EFFECTS OF FOLIAR FERTILISERS CONTAINING MAGNESIUM, COPPER AND

ZINC ON YIELD AND QUALITY OF MATURE TEA.

By

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DECLARATION

I declare and certify that I have supervised this dissertation and it is now ready for evaluation

Name of supervisor

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Date

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DEDICATION

To my parents Mr and Mrs Mashingaidze and my future wife I. Duri

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ABSTRACT

Tea plantations of Southdown estate are deficient in nutrients such as Copper, Magnesium, and Zinc. This was shown by leaf analysis done in 2012 to mature tea in several tea gardens of Southdown estate. These nutrients have been given little attention in Zimbabwe tea fertilizer recommendations despite their continual removal from the tea fields during harvesting. A study was therefore conducted to assess the effect of Copper, Magnesium and Zinc foliar fertilizers on yield and quality of tea at Southdown estate, Chipinge in Zimbabwe. The experiment was laid in a randomized complete block design with 3 replications. The treatments were; no fertilizer application (control), Copper sulphate, Zinc oxide, Magnesium oxide and a combination of Copper sulphate, Magnesium oxide and Zinc oxide. The different foliar fertilizers affected yield (shoot weight and shoot density) significantly ($P<0.05$), Copper sulphate reduced the yield significantly, 27.3% lower than the control. Zinc oxide increased yield significantly, 23.82% higher than the control. Magnesium oxide did not have a significant effect on yield of tea. Tea quality parameters (brightness, briskness, colour of liquor, strength of liquor and milk take) were affected significantly ($P<0.05$) by the different foliar fertilizers. Copper sulphate gave the highest average score implying highest quality, whilst the control (no fertilizer application) gave the lowest total average score, thus the lowest yield. The different foliar fertilisers increased the quality of tea. Results from this study showed that application of Copper sulphate results in increase in quality but not in yield. Application Zinc oxide increases both yield and quality of tea. Application of Magnesium oxide results in increase in quality but not yield. Application of the combination of Copper sulphate, Magnesium oxide and Zinc oxide only improved quality but not yield of tea. There is need for further researches on the different concentrations of foliar fertilizers to determine the best concentration which improves both quality and yield of tea. There is also need to repeat the experiment for more than one season and also in different sites.

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CHAPTER 1: INTRODUCTION AND JUSTIFICATION

1.0 Background

Tea is mainly used in the manufacturing of beverages and traditional medicines for asthma and coronary diseases. Tea is also a source of minerals i.e. Manganese, Iron and Zinc (Wrobel *et al*., 2002). Tea, owing to its favourable effects on human health, currently enjoys a great popularity among other beverages worldwide (Ruan and Härdter, 2001). In Zimbabwe, tea industry plays a vital role in the economy. The total land under tea in Zimbabwe currently stands at about 10 000 hectares. Tea production is currently responsible for a total direct employment of about 17 000, supporting up to 76 000 people in Zimbabwe (Tanganda News, 2011). Zimbabwe exports 77, 2% of the total tea produced in the country, bringing in up to US$4, 5 million worth of foreign currency annually. Tea production in Zimbabwe makes up about 1,3% of the total global tea and is amongst the world's leaders in productivity (Buttler, 2007).

In spite of the economic importance of tea in Zimbabwe, the challenges affecting its production include drought stress, climate change, low soil pH and high costs of inputs which lead to low yield and poor quality of tea (Kagira *et al*., 2012). In Zimbabwe the major challenge in tea production is soil acidification (Nyasulu, 2006). Tea soils mostly become acidic due to fertilization with nitrogenous fertilizers which include ammonium nitrate and urea (Dang, 2005). Soil pH survey done on tea soils by Nyasulu (2006) showed a low pH status in Zimbabwean soils. The majority of Zimbabwean soils showed some pH levels below 4.5 which lead to unavailability of nutrients such as Copper,

Magnesium and Zinc to the crop. More recently, micronutrient deficiencies, such as Sulphur, Zinc, Boron, Copper, Iron and Magnesium have been observed in several tea plantations in Zimbabwe to be the key limiting factor to optimum yield and quality of tea (TRFCA, 2000).

