soils provided the soil reaction is acidic. The optimum pH range for tea is 5.0 to 5.6 (Othieno, 1992). The removal of nutrients from the soil by tea crop is very high due to the young shoots harvested having high concentration of the essential plant nutrients. Consequently, high rates of inorganic fertilizers are used in order to sustain high yields. Fertilizer rates in the range of 250 - 300 kg N/ha/year equivalent to 1000 - 1200 kg/ha of NPK 25:5:5 are used by large scale estates owned by Brooke Bond Tanzania Limited and Mufindi Tea Company

(Mhosole,1995). Currently, yields in these estates are in the range of 2500 - 3000 kg of made tea/ha/year (Car and Stephen, 1992). High yields resulting from the applications of such high rates of nitrogen, phosphorus, and potassium year after year results in the mining of other nutrients from the soil including copper. High levels of nitrogen and phosphorus have been observed to induce copper deficiency (Tisdale *et al.*, 1993). Since copper is not included in the fertilizer formulations, its content may have decreased to deficiency levels in the tea growing areas of Mufindi.

Adequate supply of copper to tea is important for plant growth and in the fermentation stage during processing in the factory (Tea Research Foundation of Kenya,TRFK, 1986; Eden, 1958; Acland,1991; Clowes and Mitini-Nkoma 1987). Tea leaves deficient in copper produce poor quality made tea due to slow and poor fermentation. Copper is a constituent of an enzyme, oxidases, which enhance browning and fermentation (Tea Research Foundation of Central Africa, TRFCA, 1965; TRFK, 1986; Eden, 1958; Acland,1991). Thus adequate supply of copper is important for both quantitative and qualitative aspects of tea.

Information on copper nutrition in Tanzania and Mufindi district in particular, is very scanty because no detailed research has been carried out. This situation is however, different in neighboring Malawi and Kenya where extensive research on the nutrient has been carried out. Experiments conducted in Malawi and Kenya showed that foliar spray of $CuSO_4$ improved fermentation ability of harvested tea leaves during manufacturing process. For example copper spraying has been practised for several years in a limited number of districts in Kenya where poor fermentation of tea leaves during manufacturing process had been observed (TRFK, 1986). Foliar application of 0.5% $CuSO_4$ at the rate of 977.7 liters per hectare improved the fermentation ability of leaves harvested from tea growing on copper deficient soils (TRFCA, 1965). Clowes and Mitini-Nkhoma (1987) obtained similar results due to foliar application of 2.5kg $CuSO_4$ per hectare to clonal tea growing on copper deficient soils of Pwazi Tea Estates in Malawi.

Mhosole *et al.* (1998) found the status of copper in soils of Mufindi tea growing areas to be low, similarly the contents of copper in the tea leaves were found to fall far below the adequate range of 15-30 mg Cu/kg (Bonheure and Wilson, 1992). Further, harvested tea leaves take longer time than normal to ferment during the processing of the tea (Acland, 1991). Acland (1991) further reported that slow fermentation of harvested tea leaves during the processing of the tea occurs in parts of southern Tanzania and Kericho district in Kenya and argued that this could be corrected by foliar spray of $CuSO_4$. This indicates Cu deficiency in tea (TRFK, 1986). In some parts of Tanzania the status of copper contents in soils are very low (Mkangwa, 1992, Mhosole, 1995). For example, Mkangwa (1992) obtained average values of 1.29mg Cu/kg DTPA extractable copper in some soils of Iringa district. The observed copper deficiency in the soils of Mufindi tea growing areas (Mhosole, 1995) have been attributed to the low contents of this nutrient element in the parent materials from which these soils were formed, increase in crop yields due to increased levels of N, P, K fertilization and high yielding clones and lack of replenishment of the portion of this nutrient taken up by the tea crop over years of production. Copper deficiency may therefore be a major yield and quality-limiting factor in Mufindi tea growing areas. There is need, therefore, to asses the magnitude and extent of the copper problem in Mufindi tea growing areas and the most agronomical and economical method of reconstituting Cu supply to the tea under Cu deficient soils like those of Mufindi.

This study was therefore conducted with the following main objective;

to investigate the effect of different rates of copper application on yield and quality of tea growing in two tea estates (Luiga an Lugoda) in Mufindi tea growing areas.

The specific objectives were;

i to asses the effect of foliar and soil application of Cu on the yield and quality of tea

ii to determine the optimal rate of application of copper for optimal yield and good quality tea.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1. Historical background.

Copper was established as an essential plant nutrient by Sommers in 1931. Its value as a plant nutrient as well as its toxicity to plants when present in excessive amounts are well documented (Mengel and Kirkby, 1982). Copper deficiency was first recognized as the actual cause of dieback disease of citrus by Flower in 1896 as quoted by Gilbert (1952).

Stimulation of plant growth by copper was recognized at around 1900 in areas where Bordeaux mixture (copper sulfate and lime) was used as a fungicidal spray on trees and truck crops as cited by Troeh and Thompson (1993). Several years later, Floyd (1917) cited by Troeh and Thompson (1993) recommended the application of copper sulphate to the soil and Bordeaux mixture as foliar spray to control dieback of citrus. Felix (1927) noted improvement in the growth of plants which were growing on peat soils by application of copper sulfate either to the soil or in solution to the leaves. Greening effects were obtained in chlorotic leaves of plants which were growing in peat soils after being treated with copper sulphate or manganese sulphate solutions (Bryan, 1929). Allison *et al.* (1927) produced crops on unproductive peat soils of the Florida Everglades by the application of copper sulphate.

2.2 COPPER IN SOILS

2.2.1 Total Copper

Soil copper is contained in minerals like chalacopyrite ($CuFeS_2$), chalcocite (Cu_2S) and bormite ($CuFeS_4$) as primary minerals and oxides, carbonates, silicates and chlorides as secondary copper containing minerals (Tisdale *et al.*, 1993). Total copper ranges from 1-3 mg Cu/kg soil in deficient soils to values up to 200 mg Cu/kg soil or more in soils where excessive copper - bearing sprays, dusts or any other sources have been used or applied (Fiskel, 1965). The total Cu contents in some citrus grave soils of Florida varied from 100 to 380 mg kg^{-1}. This is due to heavy rates of Cu application in the early 1940's, because copper was recommended to control citrus die back (Zhu and Alva, 1993; Zhang *et al.*, 1997). Haff (1951) reported total copper of up to500 mg Cu/kg soil in soils that are near copper deposits However, the total quantity of copper in a soil does not give a good indication of the amount of available copper to plants growing on that soil (Gilbert, 1952:, Tandon, 1995).

2.2.2 Forms of Copper

Knowledge of distribution of copper in various chemical pools in soils is helpful in understanding the inherent capacities of the soils to supply copper to the growing plants. According to McLaren and Crawford (1973) and Shuman (1985), there are five fractions of soil copper and these are (i) soil solution and exchangeable copper, (ii) copper weakly bound to specific sites (iii) organically bound copper, (iv) copper occluded by oxides and (v) residual copper mainly in clay lattice structures. Copper exists in soils predominantly as organically bound residual forms (McLaren and Crawford, 1973; Shuman, 1979; Saha *et al.*, 1991), as precipitated forms (Zhu and Alva, 1993) or as acid soluble forms (Bert and Jacob, 1996).

2.2.3 Available Copper Status of Soils and Factors Affecting it

The availability and movement of copper in soils are influenced by the types of soil parent materials and the extent of weathering, soil texture, pH, cation exchange capacities (CEC), organic matter contents, hydrous oxides contents, interactions with other elements and plant factors (Steenbjerg and Boken, 1950).

2.2.3.1 Available Copper and Soil Parent Materials

Available copper in the soil is closely related to the type and composition of the soil parent materials and the extent of its weathering (Gilbert, 1952; Lal and Biswas, 1973; Kamasho, 1980). Gilbert (1952) noted a wide range in copper contents of Cecil and Decatur soils from Southern United States although they belonged to the same soil great groups and had similar pH values, texture, and color but derived from different parent materials. Lal and Biswas (1973) found that old alluvial soils from alluvium- arenaceous materials had lower Cu than the less weathered desert soils formed from aeolian deposits of fine sand. Further Lal and Biswas (1973) observed that relatively more weathered gray brown, red foot-lile, yellowish brown, and black soil derived from various sedimentary alluviums contained high amounts available copper. Nyandat and Ochieng (1976) analyzed 121 soil samples using ethylenediamine- tetra acetic-acid (EDTA) and observed that 34 samples had deficient levels of copper out of which 14 were derived from volcanic ash and pumice, 8 from sand, sandstone or shale, 5 from phonolite and the rest (7) from various other rocks. Kamasho (1980) reported similar results on available copper in pumice. The DTPA extractable copper and its distribution pattern in Mbeya district, Tanzania showed that the pumic layer invariably contained less available copper thatn the overlying or the underlying horizons (Kamasho, 1980). Generally soils derived from some materials like volcanic ash, pumic, quartz, shale and phonolite contain low levels of available copper (Kamasho, 1980). Eden (1958) reported that Malawi and Southern Tanzania soils have very low contents of available soil copper (7mg Cu/kg soil) because these areas are deficient in sulphur and geologically, copper and sulphur are closely related. Mhosole *et al.* (1998) further reported the available copper in Mufindi tea growing area as being very low, hence not adequate for the optimal requirement for tea growth and development.

2.2.3.2 Available Copper in Relation to Soil pH

The concentration of copper in soil solution decreases with increasing soil pH and hence its supply to plants reduced, because of decreased solubility and increased adsorption by soil colloids/constituents. Copper adsorption by the soil constituents increases with increasing soil pH due to (i) increased pH dependent negatively charged sites on clays and organic matter, (ii) reduced competition with H^+ and (ii) change in the hydrolysis state of Cu in solution (Tisdale *et al.*, 1993). According to

Lindsay (1972) the solubility of Cu fertilizers and other Cu compounds in soils decreases with increasing pH due to reduced activity of the Cu-ions. McBride and Blasiale (1979) and Lexmond (1980) have also reported that Cu^{2+}ion activity decreases with increasing soil pH while Patel and Singh (1995) reported that solubility of Cu decreases with increasing soil pH. It was further reported that Cu was strongly adsorbed by soil colloids with increasing pH and precipitated as hydroxides and hydroxyl carbonate above pH. 5.5. Alva *et al.* (2000) observed that the readily soluble Cu (exchangeable and sorbed Cu) concentration decreased considerably with increase in soil pH above 6.5. However, Mayona (1977) reported a non- significant and negative correlation (r= - 0.4 6) between extractable copper and soil pH for soils of Tukuyu, Tanzania and this was attributed to the acidic nature of the soils. Martens (1967) obtained a negative correlation (r = -0.258) between extractable copper and soil pH in acid soils. While Chattopadyay *et al.* (1996) showed that available Cu was significantly and negatively correlated with soil pH (r = -0.48). Semu and Singh (1996) in their study on accumulation of heavy metals in soils after long-tem use of fertilisers and fungicides in vegetables and tobacco growing areas of Iringa district found that total copper showed significant negative correlation with pH.

Haynes and Swift (1985) studying the effect of liming on extracted Cu of heavy metal including copper found that there was a decline in extractable Cu with liming. Copper decreased from 3.4 to 1.5mg/kg for 0.1 M HCl and 2.5 to 1.0 mg/kg for 0.005 M DTPA with liming. The decrease in extractable Cu with liming was due to the increased pH of the soil consequent to the liming and increase in the number of copper retention sites on the soil colloids.