Magnesium is important in the formation of chlorophyll. Since Mg^{2+} is a mobile ion in the plant systems, the deficiency begins in the older leaves. Yellowing of mature leaves, inter-vernal chlorosis and premature leaf fall are the typical symptoms of Mg^{2+} deficiency which is common in acidic soils (Wu Xun *et al*., 1997). Zinc plays a role in chlorophyll formation and is involved in production of plant hormone IAA which is responsible for shoot growth in tea (Alam and Raza, 2001). Zinc is not very mobile in the soil and is therefore often present in soil tests, but unavailable to the plant (Alloway, 2008). Zinc deficiency in tea is identified by very short internodes; chlorotic and small sickle shaped leaves and stunted auxiliary shoots (Verma, 1999). Copper is involved in chloroplast and protein formation. It is often deficient at high pH and on sandy leached soils. If deficient, it results in deformed and stunted growth and often cupping of leaves (Yruela, 2005). Copper is also an essential constituent of the enzyme polyphenol oxidase, which is vital for fermentation in tea therefore its deficiency affects quality of tea (Bonheure and Willson, 1992).

In Zimbabwe the current fertilizer recommendations for tea mainly focuses on the macronutrients which are Nitrogen, Potassium and Phosphorous. Little attention is given to nutrients like Copper, Magnesium and Zinc although they are required in small amounts; they are very essential in yield and quality of tea, (Sultana *et al*., 1978). Therefore there will be always a drain of these elements due to their use without

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replacement and this will lead to their deficiencies in tea plantations (Dale, 1971). Deficiencies of these nutrients leads to reduction in both yield and quality of tea and this could be addressed by foliar application of these nutrients. This study is therefore meant to determine the effects of copper, magnesium and zinc foliar fertilizers on yield and quality of tea in Zimbabwe.

1.1 Main objective

To determine the effects of foliar fertilizers containing copper, magnesium and zinc on yield and quality of tea.

1.2 Specific objectives

1. To determine the effects of foliar fertilizers containing copper, magnesium and zinc on yield components (shoot weight and shoot density) of tea.

2. To determine the effects of foliar fertilizers containing copper, magnesium and zinc on quality parameters (briskness, colour of liquor, colour of infusion and milk take) of tea.

1.3 Hypotheses

1. Foliar fertilizers containing copper, magnesium and zinc have a significant effect on yield components (shoot weight and shoot density) of tea.

2. Foliar fertilizers containing copper, magnesium and zinc have a significant effect on the quality parameters (briskness, colour of liquor, colour of infusion and colour with milk) of tea.

CHAPTER 2: LITERTURE REVIEW

2.1 Origin and distribution of tea

Tea belongs to the Theacia family and is the most important species of the *Camellia* genus. There are two major varieties which are the small leafed Chinese tea plant (*Camellia sinensis* var *sinensis*) and Assam tea (*Camellia sinensis* var *assamic*). The *Sinensis* tea originated from Sichuan in South-eastern China and the Assamica tea variety originated from the Asam forests in north-east India (Elliot and Whitehead, 1996). Due to extensive hybridization, most of the commercial cultivars grown at present have characteristics which lie between the *assamica* and the *sinensis* varieties (Mondal *et al*., 2004). Currently tea is now produced all over the world and the major producing countries are China, India, Indonesia, Sri Lanka, and Japan. Tea is also successfully grown in Africa, particularly in Kenya, Malawi, Zimbabwe, and South Africa (Greenop, 1997).

2.2 Production and importance of tea in Zimbabwe

In Zimbabwe tea was first planted in 1924 on an estate known as New Year's Gift in the Chipinge district of the Eastern Highlands of Zimbabwe (Ellis and Nyirenda, 1995). Tea growing did not really take off in Zimbabwe till the 1960s.The tea industry plays a vital

role to the economy of Zimbabwe. The total land under tea in Zimbabwe currently stands at 10 000 hectares. It is estimated to directly and indirectly employ about 20% of the people surrounding the tea estates (TRFCA news, 2011). Tea is one of the major export crops contributing about 7 to 8% to Zimbabwe export earnings (TRFCA, 2010). The two main tea-growing regions in Zimbabwe are the Honde Valley and Chipinge which are found in Natural region 11. Zimbabwean tea estates tend to be large and mechanized. Most tea is sold privately, and reaches the international market via the South African port of Durban. Zimbabwe produces youthful blending teas that give a full flavoured brew; it produces both black and red tea which is sold for the UK tea-bag market (TRFCA Annual report, 2010).

2.2 Challenges in tea production

The challenges affecting tea production in Zimbabwe are drought stress, climate change, low soil pH, high costs of inputs, use of old tea gardens and lack of knowledge which lead to low yield and poor quality of tea (Kagira *et al*., 2012). In Zimbabwe the major challenge in tea production is the depletion of soil fertility due to soil acidification (Nyasulu 2006). Tea soils mostly become acidic due to fertilisation with nitrogenous fertilisers which include ammonium nitrate and urea (Dang, 2005). Most estates in Zimbabwe are focussing on the production of bulk undifferentiated tea leading to production of low quality tea. This challenge can be addressed by adopting improved varieties of tea, applying right amount of fertilizer and application of manure.

2.3 Soil requirement for tea production

Tea is generally cultivated in a wide range of soil types but specific soil characteristics are required for successful tea cultivation (Goswami *et al*., 2001). For optimum growth

and shoot development it requires deep well drained, permeable acidic soils with pH range of 4.5 to 5.5 (De Silva, 2007). Some reports indicated that a pH range of 4 to 6 is ideal to tea (Othiena, 1992). A soil depth of at least 2m, crumbly structured soil with about 50% pore space are required for optimum growth of tea (Tchienkoua and Zech, 2004). Tea grows well in soils of texture ranging from sandy loam to clays, silts and loams of all kinds, however due to their low field capacity sandy loam soils are not desirable unless a mechanism for a good distribution of water and nutrients is implemented (Solomon *et al*., 2002). In Zimbabwe, tea is grown in the Eastern Highlands where the dominant rock types are dolorite, shale, schist, siltstone, sandstone, quartzite and gneiss. These areas show a characteristic of othoferrallitic soils which are relatively poor in their nutrient status so they are not used for normal cultivation and are largely taken up by forestry and the growing of tree crops, especially tea and coffee (Nyamapfene, 1991).

2.3.1 Acidification of tea soil

Acidic soils are common in tea gardens. Tea soils are acidified by the tea plants themselves due to deposition of large quantities of organic acids (Dang, 2005). Use of nitrogenous fertilizers such as ammonium sulphate, ammonium nitrate and urea also leads to soil acidification in tea soils (Dang, 2005). Tea requires large amounts of nitrogen fertilizer (260kgN ha^{-1}yr^{-1}) since the vegetative parts (shoots) contribute to yield. The use of high levels of nitrogen increases the levels of aluminum therefore decreasing soil pH and levels of exchangeable cations (Ruan *et al*., 2006).

Deficiencies of nutrients is common in low pH soils since the soil conditions would not allow for efficient uptake of nutrients and this is due to Al toxicity. Al toxicity is the

major factor limiting plant growth in tea and this will be responsible for low yield and poor quality of tea. A study by Fung *et al*. (2008) showed that the uptake of Cu, Zn and Fe were reduced by Al treatments. Acidification in tea plantations also arises from prunnings which are left in the field after pruning. Decomposition of the prunnings releases organic acids which acidify rhizosphere leading to high levels of Al (Jin *et al*., 2008).

2.4 Tea nutrition requirements

Tea requires various nutrients for normal growth and productivity like all other plants. Mostly plants acquire the nutrients from the soil except for small quantities of nitrogen and other elements that can be obtained from air and rain water through absorption by the leaves (Kamau, 2008). Excessive and inappropriate fertilizer use may lead to reduced yields, low tea quality, and nutrient imbalances in the soil with consequent environment degradation (Wachira, 2010). Since soil cannot supply adequate quantities of the plant nutrients, growers should supplement the soil nutrients with fertilizers. In tea, the harvesting involves the removal of young tender shoots which contain considerable amounts of nutrients. The main elements that are removed during harvesting are nitrogen, phosphorus, potassium, magnesium, copper and zinc. The quantities which are lost depend on the area of production, cultivar and the type of cultivar (Owuor *et al*., 2000). Nitrogen removal during plucking ranges from 40 to 160kg/ha assuming made yields of 1 to 4 t/ha (Kamau, 2008). According to Sedaghathor *et al*. (2009), in the shoots ready for harvesting there will be high levels of nitrogen followed by potassium and phosphorus. Harvested shoots contains 3-5% nitrogen on dry matter. Other nutrients are removed

during harvesting of the tea shoots in small amounts and these include Mg, S, Ca, Fe, Mn, B, Cu, and Zn (Kamau, 2008).

2.5 Significance of Copper, Zinc and Magnesium in tea production

Copper, magnesium and zinc are among essential nutrients required in plant nutrition. Although they are required in small amounts, they have very important roles in crop physiology (Alam *et al*., 2007). The elements take part in important biochemical reactions within the plant and they also form part of the enzymes in plants of which some of the enzymes aid in metabolism of photosynthetic products and in the reduction of oxidase stress (Fernandes and Henriques, 1991). Copper for example is associated with enzymes like cytochrome oxidase, phenols, polyphenol oxidase and Copper also aids in the chlorophyll synthesis and metabolism of carbohydrates and proteins (Alam and Raza, 2001). Zinc is required in the production of growth regulators such as indole acetic acid (IAA) and it also acts as an activator of a number of enzymes (Raza, 2001). Magnesium is an essential part of chlorophyll and it also adds the formation of sugars, oils and fats.