Other workers have also observed that the relationship between copper and soil pH can be variable. For example Brennan *et al.* (1980) concluded that pH did not affect the availability of copper in the soil. The contradicting results obtained with respect to the relationship between extractable Cu and soil pH could be due to heterogeneous nature and variability of soil constituents. Tea plants require acid soils with pH values between 4.5 and 5.5 (Mabbett, 1999). Mhosole (1995) reported pH range of 4.5-5.6 in selected tea estates in Mufindi district, Tanzania. Kitundu (2001) reported pH range of 4.01-6.24 and 4.13-5.8 of Lihogosa and Itambo estates respectively in Kibena Tea Estates in Njombe district, Tanzania. Low pH in tea soils could be attributed to extensive weathering of the soils, extensive leaching, predominance of exchangeable Al^{3+} and H^{+} on the exchange sites and in the soil solution (Thomas and Hagrove, 1984). Burges (1992) suggested that application of high N fertilizer rates lowers soil pH. Low pH soils are dominated by exchangeable Al^{3+} which through hydrolysis release H^{+} in soil solution. Consequently Na^{+}, Ca^{+}. Mg^{+} and K^{+} are replaced from the exchangeable sites by Al^{3+} and H^{+}. As a result the replaced bases are leached beyond the root zone and become unavailable to plants (Othieno, 1992).

2.2.3.3 Available Copper in Relation to Soil Texture.

Copper content in the soil solution is usually lower in excessively leached podzolic sands and calcareous sands than other soil types (Tisdale *et al.*, 1993). Several researchers have reported that clays play a major role in retention of Cu (Steger, 1973; Kabata-Pendiasi, 1980). Some researchers have also shown that clay surfaces contain significant number of Cu-retention sites (Traina and Doner, 1985). Fagbami *et al.* (1985) reported that copper is translocated with clay and tends to be most abundant in soils when clay contents are high. Copper ions are specifically or chemically adsorbed by layer silicate clays and also retained by soils through entrapment in the clay mineral lattices (Tisdale *et al.*, 1993). Baker (1990) reported that the adsorption of Cu^{2+} on weight basis of clays is in the order kaolinite >illite >smectite.

The above observation contrast with observations made by Mwalilimo (1997) and Baruti (1997) who reported non significant relationship between total Cu, DTPA-Cu and percent clay. It can, therefore, be suggested from the above literature that effect of clay content and composition on Cu retention and distribution of added copper to soils is somehow variable depending on the nature of the clay minerals of the soils.

2.2.3.4 Available Copper in Relation to CEC and Hydrous Oxides

As the soil pH is raised hydrolysis of Cu^{2+} adsorbed on the cation exchange sites on the soil colloids decreases exchangeable Cu^{2+} and increases chemisorbed Cu (Brady, 1984; Forth, 1990). The Cu^{2+} is specifically or chemically adsorbed by the layer silicate clays, organic matter, and iron, aluminium or manganese oxides (Tisdale *et al.*, 1993). With exception to lead (Pb^{2+}), Cu^{2+} is the most strongly adsorbed of the divalent metals on Fe and Al oxides (Tisdale *et al.*, 1993). The mechanism of adsorption by these oxides involves formation of Cu-O-Al or Cu-O-Fe surface bonds. This chemisorption process is thus controlled by the quantity of surface OH^- groups (Tisdale *et al.*, 1993).

Brady (1984) pointed out that the cation exchange capacities of most soils increase with increasing soil pH. Brady (1984) further explained that, as the pH is raised, the hydrogen held by the organic colloids and silicate clays, such as kaolinite, becomes ionized and replaceable. It was also indicated that, the adsorbed aluminium hydroxy ions are removed, forming $Al(OH)_3$ hence releasing additional charge sites on the mineral colloids (Brady, 1984). The net result is an increase in the net negative charge on the colloids and in turns an increase in the cation exchange capacity, thus increasing electrostatic attraction force on the mineral colloids' surfaces.

2.2.3.5 Plant Factors

The genotypic differences in the copper nutrition by plants are related to (i) difference in the rate of copper absorption by roots, (ii) better exploration of soil through greater root length per plant per unit area (iii) better contact with soils through longer root hairs (iv) modification of copper availability in soils adjacent to root exudation zone (v) acidification or change in redox potential in the rhizosphere (vi) efficient transport of copper from roots to shoots, and or (vii) tissue requirement for copper (Tisdale *et al.*, 1993). Child (1955) reported that tea clones defer notably in their ability to take up copper and possibly also in their ability to synthesis copper-protein complexes. Copper contents in leaves in Mufindi, Tanzania was reported to range from 10.7 to 15ppm for six clones and from 13.3 to 16.4ppm for five mother bushes.

2.2.3.6 Available Copper in Relation to Organic Matter (OM)

The availability of copper decreases with increasing organic matter contents in soils. The divalent copper ion (Cu^{2+}) is strongly bound in soils' humic and fluvic acids, forming Cu-organic matter complexes (Stevenson and Fitch, 1981). McBride (1978) reported that complexation by organic matter is an effective mechanism of Cu retention in soils. It was further reported that Cu^{2+} ions were directly bounded to two or more specific organic functional groups (mainly carboxylic, carbonyl and phenolic) such that the Cu was immobilized in the rigid inner sphere complex. According to Alva *et al.* (2000) copper, which is not taken up by plants, tend to accumulate in the top few centimeters of soil due to the binding of copper by organic matter. In solution, up to 98% of the copper is complexed to low molecular weight organic compounds (Hodgson *et al.*, 1966). These low molecular weight organic compounds are highly stable organo- copper complexes which are not immediately available to plants. Because of the high affinity of Cu^{2+} for various ligands (amino, phenolic and synthetic chelates), even in nutrient solution, added Cu^{2+} may be rapidly complexed (Graham, 1979). Cu retention is highest in peat and muck soils where deficiencies of copper are common (Hodgson *et al.*, 1965; Singh *et al.*, 1986). Steenbjerg and Boken (1950) suggested that the high copper deficiency in newly cultivated peat soils could be explained by the initial low contents of available copper because the Cu in such soils is strongly retained by the soil organic matter. This is aggravated by dressings of nitrogen, phosphorus and potassium which results into increased plant growth rate hence proportionally greater Cu uptake from the soil (Tisdale *et al.*, 1993; Steenbjerg and Boken, 1950; Hodgson, 1963).

The relationships between organic matter and copper using chelates have been studied extensively (Tisdale *et al.*, 1993). However, it appears that the correlation between organic matter and available copper using 0.1 M HCl, EDTA or DTPA as extractant varies considerably from one study to another. Martens (1967), working with Virginia soils reported non significant, positive correlation ($r = +0.483$) between 0.1 M HCl extractable copper and OM while Osiname *et al.* (1973) observed that OM was not significantly correlated ($r = -0.270$) with available copper using 0.1M HCL extractant for some Nigeran soils. In pasture soils of Salamanca, Spain, however, Macias (1973) reported a negative and significant correlation ($r = -0.2969$) between OM and O.1 M extractable Cu.

Mayona (1977) obtained negative, non significant correlation ($r = -0.23$) between 0.1MHCl extractable copper and OM for soils from Tukuyu Tanzania and no correlation ($r = +0.01$) for soils from Tanga Tanzania.

Singh *et al.* (1986) obtained significant correlation between EDTA and DTPA-extractable Cu and OM ($r = +0.5709$ and 0.579), respectively. Maji *et al.* (1993) working with coastal soils of Sundarbans, West Bengal, found that available Cu was positively correlated with organic matter ($r = 0.54$). The study of Raghapathi and Vasaki (1993) revealed that the correlation between total Cu and organic matter was highly significant ($r = 0.650$) indicating that total Cu increased with increase in soil organic matter.

Mkindi (1990) obtained negative correlation between organic carbon and DTPA-Cu in the assessment of Cu accumulation in soils due to copper sprays in coffee soils of Moshi district, Tanzania. Mwalilino (1997) assessed heavy metals accumulation in soils of vegetable growing areas of Mbeya district due to pesticide use and found that DTPA-extractable copper was negatively correlated with soil organic carbon similar to the observation obtained by Williams and McLaren (1982).

Organic matter contents in tea soils ranges from less than 1% in some tropical highly leached soils to over 30% in some peat soils. Wilson (1969) reported that well maintained plants generate a lot of organic matter from leaf fall and pruning, hence high percent of organic matter contents and consequently high copper retention.

2.2.3.7 Availability of Copper in Relation to Interaction with Other Nutrients.

(i) Copper - Nitrogen Interaction

There are numerous reports which suggests that copper interacts with nitrogen. Some studies showed that the interaction between Cu and N is antagonistic but others reported a synergistic effect (Tandon, 1995). It has been shown repeatedly that nitrogen application accentuates copper deficiency and when nitrogen supply is high, the application of copper is required for maximum yield (Robson and Reuter, 1981). Camp and Fudge (1939) as cited by Gilbert (1952) were first to repot that Cu deficiency symptoms became more apparent when N was applied to soils deficient in copper. This has been confirmed by a number of workers since then (Tandon, 1995). Copper deficient citrus were found to contain more N than Cu-sufficient leaves (Camp and Fudge, 1939) as cited by Gilbert (1952). On the other hand, Cu accumulation in citrus roots was found to be directly related to the proteins in roots (Smith, 1953). 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 to the formation of free aluminium and iron oxides on which Cu is adsorbed. Furthermore, increased growth resulting from the application of nitrogen without the application of Cu to Cu-deficient soils proportionally dilutes the copper concentrations in plants. Increasing the nitrogen supply to crops can reduce mobility of copper in plants, since high nitrogen in plants impedes translocation of Cu from older leaves to the young leaves (Hill *et al.*, 1978).

(ii) Copper - Phosphorus Interaction

It has been found that high doses and prolonged use of phosphorus fertilizers interferes with the supply of soil available copper to plants (Bingham, 1963). The concentration of copper in sour orange seedlings decreased by increasing the level of P in refined sand (Bingham, 1963). It was also noted that, there were no influence of P on Cu concentration in red kidney beans, tomato or sweet corn and thus concluded that the deference between genera and species of plants might be attributed to the genetic composition of plant species (Binghm, 1963). In rainfed wheat growing under field condition, the grain and straw yield were increased as well as the N and K uptake with the application of Cu but significantly depressed P uptake and concentration in wheat straw (Vecanteswarlu and Misra, 1987). Eun (1981) cited by Chatterjee (1992) reported that copper application to rice plant increased the dry matter, total leaf chlorophyll but decreased P concentration in plant. Barrow (1987) 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.

According to Spencer (1966), phosphorus application reduced concentration of copper in leaves and roots of cleopatra mandarin seedlings. Experimental results indicated a significant decrease in concentration of copper in sour orange seedlings as the rates of phosphorus increased from 100 to 900kg P/ha (Bingham and Garber, 1960). Bingham *et al.* (1958) observed severe copper deficiency in citrus where 360kgP/ha or more were applied to soils in California. Application of copper corrected the symptoms and increased the growth of citrus (Bingham *et al.*, 1958).

High activity of Al, Fe, and Mn in soils were reported to influence the availability of phosphorus (Schewrtmann and Herbillon, 1992; Lopeze-Hermandezz *et al.*, 1986).

(iii) Copper -Potassium, Zinc, Iron, Sulphur Interactions.