2.5.1 Importance of Copper in tea production

Cu is one of the essential elements in plant nutrition, it exists in two oxidation states which are Cu^{2+} and Cu^{3+} (Yruela, 2005). It also acts as a structural element in regulatory proteins. Copper also takes part in the photosynthetic electron transfer, mitochondrial respiration, oxidative stress responses, cell wall metabolism and hormone signaling (Yruela, 2005). According to Fernandes and Henriques (1991), most copper containing metalloenzymes are involved in catalyzing redox reactions since copper has a high redox potential which makes it very reactive with oxidants. It forms part of the superoxide dismutase, which is a Cu and Zn containing enzyme. This enzyme is associated with the

chloroplast and according to Alscher *et al*., (2002) it is the first line of defense against redox oxygen species formed by different compartments of the plant cell such as mitochondria, microsomes, glysomes, peroxomes, apoplasts and cytosol. Copper has significant effects on the yield and quality of tea and its effects has been reported by a number of authors (Barua and Dutta, 1972; Gartrell, 1981; Wilson and Clifford, 1992; Barooah *et al*., 2005; Saikh 2007). In terms of tea quality, copper is an essential element for the formation of polyphenol oxidase, an essential copper containing enzyme, catalyst in the fermentation process of black tea manufacturing (Seenivasan *et al*., 2008). Copper also plays an important role in enhancing processes involved in the pro-oxidant actions of tea polyphenols, this is an important mechanism for their anti-cancer properties (Azam *et al*., 2004). According to Azam *et al*. (2004), the oxidation of catechins by copper to form anti-cancer pro- oxidants makes it an important element when the market will be focusing on tea health benefits. Copper has been also applied as a fungicide in tea as copper hydroxide, Copper oxychloride and Copper oxide (Barua and Dutta, 1972; Saikh, 2007).

Both deficient and excessive levels of Copper are detrimental to plant growth and development. The deficiencies of Copper are mostly found in young leaves and reproductive organs (Yruela, 2005). Its deficient plants exhibit an alteration in the expression of certain genes and the activation of morphological changes for example root and leaf pose (Loustalot *et al*., 1949). Some typical Copper deficiencies are also found in young leaves and also extent downwards along leaf margins where malformation of leaves, chlorosis and necrosis occurs; its deficiency also results in plostocyanin which leads to a reduction in photo system 1 electron transport (Yruela, 2005). Inhibition of

photosynthesis and suppression of enzyme activities are the major causes of excess Copper in plants (Alaoui – Sosse *et al*., 2004). According to Yruela, (2005) the redox recycling of Cu^{2+} and Cu^{+} catalyses the production of highly toxic hydroxyl radicals which damages DNA, lipids, proteins, and other bimolecules.

2.5.1.1 Factors affecting availability and uptake of Copper from the soil

The total Copper available in the soil cannot be related to plant uptake and the application of Copper to the soil cannot be related to the increase in plant Copper levels (Fernandes and Henriques, 1991). In the soil Copper is available in a various forms i.e. water soluble, exchangeable, organically bound, associated with carbonates and hydrous oxides of Iron, Manganese, and Aluminium, it is also available in residual form (Zhang *et al*., 2006). It has reported that Copper exists in soil as organically bound (Stevenson, 1991) and residual forms or as acid soluble forms (Alva *et al*., 2000). The main factor controlling the uptake of Copper from the soil is pH besides organic matter content, clay content and total Copper available in soil.

2.5.2 Importance of Zinc in tea production

Zinc is an essential micronutrient, it has a physiological function in all living systems, and it is a co-factor of a number of enzymes in biochemical pathways that are concerned with carbohydrate metabolism in photosynthesis, protein metabolism, auxin growth regulators, pollen formation, and the maintenance of membrane integrity (Alloway, 2008). According to Barbora et al. (1993) application of $1 – 2\%$ $ZnSO_4$ increased nitrate reductase activity and resulted in 15- 20% increase in nitrogen and protein content of tea shoots, this shows that Zinc is also involved in nitrogen metabolism in plants. Zinc is also required for the synthesis of IAA which is responsible for shoot growth in tea

(Sedaghathoor *et al*., 2009). It also play a role in photosynthesis and mobilization of assimilates and it has shown to mobilize photosynthesis towards pluckable shoots in tea (Barbora *et al*., 1993). Zinc also increases the caffeine content in tea (Alloway, 2008). Inadequate supply of Zinc affects chlorophyll content, stomatal conductance and net photosynthesis (Sedaghathoor *et al.*, 2009) therefore it plays an important role in shoot weight and shoots density. Reduced leaf size and stunted growth are the most visible symptoms of Zinc, and this is a result of disturbances in the metabolism (Alloway, 2008). In tea, Zinc deficiency include sickle shaped leaves, wavy leaf margins, greenish – yellow chlorosis and resetting of flushing shoots (Barbora ., 1993). The effect of Zinc on yield of tea has been reported by several authors (Barua and Dutta, 1972; Malenga, 1986; Fung and Wang, 2001). In India addition of Zn showed a 20% increase in yield of tea (Fung and Wang, 2001).