High absorption of K, Zn and Fe and S from soils by plants can depress copper absorption by plant roots hence intensifying copper deficiency. Bujtas and Cseh (1981) found that excess of copper inhibited the uptake of potassium in both apical and basal parts of roots of maize and wheat. In a study on wheat, the copper- sulphur interrelationship was negative in roots but not in shoots (Raj *et al.*, 1993) as cited by Patel and Singh (1995). Copper deficiency in mustard grown in refined sand were partially alleviated at high levels of S and this effect was more pronounced in the presence of nitrate-N as compared to ammonium-N in solution (Chatterjee, 1992). Copper has shown to act antagonistically with zinc in diferent plant species (Adroano *et al.*, 1971; Levesque and Mather, 1983). Application of Cu and Zn to wheat in alkaline calcareous soil inhibited the uptake of each other but in rice only copper uptake was reduced when Zn was applied (Kauser *et al.*, 1976) and this was explained as an antagonistic relationship between the elements (Brar and Senkhon, 1978). Spenser (1966) reported that iron chlorosis due to toxic effect of copper was alleviated by the addition of iron but all the adverse effects of excess Cu were not completely overcome by iron. Jain *et al.* (1989) as cited by Chatterjee (1992) observed that increasing the concentration of cooper and uptake of iron was reduced and vice versa. Lindsay and Norvell (1978) suggested that critical level of Fe as 6.0

and 4.5ppm. Arora and Sekhon (1981) suggested that critical limit for normal growth as 2.0ppm.

2.3 Status of Copper in Plants

All plants contain copper because it is one of the essential nutrient elements for plant growth and development. The amount of copper in plants vary depending on species, soil condition, plant parts, stage of growth and amount of fertilizers used (Gilbert, 1952). In plants, copper contents are in the range of 5-25 mg/kg plant material. Tandon (1995) reported the adequate range of Cu content in bean plants as 7-30 mg/kg; 5-25 mg/kg for spinach and 5-20 mg/kg for tomatoes. Jones and Smith (1964) and Reuther and Smith (1953) reported optimum copper content in citrus leaves to be 5 to 16 mg Cu/kg. Tso (1972) observed that the optimum content of copper in flue- cured tobacco range between 14.9-21.1mg Cu/kg. The normal copper content in wheat plant was reported to range between 3.7-8.7 mg Cu/kg plant material (Kamashos, 1980) while for mature trifoliate leaves of beans, the Cu content range between 15 – 30 mg/kg (Geraldson *et al.*, 1973). Bonheure and Wilson (1992) reported the adequate range of copper in tea leaves as 15-30 mg Cu/kg of dry leaves.

Copper content in plants differs with the stage of growth/maturity of the plants. Haque *et al.* (1979) reported that the copper concentration in rice was 5.50 mg at 30 days and 3.30 mg at 60 days after transplanting. Jones (1972) in his study on copper concentration in soya bean found that at ten days after emergence concentration in leaves was 12 mg, at pod formation the concentration was 15mg and then decreased to 13 mg at maturity. Critical concentration of copper in plants differs according to plant Cu requirements. For example Jones and Eck (1983) reported the critical level of copper in maize as 5 mg. According to Makarim and Cox (1973), critical level of copper for wheat was found to be 5 mg. Small and Ohlrogge (1973) reported that the critical level of Cu for soya beans was 10 mg Cu/kg. Tandon (1995) found that critical levels of copper in beans ranges between 4 and 6 mg Cu/kg, 3 and 4 mg Cu/kg for spinach and 3 to 4 mg Cu/kg for cabbage. Karim and Vlamis (1962) reported the critical level for copper in mature rice plant to be 6mg. Singh, *et al.* (1986) reported the critical levels for copper in barley to be 6.75mg Cu/kg. It could there fore be concluded that the critical Cu requirements for most crops ranges between 4-10 mg Cu/Kg.

Copper concentration in plants varies with plant parts. Muthur *et al.* (1979) reported the mean copper concentration in roots, straw and grain to be 80.95, 6.84, and 5.46 mg Cu/kg, respectively for wheat. Merry *et al.* (1985) observed that Copper concentration in tops and roots of silver bean was 91 and 205 mg Cu/kg, respectively. The amounts of copper in plants may be increased by copper application. Bacon (1950) and Sawnback (1950) as cited by Gilbert (1952) found that copper was taken up by leaves of tobacco plants in amounts that varied directly with the amounts applied to the soil.

2.3.1 Role of Copper in Plants

The presence of Cu in the soil in quantities lower or greater than optimal amount could adversely affect plant growth (Alva *et al.*, 2000). Most of the functions of copper as a plant nutrient are based on its participation in the enzymatic redox reactions. In the redox reaction of the terminal oxidases, copper enzymes react directly with molecular oxygen (Marschner, 1995) hence terminal oxidation in living cells is catalyzed by copper and not by iron (Marschner, 1995). The Cu capacity to form organic compounds is equally important and its metabolic role is evident from its presence in cytochrome oxidase (Patel and Singh, 1995; Marschner, 1995). Furthermore copper normally occurs as a constituent of proteins, mostly enzymes, and these are involved in vital metabolic functions (Patel and Singh, 1995). These enzymes are cytochrome oxidase, ascorbate oxidase, phonolase, laccase, superoxide dismutase, plastocynin, azurin and stella cynin (Shorrocks and Alloway, 1988) as cited by Patel and Singh (1995).

Copper has some role in chlorophyll formation (Gilbert, 1952). Copper sprays on leaves have been found to increase the chlorophyll contents of wheat and other plants (Gilbert, 1952). Also copper spraying has been found to protect chlorophyll against destruction (Gilbert, 1952). Further copper is involved in carbohydrate and nitrogen metabolism (Gilbert, 1952; Marschner, 1995). For plants suffering from copper deficiencies the contents of soluble carbohydrates are considerably lower than normal during the vegetative growth stage (Tandon, 1995).

For legumes receiving low copper supplies, nodulation and N_2 fixation is depressed (Hallsworth *et al.*, 1964). In non- legumes, free amino acids and nitrates may accumulate in copper deficient plants (Brown and Clark, 1977). Leaves of copper deficient plants are often dark green (Marschner, 1995). Consequently their photosynthetic efficiencies are much lower which correspond to their lower carbohydrates content (Marschner, 1995). Experimental results showed a high significant reduction in the rate of carbon dioxide assimilation both in slightly and markedly copper deficient leaves of tung trees (Laustalt *et al.*, 1945).

Copper is involved in the formation and chemical composition of cell walls (Patel and Singh, 1995). Impaired lignification of cell walls is the most typical anatomical change manifested by copper deficiency in higher plants (Marschner, 1995). Copper deficiency gives rise to the characteristic distortion of young leaves, bending and twisting of stems and twigs and increased lodging susceptibility of cereals, particularly in combination with a high nitrogen supply (Oldenkamp and Smilde, 1966).

Copper application not only increase crop yields, but it increases the plant resistance to frost damage (Davis, 1950 as quoted by Gilbert, 1952). Little or no damage was done to the completely Cu fertilized citrus trees but considerable defoliation and fruit drop occurred on trees not receiving the copper.

In tea, copper is important in the fermentation stage during the manufacturing process in the factory (Othieno, 1992; Ellis, 1966; Acland, 1991: TRFK 1986). Tea leaves deficient in copper produce poor quality made tea due to slow and poor fermentation (TRFK, 1986; Bonheure and Willson, 1992; Acland, 1991; TRFCA, 1965). Copper is a constituent of an enzyme polyphenol oxidases which enhance browning and fermentation (Eden, 1958; Ellis, 1966; Bonheure and Willson, 1992). Polyphenol oxidase takes part in the synthesis of chlorophyll and some vitamins (Bonheure and Willson, 1992).

2.3.2 Crop Response to Copper

Experimental results have shown that some crops respond to copper applications while others do not and this was attributed to the plant available Cu-contents in soils and differences in plant variatal/species Cu-requirements. Lucas (1948) working with 16 crops reported increase in yields of 13 crops out of 16 due to copper application at a rate of 28 kg Cu/ha as copper sulphate. Murphy and Walsh (1972) reported that wheat, spinach, onion, oat, letuce, and carrots are high copper responsive crops and barley, cabbage, maize and sweet corn are medium copper responsive crops. It was further reported that the low copper responsive crops include beans, peas, potatoes and soya beans.

Application of copper to soil testing less than 1.00 mg/kg EDTA - extractable copper resulted into a significant response by flue - cured tobacco (Semoka *et al.*, 1981). Copper applications have resulted in marked crop increases even though the copper content of the soil appeared to be ample. In field experiment carried out in North Carolina, South Carolina and Viginia in the US, the average yield of tomato was increased by 43.9% and the quality by 10.4 percent while the yield of cotton was increased by 20.23 percent (Churchman *et al.*, 1936; 1937 cited by Gilbert, 1952).

Mkangwa (1992) reported that application of copper at a rate of 5 kg/ha to four soils of Iringa district, increased maize dry matter yields ranging from between 3.6% to 16.9%. Bootson (1976) reported a smaller non-significant yield increase of 5.4% of mature Indian seedling tea, which were treated once by aerial application of $CuSO_4$ at a rate of 2.0kg/ha.

Briger *et al.* (1962) obtained response of sorghum, turnips, radish and snap beans to foliar and soil applied copper ammonium phosphate ($Cu(NH_4)PO_4..H_2O$) and this compound proved to be an effective source of Copper for both methods of application. Application of 28kg copper oxide per hectare in Winsconsin in the Us, resulted into yield increase of oats, red beets, carrots, cabbage, potatoes, field and sweet corn, and onions (Berger, 1965 as cited by Murphy and Walsh, 1972). Reith (1968), reported that soil application of 11 to 12kg copper sulphate per hectare corrected copper deficiency in spring seeded oats. Jakobsen (1976) and Kamasho and Ley (1976) reported round potato response to copper application at Mbimba experimental station, Mbeya, Tanzania. Nilsson (1973) reported that application of Cu together with N and P enabled wheat and barley to head and increased the yield of both crops.

In an experiment with tobacco in Ohio Valley State, Viginia and Carolina in the US, Gilbert (1948) obtained 80 percent increase in both yield and quality of tobacco when Cu was applied. Berger and Trigger (1949) as cited by Gilbert (1952) observed an increase of yields of usable corn of 5 to 40 percent when copper sulphate was added to the NPK fertilizers. Barnes and Cox (1973) reported a significant increase in yields of wheat and soyabean growing in soils, which received 2.8 kg copper/ha from sulphate sources in North Carolina. Kar *et al.* (1988) as cited by Patel and Singh (1995) found that yield and quality of mandarin orange increased when 0.4 per cent spray of copper was applied to 48 years old mandarin orange trees followed by phosphorus application. Highest yields was obtained when copper spray was applied with N, P and K.

Ngeregeza (1999) working with some soils of central part of SUA farm, Morogoro, Tanzania noted an increase of dry matter yield of beans as a result of soil copper application. Using tobacco as a test crop, Akehurst and Sreedhann (1966) reported that it was not necessary to apply copper on soils of Iringa district, Tanzania. Maize did not respond to copper application in soils with DTPA extractable copper ranging from 0.21 to 0.95ppm (Makarim and Cox, (1983). Kruger *et al.*. (1985) noted that there was no increase in yield of wheat as a result of copper fertilization in soils with Cu ranging from 0.2-0.4 mg/kg DTPA extractable copper in Saskachewan, Canada.

Several workers have reported increases of copper in plants resulting from copper applications. For example, foliar spray of Bordeaux mixture increased copper concentration in tea leaves in Malawi (Child, 1955). Annett and Kar (1910) found 71ppm copper in tea leaves sprayed with Bordeaux mixture against 12ppm unsprayed tea. In Sri Lanka, copper treatment resulted into significant increase in tea leaf copper content from treated bushes and a marked increase in color in the treated leaf when fermented (Tea Research Institute of Sri Lanka, 1944 cited by Child, 1955). Ngeregeza noted increased copper concentration in bean shoots and uptake significantly resulting from soil copper application. Tiluhongelwa (1999) noted increased copper contents in beans growing in soils with high copper contents resulting from fungicide use in vegetables in Mgeta, Morogoro district, Tanzania.

2.3.3 Copper Deficiency

The critical deficiency level of copper in the vegetative parts of plants is generally in the range of 3 to 5 mg Cu/kg dry weight. According to Robson and Reuter (1981) this range can be wider depending on plant species, plant organ, developmental stage, and nitrogen supplies. An early symptom of copper deficiency is an unusually dark green color of the foliage, indicating high nitrogen concentration in leaves. The effect of copper deficiency in plant range from slightly reduced growth to dieback. Dieback is more common in copper deficient woody plant. Stunted growth, distortion of young leaves, necrosis of apical meristems and bleaching of young leaves ("White tip" or "reclamation disease") of cereals grown in organic soils and "Summer dieback" in trees are typical visible symptoms of copper deficiencies (Rahimi and Bussles, 1973) as cited by Maschiner (1995). For citrus, deficiency of copper can result in die back (Turke *et al.*, 1995) as quoted by Alva *et al.* (2000). In tea deficient in copper, plants have slightly darker foliage than normal, but it is difficult to detect the symptoms in the field. The main effect of copper deficiency is the inhibition of fermentation of tea leaves in the factory. Thus a sure clear sign of copper deficiency is the length of fermentation time that is if the fermenting leaf takes longer than normal and the leaf becomes dark brown rather than bright orange, then copper deficiency is to be suspected (TRFK, 1986; Bonheure and Willson, 1992). The normal fermenting time is 2 hours (Mcllroy, 1973).

Several workers have reported copper deficiencies in tea growing soils. Othieno (1992), Clowes and Mitini-Nkoma (1987) and Templer 91972) reported copper deficiency at Kericho-Kenya, Malawi and Uganda, respectively. Harler (1951) cited by Child (1955) reported that copper content in poor fermenting leaf in Malawi ranged from 7 to 15 mg Cu/kg. Child (1955) further reported that the copper content of poor fermenting leaf in Tukuyu district Southern Tanganyika (Tanzania) ranged from 7.9 to 13.1 with average of 11.0 mg/kg. Kitundu (2001) reported a mean DTPA extractable copper of 0.18 and 0.14ppm for Lihogosa and Itambo Tea Estates in Kibena tea soils Njombe district, Tanzania. Lindsay and Norvell (1978) suggested that 0.2 mg Cu/kg soil DTPA extractable copper as critical limit for normal plant growth.

2.3.4 Correction of Copper Deficiency in Tea.

Several researchers have reported on the correction of copper deficiency in tea. For example, foliar application of 2.0kg copper sulphate per hectare on young tea trees in Malawi resulted into improved fermentation ability of tea leaves (TRFCA, 1965). TRFK (1986) reported that foliar application $CuSO_4$ improved fermentation ability of poor fermenting leaves in Kenya and the effect lasted for three months. Ellis (1966) reported two months lasting effect of foliar spray of $CuSO_4$ on the improvement of quality of made tea. Clowes and Mitini-Nkoma (1987) observed reduction of fermentation time (minutes) of harvested tea leaf at Pwazi estate in Malawi as a result of forliar application of $CuSO_4$ and $CuOCl_2$ and the effect lasted for four years. Harler (1951) cited by Child (1955) reported two years lasting effect of foliar spray of Bordeaux to tea on fermentation of poor fermenting leaf in Malawi. Soil spray of copper in Malaya was also reported to improve fermentation and quality of made tea (Child, 1955).

Macllory (1973) and Keegel 1965) reported that color of the liquor, strength of the liquor, briskness and color of the infusion which are developed during fermentation are improved by short period of fermentation. Macllory (1973) further suggested that under and over fermentation cause greenish and dull color of the liquor, respectively whereas Keegel (1965) suggested that prolonging fermentation time reduce strength and briskness of the liquor.

The effect of forliar spray of dilute solutions of compounds containing the deficient element was reported to be temprally. Mittleider and Nelson (1970) and Marschner (1995) suggested that foliar spray of mineral nutrients supplies nutrients to higher plants more rapidly than root application but the supply is more temporal.

2.4 Status of Copper in Mufindi Tea Growing Areas

Mufindi tea growing areas are grouped into two agroecological zones (Mhosole, 1995). Zone one fall under Agroecological Zone Three (Samki and Dewan, 1981) and is characterized by steeply desiccated topography, low shrubs and humid forest with annual rainfall amounting to 1300mm-1600mm. Zone two fall under Agroecological Zone Fourteen (Samki and Dewan, 1981) and is characterized by flat to undulating topography, scattered shrubs and trees with annual rainfall amounting to 900mm-950mm. On the status of copper in Mufindi tea growing areas, Mhosole *et al.* (1998) found the mean total copper in the soils to be 8.42 mg Cu/kg and 9.72 mg Cu/kg in zone one and two, respectively. The mean DTPA extractable copper in soils of zone one was 0.22 mg Cu/kg whereas in zone two it was 0.17 mg Cu/kg. The average content of copper in leaves of Clone 207 in zone one was 8.13 mg Cu/kg and in zone two was 5.06 mg Cu/kg. The copper content in the leaves of seed tea in zone one was 5.34 mg Cu/kg of leaves whereas in zone two, the copper content was 5.35 mg Cu/kg of leaves. It was concluded that the status of copper in those soils was low, similarly the content of copper in the tea leaves indicate a serious copper deficiency as they fall far below the adequate range of 15-30 mg Cu/kg (Bonheure and Wilson, 1992). The status of copper in soils is very low compared to values obtained by Mkangwa (1992) working with soils of Iringa district. Mkangwa (1992) reported an average value of DTPA extractable copper in some soils of Iringa district to be 1.29mg/kg. Acland (1991) reported that copper deficiency is common in southern Tanzania tea growing areas causing slow fermentation in factories of leaf harvested from tea plants growing in these soils. Acland (1991) thus concluded that the problem could be corrected by foliar spray of $CuSO_4$. Copper deficiency may therefore be a major yield and quality-limiting factor of tea in Mufindi tea growing areas.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

The study was conducted at 2 sites in different agroecological zones, namely Agroecological Zone Three and Agroecological Zone Fourteen (Samki and Dewan, 1981).

3.1.1 Site One

This site is at Luiga estate. The site 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 1300-1600mm.

3.1.2 Site Two

This site was at Lugoda estate. The site falls under Agroecological Zone Fourteen (Samki and Dewan, 1981) characterized by flat to undulating topography, scattered shrubs and trees. The annual rainfall amounts to about 900-950mm.

3.2 Materials

3.2.1 Soil

Two composite soil samples were collected from the two selected tea estates namely Luiga and Lugoda.

3.2.2 Test Crop

Tea (*Camellia sinensis* L.) was used as a test crop. The very promising clone 207 was chosen for the study.

3.2.3 Cu-source.

Copper sulphate ($CuSO_4.5H_2O$) (25% Cu) was used as the source of Cu for both foliar and soil application.

3.3 Methodology

3.3.1 Soil Sampling and Characterization.

A composite soil sample was collected from each experimental site that is Luiga and Lugoda. The depth of sampling was 40cm. The sampling was done using an auger. For each site, the composite soil sample (representative soil sample) was made up of 20 auger-samples, randomly collected from the experimental site ($600m^2$).

The twenty auger samples for each site were thoroughly mixed together, air dried, and then ground to pass through a 2mm sieve. The 2mm sieved composite soil samples (two samples one for each experimental site) were used for the physical and chemical characterization of the soils from the two sites.

3.3.1.2. Laboratory Analysis for the Physical and Chemical Characterization of the Composite Soil Samples from the Study area.

The soil samples collected where analyzed for different attributes as follows:

Parameter.	Method of analyses	References
i. Particle size analyses	Hydrometer method	Juo (1979)
ii. pH	Using pH meter (electrometric method)	McLean (1982)
iii. Organic carbon % and OM = %C X 1.72	Walkley- Black method	Nelson and Sommers (1982)
iv. Total N	Semi–macro Kjedahl digestion-distillation method	Bremner and Mulvaney (1982)
v. Available P	Bray and Kutz – I	Olsen and Somners (1982)
vi. Exchangeable bases (Ca^{2+}, Mg^{2+}, K^{2+} and Na^{+})	Saturation with 1M neutral NH_4OAC extracts and determined by atomic absorption spectrophotometery (AAS)	Thomas (1982)
vii. Cation exchange capacity (CEC)	Saturation with 1M neutral NH_4OAC extract followed by ethanol and acidified 1M KCl and the adsorbed NH_4^- determined by Kjedahl 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)
x. Available Zn, Cu, Fe and Mn	DTPA extraction followed by determination using AAS.	Lindsay and Norvell (1978)

3.3.2 Field Experiments

Field experiments were conducted at the two selected estates namely Luiga and Lugoda on mature tea (clone 207). At Luiga the plants were planted in 1986 whereas at Lugoda the plants were planted in 1970s. Both estates were well maintained. Weed control was regularly done by chemical weeding and hand pulling. NPK fertilizer at the rate of 250kg N/ha/year equivalent to 1000kg/ha NPK 25: 5: 5 was applied in mid January 2001 on both estates. Tea plants of selected fields from each experimental site were in the third year cycle of prune. They were pruned in June/July 1998.

Five levels of copper 0, 2.5, 5.0, 7.5, and 10kg Cu/ha for soil and 0, 1.5, 3.0, 4.5 and 6kg Cu/ha for foliar application were tested in a completely randomized block design (CRBD) with three replicates. A treatment plot of 72 bushes spaced at 1.2m x 0.6m (= $52m^2$) equivalent to an area of $0.72m^2$ per plant was dermacated at Luiga estate whereas at Lugoda estate a plot of 48 bushes spaced at 1.2m x 0.9m (= $52m^2$) equivalent to an area of $1.08m^2$ per plant was dermacated. Each treatment plot ($52m^2$) was separated by two guard rows. Foliar application of copper was effected by using knapsack sprayers. About five liters of water was used to dissolve 31.2, 62.4, 93.6,and 124.8g $CuSO_4$ for 1.5, 3.0, 4.5, and 6kg Cu/ha respectively before spraying it evenly on the tea leaves in the experimental plots. For soil application, copper sulphate was band applied close to plant lines. On each line, foliage accumulated on the ground were removed before applying $CuSO_4$ to make it go direct to the soil surface where feeder roots are concentrated. The foliage were replaced after applying $CuSO_4$. To ensure evenly distribution, copper sulphate portions for soil application were thoroughly mixed with one kilogram of sand. Both foliar and soil treatment of copper were applied early February 2001 during the dry spell. The reason for applying copper during this period was to avoid washing down of the foliar applied copper by rains, thus making sure that foliar applied copper remains on leaves and leaves get enough time to absorb it. Yield recording started four weeks later and continued for three months. Yield data in kilogram green leaf per plot were converted to kilogram 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 kilogam of green leaf harvested.

3.3.3 Leaf Samples from Experimental Plots.

Leaf (third leaf) sample of the selected clone were collected from randomly selected plants from each experimental plot three months after treatment, oven dried at 65^0C and ground to pass through one mm sieve using a Tecator 1093 cyclotec sample mill prior to analysis.

3.3.3.1 Laboratory Analysis of Leaf Samples Collected from Experimental Plots

The leaf sample collected where analyzed for Cu by wet digestion method using H_2O_2-HNO_3-HNO_3-$HClO_3$-HF mixture and determined by AAS (Juo 1979).

3.3.4 Quality Analysis

Five samples of 1.5 kg of harvested green leaf (one for each treatment) were taken for processing in the mini-processing manufacture unit (MPU) at every plucking round starting four weeks after Cu application. The time taken for each sample to ferment was recorded or, alternatively, fermentation was for a standard time (70 minutes). Liquors were prepared from the made tea and "blind" testing was carried out for color of tea, strength of liquor, color with milk, briskness and color of the infusion. These quality parameters were rated using a scale of 0 to 10. The higher the rating the better the quality. For each treatment, the composite green leaf samples (representative green leaf sample) were made up of 0.5kg green leaf samples harvested from each replicate. Other quality control measures were monitored effectively to make sure that fermentation of harvested leaves starts in the factory. These control measures include; plucking 2 leaves and a bud only, proper handling of plucked leaf to avoid crushing it and transportation of plucked leaf to the factory immediately after plucking.

3.4 Statistical Analysis.

The analysis of variance was used to assess treatment effects in field experiment based on the statistical model

$$Y_{ijk} = \mu + \beta_i + \alpha_j + \omega_{ij}$$

Where: Y_{ijk} = Response

μ = General effect

β_i = Replication (block) effect

α_j = Treatment effect

ω_{ij} = Random error effect

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

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Some of the Physical and Chemical Properties of the Composite Soil Samples from the Experimental Sites:

The physical and chemical properties of the composite soil samples from site one and two were as presented in Table 1. Based on the percent sand, silt and clay particles in the composite soil samples, the textural class of the soil for site one (Luiga estate) is predominantly clay whereas the textural class of the soil of site two (Lugoda estate) is predominately sandy clay (FAO, 1990). The clay and sand clay textural classes of the composite soil samples from site one and two, respectively, would have some influence on the cation exchange and retention capacities of the soils (Hillel, 1982) and Cu availability (Trainar and Doner, 1985; Fagbami *et al.*, 1985; Tisdale, 1993; Steger, 1973; Kabata-Pendias, 1980). Further based on the textural classes of the composite soil samples, it would be implied that the soils would have high water retention capacities and hence water logging during the rainy seasons and thus would have detrimental effect to the performance of tea. However, from the CEC data and exchangeable bases, the clay fractions of the soils are dominated mostly by the 1:1 clay minerals hence would not affect water infiltration.

The soil pH (1:2.5 soil: distilled water) for site one and two was 4.54 and 4.53, respectively. These pH values are rated as low (Landon, 1991).

Table 1. Some of the Physical and Chemical Properties of Soils Used in the Study.

Parameter	Location	
	Luiga (site one)	Lugoda (site two)
pH (1:1.25)		
H_2O	4.54	4.53
CaCL	3.74	3.86
P.S.D		
% clay	46	44.5
% silt	13	9
% sand	41	46.5
Textural class	C	SC
O.C %	5.38	4.96
Total N %	0.34	0.33
Bray-1P mg/kg	3.56	11.51
CEC (cmol/kg soil	20.0	16.5
Exch. Bases (cmol/kg soil)		
Ca^{2+}	5.15	5.03
Na^{+}	0.09	0.06
Mg^{2+}	1.25	1.55
K^{+}	0.34	0.23
Total exchangeable bases (cmol/kg soil)	6.83	6.87
Micro nutrients (mg/kg)		
Copper	0.31	0.50
Zinc	0.52	0.54
Iron	30.06	30.45
Manganese	11.07	12.03
Exch acidity (cmol/100g)		
Al^{3+}	2.6	2.7
H^{+}	0.5	0.3
Total exchangeable acidity	3.1	3.0

Landon (1991), the soil reactions are strongly acid; that is below 5.5. The low pH of the soils could be attributed to the extensive weathering of the soil; extensive leaching of exchangeable bases due to high rains in Mufindi and the predominance of exchangeable Al^{3+} and H^{+} on the exchange sites and in the soil solutions (Thomas and Hargrove, 1984). The pH of the soils are within the range for tea growth; that is between 4.5 and 5.5 (Mabbett, 1999) thus the pH is not a limiting factor. However, according to Othieno (1992), the pH values for the soils of both sites are below the optimum pH range (5.0-5.6) for tea plants.

The total nitrogen in the soils of site one was 0.34 and the organic carbon content was 5.38% (9.25% organic matter content) whereas the total nitrogen for the composite soil sample of site two was 0.33%, and the organic carbon content was 4.96% (8.53% organic matter content). Based on the categorization by Landon (1991), the status of nitrogen of the studied soils fall under the medium level despite of high nitrogen rates supplied annually. This could be attributed mainly to the removal of soil nitrogen by the tea crop due to the young shoots harvested. According to Bonheure and Wilson (1992), 40kg of nitrogen are removed from the soil for every 1000kg of made tea produced. Also the status of organic carbon for soils of both site one and two fall under medium category in accordance with the categorization by Landon (1991). High organic matter content coupled with textural classes would imply high moisture and ion retention capacity. Copper retention would be significant also.

The results are contrary to findings reported by Wilson (1969) who reported that well maintained plants generate a lot of organic matter from leaf fall and pruning, hence high percent of organic carbon contents. These contrasting findings could be attributed to the high decomposition rate of organic matter.

The Bray–1 phosphorus was 3.56 mgp/kg soil and 11.51 mgp/kg soil for soils of site one and site two, respectively. According to the categorization by Landon (1991), the status of phosphorus of the soils fall under low category. The low levels of Bray–1 phosphorus in the soils may have been attributed to high activities of Al, Fe, and Mn in these soils which form insoluble complexes with phosporus (Schwertmann and Herbillon, 1992; Lopez- Hermandezz *et al.*, 1986) and removal of soil phosphorus by the tea crop. The removal of soil phosphorus by the tea crop is about 3.7 kg P per every 1000kg of made tea that are produced (Bonheure and Wilson, 1992). Thus P is a limiting factor for tea growth at the studied areas.

The CEC of the soils at site one and two were 20 and 16.5 Cmol/kg soil respectively. According to Landon (1991), the CEC of soil in site one fall under the high category whereas the CEC of the soil in site two fall under the medium category. The observed high CEC status of the soil for site one as compared to site two, might have been attributed to differences in organic matter, clay contents of the soils and/or nature of the parent material from which the soils were derived.

The sum total of exchangeable bases of soils of sites one and two were 6.83 and 6.87 cmol/kg soil, respectively. All soils had low total exchangeable bases in accordance with Landon (1991) rating. Similarly, the base saturation was 34.15 % and 41.64 % for soils of site one and two, respectively. Based on the categorization by Landon (1991) that soils with BSP< 50% (Dysrict = less fertile status) are of low fertility status, hence the soils under study are therefore of low fertility status. The low total exchangeable bases and BSP were contributed to the low amounts of the individual exchangeable bases in the parent materials from which the soils were formed, losses through leaching and losses through the harvested shoots.

On the other hand, the exchangeable Al and acidity values were 2.6 and 0.5 Cmol(+)/kg soil respectively for soils of site one, whereas the exchangeable Al and acidity values for soils of site two were 2.7 and 0.3 Cmol (+) kg soil respectively. The Al saturation (Al: CEC) was 13.0 % and 16.36 % for soils of site one and two respectively. The observed Al saturation can cause detrimental effects to sensitive crops despite of being less than 50%.

4.1 Micro Nutrient Status of the Studied Soils:

The DTPA extractable Cu in soils of site one and site two were 0.31 and 0.50 mg/kg respectively. Levels of the DTPA extractable Cu in the soils were above the critical limit of 0.2mg Cu/kg for normal plant growth (Lindsay and Norvell, 1978). However, the observed levels of DTPA extractable Cu in the studied soils are lower than those obtained by Clowes and Mitini– Nkoma (1987) in tea soil in Mlawi from which harvested tea leaves did not ferment or fermented poorly during processing. Clowes and Mitini– Nkhoma (1987) reported 0.7 and 0.9 mg/kg DTPA extractable Cu in tea soils in Malawi.

The DTPA extractable zinc in soils of site one was 0.52 mg/kg soil and in soils of site two, was 0.54 mg/kg soil. Based on the critical limit of DTPA extractable Zn as was suggested by Lindsay and Norvell (1978), the soils under study (Table 1) are considered marginally supplied with available Zn. Thus supplying Zn to tea plants may result into increased tea yield.

DTPA extractable manganese was 11.07 mg/kg in soils of site one and 12.03 mg/kg in soils of site two. Lindsay and Norvell (1978) and Arora and Sekhon (1981) suggested 1.0 mg/kg of DTPA extractable Mn as the critical limit for available Mn. In view of this, the soils under study are sufficiently supplied with available Mn.

The DTPA extractable iron was 30.06 mg/kg and 30.45 mg/kg in soils of site one and two, respectively. Based on the critical limits suggested by Lindsay and Norvell (1978) and Arora and Sekhon (1981), the soils under study are adequately suppled with plant available Fe. The higher level of Fe in these soils can affect the availability of other nutrients, especially Cu and Zn. High levels of Fe in soils can also react with phosphorus in the soil resulting into formation of insoluble Fe-P complex compounds that cannot be taken up by plants.

4 .3 Effect of Foliar and Soil Applied Copper on the Fermentation and Quality of Made Tea.

The effect of foliar and soil applied copper on the fermentation and quality of tea at the two sites were as presented in Table 2 and Appendices 1 and 2. The fermentation time (in minutes) of tea leaves decreased with increasing rates of both folar and soil applied copper. However the effect of foliar applied copper on fermentation of tea leaves was faster and lasted for about three months as compared to soil applied copper in which the effect on fermentation started two months after applying copper and the effect lasted for longer period. The effect of foliar Cu spray on fermentation time decreased as from the 64^{th} day after application for which harvested leaf from both sites (one and two) for each treatment completed fermentation after 120 minutes normal fermenting time (Table 2 and Appendix 1 a and b). The minimum fermenting time for leaves from site one was 140 minutes for 6.0 kg Cu/ha while for leaves harvested from site two, the minimum fermenting time was 133 minutes for 3.0 kg Cu/ha (Table 2 a and b). Effect of foliar Cu spray was not observed 85 days after Cu treatment (Table 2).

The quality of made tea based on blind testing for color of the liquor, strength of the liquor, briskness and color of infusion (Appendix 2 a and b) increased with increasing rates of both foliar and soil applied copper. The increase in quality of tea for foliar application was more pronounced for site two as compared to site one. The increases in quality of tea was however more pronounced for the foliar applied copper as compared to the soil applied copper. On average, the highest score rating at both sites were obtained at application rate of 6.0 and 5.0 kg Cu/ha for foliar and soil applied copper respectively (Appendix 1). For forliar applied copper, the quality increase for foliar applied copper ranged from 13.59 to 26.59 percent at site one whereas at site two the quality increase ranged from 26.97 to 31.06 percent. For soil applied copper, the quality increase of up to 15.76 and 14.87 % were obtained at site one and two, respectively. Generally, the score rating for color of the liquor, strength of the liquor, briskness and color of the infusion which are developed durir fermentation (Mcllroy, 1973) increased with increasing rates of Cu application ar decrease in fermentation time.

On the other hand, the total score of quality of made tea for foliar applied copp tested on the 30th day after treatment and fermented at 70 minutes (fixed tim increased from 18.6 in control to 23.6 in copper treated tea plants for leaves from si one. For leaves from site two, the total score of quality of made tea increased fro 15 in the control to 22.6 in copper treated tea plants (Appendix 1 c). Thes observations show that application of Cu on foliage increases the quality of made te

The results obtained in this study on the effect of foliar application on fermentatio of tea leaves and quality of made tea conform to observations reported by TRFI (1986) and somehow to Ellis (1966). TRFK (1986) reported that the effect of foli Cu spray on fermentation lasts for about three months after which another spra should follow. Ellis (1966) reported two months lasting effect of foliar spray o $CuSO_4$ on the improvement of quality of made tea harvested form young te However, the observations from this study contradict with observations made b other workers in Malawi. Harler (1951) as cited by Child (1955) reported two year lasting effect of foliar spray of Bordeaux mixture to tea on fermentation ability o poor fermenting leaf from Mlanje area. Booston (1976) reported that the effect o foliar spray of $CuSO_4$ on fermentation ability and quality of made tea remaine evident for about four years.

The observed differences on the improvement of fermentation of harvested leaf between foliar Cu spray and soil Cu application may be due to an immediate uptake of Cu sprayed on leaves as compared to slow uptake of Cu from the soil by roots. This may have been attributed to fixation of soil applied Cu by soil organic matter (Alva, 2000), clays, iron, aluminum or manganese (Tisdale *et al.*, 1993) and interaction with other nutrients especially N, P and K (Tandon 1995) applied in mid January 2001 two weeks before Cu application. Based on these observations, foliar application could be recommended for immediate correction of the problem of slow fermentation of harvested leaf during processing. Soil copper application can be recommended for long time effect on improvement of fermentation ability of harvested leaf during processing. The results obtained in this study concur with those of Mittleider and Nelson (1970) and Marschner (1995) who suggested that foliar spray supply nutrients to higher plants more rapidly than root application but the effect is more temporal or short lived.

The improvement of fermentation ability of tea leaves and quality of made tea was probably attributed to increased levels of copper in tea plants (Table 4 a and b). Cu is important in the fermentation stage during processing in the factory. It is a constituent of an enzyme oxidases which enhance browning and fermentation (TRFCA, 1965; FRFK, 1986; Acland 1991; Ellis, 1966; Othieno, 1992). The noted improvement of fermentation of leaves harvested from foliar copper applied tea in this current study agrees with suggestions made by Acland (1991) that foliar spray of $CuSO_4$ could correct the problem of slow fermentation of tea leaves harvested from tea plants growing in tea soils of southern Tanzania. It was reported that short period of fermentation, contributes to improvement of quality characteristics for made tea whereby prolonging fermentation time reduces strength and briskness of the liquor (Keegel, 1965) also over and under fermentation reduces the color of the infusion (McIlroy, 1973).

Table 2 a. Effect of Foliar Applied Copper on Leaf Fermentation Time (minutes) and Quality of Made Tea.

Location	Rates	Days after treatment				Total score	% increase
		30	47	64	85		
Site one	0.00	152	150	150	149	16.93	0.0
	1.50	118	114	145	150	19.23	13.95
	3.00	112	120	150	151	20.03	18.32
	4.50	86	81	148	148	21.08	24.52
	6.00	81	78	140	149	21.43	26.59
Site two	0.00	158	155	150	NA	18.06	0.0
	1.50	114	107	140	NA	22.93	26.97
	3.00	90	120	133	NA	23.00	27.35
	4.50	84	100	137	NA	23.23	28.63
	6.00	80	80	135	NA	23.67	31.06

Table 2 b. Effect of Soil Applied Copper on Leaf Fermentation Time (minutes) and Quality of Made Tea.

Location	Rates	Days after treatment					Total score	% increase
		47	64	85	103	131		
Site one	0.00	150	151	148	NA	155	17.45	0.0
	2.50	149	145	127	NA	138	18.73	7.31
	5.00	147	143	122	NA	121	20.20	15.76
	7.50	147	141	122	NA	90	19.23	10.17
	10.00	147	139	124	NA	85	19.1	9.46
Site two	0.00	152	148	NA	146	NA	18.43	0.0
	2.50	152	138	NA	134	NA	19.37	5.1
	5.00	148	138	NA	119	NA	21.17	14.87
	7.50	150	135	NA	105	NA	20.13	9.23
	10.00	149	130	NA	100	NA	19.47	5.64

4.4 Effect of Foliar and Soil Applied Copper on Yield of Tea.

The effect of foliar and soil applied copper on the yield of tea at site one and two were as presented in Table 3 and Appendix 3. The yield of tea tended to decrease with increasing levels of folar applied copper at both sites. The decrease of tea yield was not statistically significant. However, at site one foliar application of 4.5 kg Cu/ha non-significantly increased the yield of tea by 4.17%. The decreases in yield were more pronounced for site two as compared to site one. The yield decreased up to 5.57% at site one while at site two the yield decreased 28.2% (Appendix 5 a). The trends of yields of tea with foliar applied copper obtained in this study somehow contradict with the results reported by Booston (1976) who reported smaller non-significant yield increase by 5.4% of mature Indian seedling tea as a result of aerial spray of $CuSO_4$.

The negative response of tea yield to foliar applied copper obtained in this study could have been attributed to several factors namely; differences in the number and size of tea plants hence LAI, pruning intensities and the uneven distribution of the spray, which could have been affected the absorption efficiency. However the undefined yield trends with foliar applied copper needs to be researched and investigated upon further.

At site one tea responded significantly ($P < 0.05$) to soil application of copper. At site two the response was not significant. Yield responses of up to 26.95 and 15.44 % were obtained for site one and two, respectively. At each site 5.0 kg Cu/ha gave the highest yield response. Rates of 2.5 and 10.0 kg Cu/ha at site one decreased yield non-significantly form control. Site one with 0.31 mg/kg DTPA extractable copper gave response only at 5.0 kg Cu/ha. The yield of tea at site two increased non significantly with increasing level of soil applied copper. The copper rates showed a general trend in the increase of yield of tea with increase of copper levels applied at site two.

The positive response of tea to soil applied copper in terms of tea yields obtained in this study conform with the result reported by Child (1955) who reported that soil application of copper increased both quality and yield of tea in Malaya. The decrease in yield observed at site one could be due to negative interaction between copper and other nutrients in the soil solution and exchange sites and on the absorption sites on surfaces of plant roots. The lack of well defined trend of yields of tea at site one calls for more research and investigation.

The deference in response of tea to soil applied copper in respect of yield between the two sites could be due to several factors like for example, deferences in initial amounts of available copper inthe soils, the number and size of the plants hence LAI, the intensity of pruning, the physical-chemical properties of the soils (clay contents, soil reaction, exchangeable bases and the like) and the plucking standards.

Table 3. Effect of Copper Application on Yield of Tea.

Foliar application			Soil application		
Rate kg Cu/ha	Luiga (site one)	Lugoda (site two)	Rate kg Cu/ha	Luiga (site one)	Lugoda (site two)
0.0	1031a	975.1a	0.0	1013b	957a
1.5	1023a	700.1a	2.5	937.5b	1013a
3.0	973.6a	847.8a	5.0	1286a	1108a
4.5	1074a	816.0a	7.5	1096ab	1108a
6.0	1008a	905.7a	10.0	974b	1045a
Mean	1022.12	848.94	Mean	1061.46	1046.3
CV	11.89%	22.23%	CV	11.05%	18.49%
LSD	228.9	335.3	LSD	220.9	364.3

Means in the same row followed by the same later are not significantly different from each other according to Duncan's New Multiple Range Test (DNMRT). *: ($P < 0.05$).

4.5. Effect of Foliar and Soil Applied Copper on Copper Contents in Third Leaf and Shoots (two leaves and a bud).

The contents of copper in the third leaf and shoots as affected by foliar and soil-applied copper at site one and tow are as presented in Table 4 a and b and Appendix5 b. The copper contents in third leaf and shoots increased with increasing levels of both foliar and soil applied copper. The increase of copper in third leaf was statistically significant for both foliar and soil applied copper. For shoots the increase in copper contents was significant for foilar applied copper whereas for soil applied copper the increase was not significant. However, copper contents in tea leaves (third leaf) for both foliar and soil applied copper were below the critical limit of 15 mg/kg (Bonheure and Wilson, 1992). For foliar copper application, the percent increase of up to 115.95 and 53.54 % in copper concentration in third leaf were obtained at site one and two, respectively (Appendix 5). In shoots, the increase in copper contents was 23.39% at 1.5 kg Cu/ha. The increase in both third leaf and shoots was statistically significant ($P < 0.05$). In the controls, the copper contents were far below the critical limit. The low levels of Cu in the controls are reflected in the poor fermentation ability of tea leaves in factories during processing. The low levels of copper in the third leaves could be a consequence of continuous removal of tender succulent young shoots, which contain high amounts of nutrients. Based on Bonheure and Wilson (1992) categorization, leaf copper contents in tea leaves are in the deficient category. Leaf copper contents in control reveals that tea plants growing in Mufindi are deficient in copper. These findings concur with findings reported by other workers on copper deficiencies in tea growing soils. For example, Othieno

(1992). Clowes and Mitini-Nkoma (1987) and Templer (1972) reported copper deficiency at Kericho-Kenya, Malawi and Uganda, respectively. In another studies, Harler, (1951) as cited by Child (1955) reported that copper contents in poor fermenting tea leaves from Mlanje area in Malawi ranged from 7 to 15 mg/kg. The copper contents of poor fermenting leaf in Tukuyu district southern Tanganyika (Tanzania) were reported to range from 7.9 to 13.1 with average of 11.0 mg/kg (Child, 1955). The observed increase of leaf copper contents conform to findings reported by Child (1955), Annett and Kar (1910), Tea Research Institute of Sri Lanka (1944) as cited by Child (1955).

Soil copper application significantly ($P < 0.05$) increased copper contents in third leaf at both site one and two. The increase of copper contents in shoots was not significant. The increase of up to 83.8 and 124.75 % in copper content in third leaf were obtained at site one and two, respectively in copper treated soils against control. Soil application of Cu at a rate of 2.5kg Cu/ha increased the Cu content, whereas there was a decrease from 2.5 kg/ha to 5 kg/ha. This is probably due to experimental error or soil variability. The increased copper contents in third leaf and shoots are reflected in the improved fermentation ability and quality of made tea of leaves harvested from copper treated soils against control (Table 2 a and b). However, the results show that copper contents in third leaves are below the critical level as was suggested by Bonheure and Wilson (1992). The low content of cooper in leaves is probably a consequent of high levels of iron in soils which were reported to induce copper deficiency (Landon, 1991), slow the uptake of copper by tea plant from soil due to fixation of applied copper by soil organic matter (Alva, 2000), clay, iron, aluminium or manganese (Tisdale *et al.*, 1993), the recently applied P which was reported to interfere with the supply of soil available copper to plants (Bingham, 1963) and the recently applied N which probably increased growth rate which could dilute the copper concentration in the crop. Increased N supply to crop was also reported to reduce mobility of copper in plants (Hill *et al.*, 1978).

The increase in copper content with increasing rates of applied copper could be attributed to increased availability of copper hence increased uptake of copper by the plants. The positive response to applied copper suggests that the observed levels of available copper in soils (Table 1) are not adequate for normal tea growth. In view of this, copper application to tea soils is being recommended for increased tea production and improved quality.

Generally, the concentrations of copper in third leaf were higher at site two as compared to site one for both foliar and soil applied copper. This might have been attributed to differences in soil DTPA extractable copper and textural classes of soils between the two sites. Site one had 0.31 mg/kg DTPA extractable copper whereas site two had 0.501 mg/kg DTPA extractable copper. The texture of soil of site one was clay, which has been reported to fix copper, while the texture of soil of site two was sand clay. Thus, there was more copper uptake from the soil by tea plants at site two than at site one.

Table 4 a. Effect of Foliar Copper Application on Copper Contents (mg/Kg) in Third Leaf and Pluckable Shoots.

Rates kg Cu/ha	Luiga (site one)		Lugoda (site two)	
	Third leaf	Shoots	Third leaf	Shoots
0.00	4.833c	11.37b	7.9c	NA
1.50	8.867b	14.03a	11.83ab	NA
3.00	8.800b	10.60b	9.133bc	NA
4.50	11.63a	11.33b	12.13a	NA
6.00	12.37a	10.20b	12.0a	NA
Mean	9.3	11.507	10.6	
CV	12.65%	6.08%	13.67%	
LSD	2.216	1.318	2.729	

NA: not applicable

Means in the same column followed by the same later are not significantly diffrent from each other according to DNMRT. *: ($p < 0.05$); **: ($P < 0.01$); ***: ($P < 0.001$).

Table 4 b. Effect of Soil Copper Application on Copper Content (mg/Kg) in Third Leaf and Pluckable Shoots.

Rates kg Cu/ha	Luiga (site one)		Lugoda site (two)	
	Third leaf	Shoots	Third leaf	Shoots
0.00	4.57c	7.337a	4.97c	NA
2.50	8.40a	7.9a	7.40b	NA
5.00	5.00bc	8.967a	10.67a	NA
7.50	5.70bc	9.1a	11.17a	NA
10.00	7.50ab	7.833a	11.13a	NA
Mean	6.23	8.23	9.07	
CV	20.56 %	19.02 %	3.94 %	
LSD	2.413	2.947	0.6736	

NA: not applicable

Means in the same column followed by the same later are not significantly different from each other according to DNMRT. *: ($P < 0.05$); **: ($P < 0.01$); ***: ($P < 0.001$).

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS.

5.1 Conclusions

(a) Foliar spray of copper improved fermentation and quality of made tea of clone 207 from both sites and lasted for about three months.

(b) Soil copper application improved fermentation and quality of made tea. The effect started two months after treatment and seemed to continue even after four months after treatment.

(c) Tea did not respond significantly to foliar copper application with respect to yield. There was a small non-significant yield increase of about 4.17 % at application rate of 4.5 kg Cu/ha at site one while the rest of the application rates decreased yield slightly. At site two, foliar application of copper decreased tea yield non-significantly.

(d) Soil copper application at 5.0 kg Cu/ha increased significantly ($P< 0.05$) tea yield at site one where as at site two the increase was not significant.

(e) Foliar spray of copper increased copper leaf concentration to above deficiency level according to Bonheure (1992). However, contents of copper found in leaf were within the subnormal level of copper contents in the third leaf. This might have been caused by loss of copper through continuous removal of succulent tender shoots, which contain high amount of nutrients. Thus, at the time of leaf sampling large amount of copper in the plant were already removed.

(f) Soil application of copper increased leaf copper contents significantly though the increase did not reach the adequate level for tea as was suggested by Bonheure (1992). This might have been caused by slow uptake of copper by plant form the soil. Thus, at the time of leaf sampling, only small amounts of copper had been taken up by tea plant.

(g) Soils containing less than 0.31 mg/kg DTPA extractable copper are likely to respond to soil application of copper with respect to yield.

5.2 Recommendations.

(a) Although foliar application of copper reduces the leaf fermentation time more than soil application and it has a more immediate effect, it is labor intensive as compared to soil application as it needs split application because its effect lasts shorter than soil application. Foliar application of copper can also cause contamination of copper on leaves, as not all copper applied is absorbed by tea leaves. In view of this, Soil application of copper at a rate of 5.0 kg Cu/ha is recommended to correct copper deficiency in well managed tea estates in Mufindi

(b) Further research is proposed to determine:

i lower levels and frequency of foliar application of copper on yield and of quality of made tea.

ii the effect of foliar copper application during cold season.

iii the major cause of reduction in tea yield with foliar application especially the role of other nutrients.

iv the effect of copper application on yield and quality of other clones and seed tea.

v the effect of copper application on the enzyme activity in leaves of tea.

vi the effect of applying other sources of copper on yield and quality of made tea.

vii the long term effect of soil copper application on yield, quality and status of other nutrients in soils and tea leaves.

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APPENDICES

Appendix 1 a. Effect of Foliar Copper Application on Fermentation and Tea Quality at Luiga (site one)

DAT	Rates kg Cu/ha	Fermenting time	Quality Rating				
			Strength of liqour	Color	Briskness	Infusion	Total score
30	0.00	152	3.0	5.6	4.4	4.0	17.0
	1.50	118	5.4	5.8	5.8	5.8	22.8
	3.00	112	5.4	6.0	5.8	6.0	23.2
	4.50	86	6.0	6.0	5.8	6.2	24.0
	6.00	81	6.0	6.0	5.8	6.2	24.0
47	0.00	150	3.2	5.8	3.6	3.2	15.8
	1.50	114	5.2	5.8	3.8	5.2	20.0
	3.00	120	5.4	6.0	4.0	5.4	20.8
	4.50	81	6.0	6.0	4.8	5.8	22.6
	6.00	78	6.0	6.0	5.6	6.0	23.6
64	0.00	150	3.8	5.8	5.0	5.8	15.4
	1.50	145	4.6	5.8	5.2	5.0	14.6
	3.00	150	5.0	5.8	5.8	5.8	15.0
	4.50	148	5.8	5.8	6.0	5.6	17.4
	6.00	140	6.0	5.8	6.0	6.0	18.0
85	0.00	149	3.5	4.5	3.5	3.0	14.4
	1.50	150	3.0	4.5	4.0	3.0	14.5
	3.00	151	3.0	4.5	3.0	3.0	13.5
	4.50	148	3.0	4.5	4.0	3.0	14.5
	6.00	149	4.0	4.5	3.0	3.0	14.5
Mean	0.0		3.38	5.43	4.13	4.0	16.93
	1.50		4.55	5.475	4.7	4.5	19.28
	3.00		4.7	5.575	4.65	5.1	20.03
	4.50		5.2	5.575	5.15	5.15	21.08
	6.00		5.5	5.575	5.1	5.25	21.42

DAT: days after treatment

Appendix 1 b. Effect of Foliar Copper Application on Fermentation and Tea Quality at Lugoda (site two)

DAT	Rates (kg Cu/ha)	Fermenting time	Quality Rating				
			Strength of liqour	Color	Briskness	Infusion	Total score
30	0.00	158	3.0	5.4	4.0	4.3	17.0
	1.50	114	5.8	6.0	5.8	6.0	23.6
	3.00	90	6.0	6.0	5.8	6.0	23.8
	4.50	84	6.2	6.0	6.0	6.0	24.2
	6.00	80	6.2	6.0	6.0	6.2	24.4
47	0.00	155	3.7	5.8	4.0	4.2	17.7
	1.50	107	5.8	6.0	6.0	5.6	23.4
	3.00	120	5.8	6.0	5.8	5.8	23.4
	4.50	100	5.3	6.0	5.0	5.8	22.1
	6.00	80	5.8	6.0	5.8	5.6	23.2
64	0.00	150	3.8	6.0	5.0	5.0	19.8
	1.50	140	4.6	6.0	5.8	5.4	21.8
	3.00	133	5.0	6.0	5.2	5.6	21.8
	4.50	137	5.8	6.0	5.8	5.8	23.4
	6.00	135	5.8	6.0	5.8	5.8	23.4
Mean	0.00		3.5	5.73	4.33	4.5	18.06
	1.50		5.4	6.0	5.87	5.67	22.93
	3.00		5.6	6.0	5.60	5.80	23.0
	4.50		5.77	6.0	5.60	5.87	23.23
	6.00		5.93	6.0	5.87	5.87	23.67

DAT: days after treatment

Appendix 1 c. Effect of Foliar copper Application on Tea Quality 30 Days after Treatment (fermented at fixed time, 70 minutes).

Location	Rates kg Cu/ha	Quality rating					
Luiga		Fermenting time	Strength of liqour	Color	Briskness	Infusion	Total score
	0.00	70	5.6	5.8	4.0	3.2	18.6
	1.50	70	5.6	6.0	5.0	5.6	22.2
	3.00	70	5.6	5.8	5.8	5.4	22.6
	4.50	70	5.8	6.0	5.8	6.0	23.6
	6.00	70	5.8	6.0	5.8	6.0	23.6
Lugoda							
	0.00	70	3.8	5.0	3.8	2.4	15.0
	1.50	70	3.8	6.0	5.4	5.6	20.8
	3.00	70	4.5	6.0	6.0	5.6	22.1
	4.50	70	4.8	6.0	5.2	5.8	21.8
	6.00	70	4.8	6.0	6.0	5.8	22.6

Appendix 2 a. Effect of Soil Copper Application on Fermentation and Tea Quality at Liuga (site one)

DAT	Rates kg Cu/ha	Fermenting time	Quality Rating				
			Strength of liquor	Color	Briskness	Infusion	Total score
47	0.00	150	4.0	5.8	4.6	4.8	19.2
	2.50	149	4.0	5.8	4.5	4.8	19.1
	5.00	147	3.8	5.8	4.6	5.0	19.2
	7.50	147	4.0	5.8	4.6	5.2	19.6
	10.00	147	4.0	5.8	4.6	5.2	19.6
64	0.00	151	4.0	5.8	4.0	4.0	17.8
	2.50	145	4.0	5.8	5.0	5.5	20.3
	5.00	143	4.8	5.8	4.8	6.0	21.4
	7.50	141	6.0	5.8	5.8	6.0	23.6
	10.00	139	6.2	5.8	6.0	5.6	23.6
85	0.00	148	4.0	4.5	3.5	3.8	15.8
	2.50	127	4.5	4.5	3.5	4.0	16.5
	5.00	122	4.5	4.5	4.0	4.2	17.2
	7.50	122	4.5	5.0	4.0	4.2	17.7
	10.00	124	5.0	5.0	4.0	4.2	18.2
131	0.00	155	3	5	4	5	17
	2.50	138	3	6	5	5	19
	5.00	121	4	7	6	6	23
	7.50	90	3	4	5	4	16
	10.00	85	3	4	4	4	15
Mean	0.00		3.75	5.275	4.025	4.40	17.45
	2.50		3.875	5.525	4.5	4.825	18.725
	5.00		4.275	5.775	4.85	5.3	20.2
	7.50		4.375	5.15	4.85	4.85	19.225
	10.00		4.55	5.15	4.65	4.75	19.1

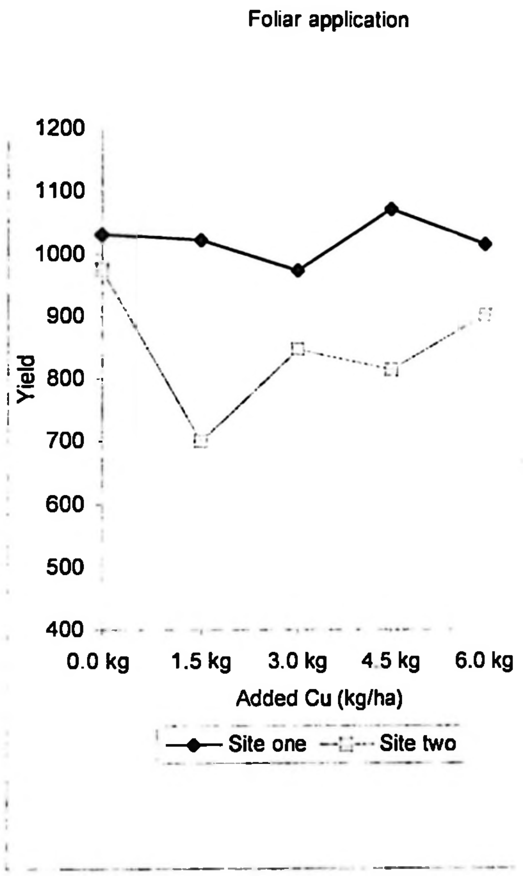
DAT: days after treatment

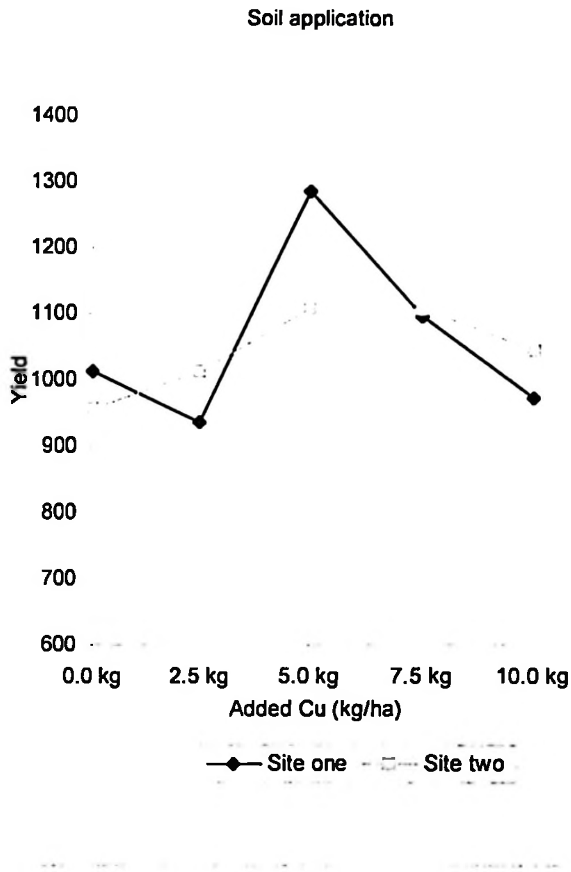
Appendix 2 b. Effect of Soil Copper Application on Fermentation and Tea Quality at Lugoda (site two)

DAT	Rates (kg Cu/ha)	Fermenting time	Quality Rating				
			Strength of liqour	Color	Briskness	Infusion	Total score
47	0.00	152	4.0	5.8	4.5	5.2	19.5
	2.50	152	4.2	5.8	4.5	5.0	19.5
	5.00	148	4.2	5.8	4.5	5.4	19.9
	7.50	150	4.2	5.6	4.8	5.0	19.6
	10.00	149	4.4	5.8	5.8	5.0	20.0
64	0.00	148	4.0	6.0	4.8	5.0	20.8
	2.50	138	4.8	6.0	5.0	5.8	21.6
	5.00	138	5.0	6.0	5.8	5.8	22.6
	7.50	135	6.0	6.0	5.8	6.0	23.8
	10.00	130	6.0	6.0	6.0	6.2	24.4
103	0.00	146	4.0	5.0	3.0	4.0	16.0
	2.50	134	5.0	5.0	3.0	4.0	17.0
	5.00	119	6.0	6.0	4.0	5.0	21.0
	7.50	105	4.0	5.0	4.0	4.0	17.0
	10.00	100	4.0	4.0	3.0	3.0	14.0
Mean	0.00		4.0	5.60	4.10	4.73	18.43
	2.50		4.67	5.60	4.17	4.93	19.37
	5.00		5.07	5.93	4.76	5.40	21.17
	7.50		4.73	5.53	4.87	5.00	20.13
	10.00		4.80	5.27	4.93	4.73	19.47

DAT: days after treatment

Appendix 3. Effect of Copper Application on Yields of Tea (kg of made tea/ha)





Appendix 4. Percent Yield Between Copper Levels.

Location	Foliar applied copper				Soil applied copper			
	0.0 and 1.5	0.0 and 3.0	0.0 and 4.5	0.0 and 6.0	0.0 and 2.5	0.0 and 5.0	0.0 and 7.5	0.0 and 10.0
Site one (Luiga)	-0.78	-5.57	4.17	-2.23	-7.45	26.95	8.19	-3.85
Site two (Lugoda)	-28.20	-13.05	-16.31	-7.12	5.54	15.44	15.44	8.88

Appendix 5. Percent Copper Levels in Third Leaves Between Copper Levels.

Location	Foliar applied copper				Soil applied copper			
	0.0 and 1.5	0.0 and 3.0	0.0 and 4.5	0.0 and 6.0	0.0 and 2.5	0.0 and 5.0	0.0 and 7.5	0.0 and 10.0
Site one (Luiga)	83.47	82.08	140.64	155.95	83.8	9.41	24.73	64.11
Site two (Lugoda)	49.75	15.61	53.44	51.9	48.89	114.69	124.75	124.94

Appendix 6 a. Factorial ANOVA Table for the Effect of Foliar Copper Application on Tea Yield at Site One (Luiga).

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
1	Replication	2	558868.294	279434.147	18.9065	0.0009
2	Factor A	4	16142.635	4035.659	0.2731	
-3	Error	8	118238.086	14779.761		
	Total	14	693249.015			

Coefficient of Variation: 11.89%

$s_{\bar{y}}$ for means group 1: 54.3687

$s_{\bar{y}}$ for means group 2: 70.1896

Appendix 6b. Factorial ANOVA Table for the Effect of Foliar Copper Application on Tea Yield at Site Two(Lugoda).

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
1	Replication	2	57561.523	28780.761	0.8085	
2	Factor A	4	127126.967	31781.742	0.8928	
-3	Error	8	284795.032	35599.379		
	Total	14	469483.521			

Coefficient of Variation: 22.23%

$s_{\bar{y}}$ for means group 1: 84.3794

$s_{\bar{y}}$ for means group 2: 108.9333

Appendix 7 a. Factorial ANOVA Table for the Effect of Soil Copper Application on Tea Yield at Site One (Luiga)

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
1	Replication	2	42976.888	21488.444	1.5608	0.2677
2	Factor A	4	231632.487	57908.122	4.2061	0.0400
-3	Error	8	110139.974	13767.497		
	Total	14	384749.349			

Coefficient of Variation: 11.05%

$s_{\bar{y}}$ for means group 1: 52.4738

$s_{\bar{y}}$ for means group 2: 67.7434

Appendix 7 b. Factorial ANOVA Table for the Effect of Soil Copper Application on Tea Yield at Site Two (Lugoda)

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
1	Replication	2	62250.232	31125.116	0.8313	
2	Factor A	4	49913.347	12478.337	0.3333	
-3	Error	8	299541.092	37442.637		
	Total	14	411704.671			

Coefficient of Variation: 18.49%

$s_{\bar{y}}$ for means group 1: 86.5363

$s_{\bar{y}}$ for means group 2: 111.7179

Appendix 8 a. Factorial ANOVA Table for the Effect of Foliar Copper Application on Copper Contents in Third Leaf at Site One (Luiga)

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
1	Replication	2	9.408	4.704	3.3968	0.0855
2	Factor A	4	105.713	26.428	19.0841	0.0004
-3	Error	8	11.079	1.385		
	Total	14	126.200			

Coefficient of Variation: 12.65%

$s_{\bar{y}}$ for means group 1: 0.5263

$s_{\bar{y}}$ for means group 2: 0.6794

Appendix 8 b. Factorial ANOVA Table for the Effect of Foliar Copper Application on Copper Contents in Third Leaf at Site Two (Lugoda).

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
1	Replication	2	0.144	0.072	0.0343	
2	Factor A	4	45.820	11.455	5.4561	0.0203
-3	Error	8	16.796	2.100		
	Total	14	62.760			

Coefficient of Variation: 13.67%

$s_{\bar{y}}$ for means group 1: 0.6480

$s_{\bar{y}}$ for means group 2: 0.8366

Appendix 8 c. Factorial ANOVA Table for the Effect of Foliar Copper Application on Copper Contents in Shoots at Site One (Luiga)

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
1	Replication	2	0.784	0.392	0.7996	
2	Factor A	4	26.863	6.716	13.6986	0.0012
-3	Error	8	3.922	0.490		
	Total	14	31.569			

Coefficient of Variation: 6.08%

$s_{\bar{y}}$ for means group 1: 0.3131

$s_{\bar{y}}$ for means group 2: 0.4043

Appendix 9 a. Factorial ANOVA Table for the Effect of Soil Copper Application on Copper Contents in Third Leaf at Site One (Luiga)

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
1	Replication	2	1.209	0.605	0.3682	
2	Factor A	4	32.647	8.162	4.9701	0.0261
-3	Error	8	13.137	1.642		
	Total	14	46.993			

Coefficient of Variation: 20.56%

$s_{\bar{y}}$ for means group 1: 0.5731

$s_{\bar{y}}$ for means group 2: 0.7399

Appendix 9 b. Factorial ANOVA Table for the Effect of Soil Copper Application on Copper Contents in Third Leaf at Site Two (Lugoda).

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
1	Replication	2	0.525	0.262	2.0542	0.1905
2	Factor A	4	92.453	23.113	180.9404	0.0000
-3	Error	8	1.022	0.128		
	Total	14	94.000			

Coefficient of Variation: 3.94%

$s_{\bar{y}}$ for means group 1: 0.1598

$s_{\bar{y}}$ for means group 2: 0.2063

Appendix 9 c. Factorial ANOVA Table for the Effect of Soil Copper Application on Copper Contents in Shoots at Site One (Luiga)

K Value	Source	Degrees of Freedom	Sum of Squares	Mean Square	F Value	Prob
1	Replication	2	15.092	7.546	3.0809	0.1018
2	Factor A	4	7.091	1.773	0.7238	
-3	Error	8	19.595	2.449		
	Total	14	41.779			

Coefficient of Variation: 19.02%

$s_{\bar{y}}$ for means group 1: 0.6999

$s_{\bar{y}}$ for means group 2: 0.9036