2.5.2.1 Factors affecting Zinc availability and uptake
A number of factors affect the availability of Zinc to the plants, and these include the presents of other nutrient elements, growing conditions and the physical properties of the soil (Barbora *et al*., 1993). Most the tea soils in Zimbabwe are Zinc deficient and the application of Zinc has been recommended to promote shoot growth, therefore increasing yield (Verna, 1999). Zn deficiency is mostly found in the following conditions: sandy soils, low pH, high weathered parent materials, and calcareous soils, salinity soils, peat and muck organic soils, high phosphate status, prolonged water logging, high magnesium content and in soils with bicarbonates (Alloway, 2008). According to Zhang *et al.* (2006), at high pH Zn has a tendency of being bound to carbonates and it also has a tendency of being bound to oxides and organic matter.

In Zimbabwe, soil acidification and high levels of organic matter are common in tea plantations therefore Zinc deficiency are expected to be common in tea plantations (Rahman and Sharma, 1974). Soil moisture also plays a role in the uptake of Zinc since its deficiency has been reported during periods of prolonged dry spells. High rainfall also aid to the uptake of Zinc due to a higher capacity of the roots to exchange cations in the soil (Sud *et al*., 1995). Investigations on the tea shoots also showed a deficiency of Zinc under higher temperatures due to increase in Manganese uptake since Zinc and Manganese are antagonistic with respect to their uptake by plants (Sud *et al*., 1995). Zinc has also showed a negative interaction with Phosphorus where the increase in Phosphorus availability decreases the Zinc concentration in the plant shoots (Lonerogan and Webb, 1993; Alam *et al*., 2007 and Alloway, 2008). Zn is readily absorbed from the soil by tea plants therefore its deficiency in tea cannot be corrected by soil application of Zn, foliar application is the most effective method in correcting Zn concentration in plants (Sedaghathoor, 2009).

2.5.3 Importance of Magnesium in tea production

The importance of Magnesium in crop production was under estimated in the last decades (Cakmak and Yazici, 2010). Compared to other nutrients little attention has been paid on this mineral nutrient by agronomists and scientists in the last decades, therefore, the term 'the forgotten element' was introduced to name magnesium (Cakmak and Yazici, 2010).

Magnesium is the central core of the chlorophyll molecule in plant tissue. It also helps to activate specific enzyme systems (Rehm *et al*., 2002). And the acute Magnesium deficiency is typically correlated with visible inter-veinal chlorosis and growth reduction,

whereas the more frequent latent deficiency is often not visible and is difficult to diagnose (Romheld and Kirkby, 2007). Development of chlorosis requires preceding degradation of chlorophyll, since Magnesium acts as central atom in the chlorophyll molecule. As Magnesium is strongly bound to this molecule, chlorosis appears to be a late response to Mg deficiency. In plants well supplied with Magnesium only about 20 % of the total Mg is bound to chlorophyll, whereas the remaining is present in more mobile forms (Marschner, 2012). The mobile forms of Mg^{2+} are readily translocated within the plant to actively growing plant parts acting as sink (White and Broadley, 2008). Consequently, due to the high mobility under Mg starvation, deficiency symptoms typically appear on older leaves of the plant (Bergmann, 1992). As chlorosis is a late visible response to Mg deficiency considerable decreases in shoot density and shoot weight can be expected.

There is some evidence that Magnesium plays specific roles in dry matter formation and carbon partitioning to sink organs, as under Magnesium deficiency carbohydrates accumulate in source leaves only (Ding *et al*, 2006).

2.5.3.1 Factors affecting uptake and availability of Magnesium in the soil
The availability of Magnesium to plants depends on the distribution and chemical properties of the source rock material and its grade of weathering. It also depends on site specific, climatic and anthropogenic factors. Agricultural systems and the agronomic management practices established at the specific production site including the cultivated crop species and crop rotation, cropping intensity and organic and mineral fertilization practice also affect the availability of magnesium in the soil (Mikkelsen, 2010).

2.6 Significance of foliar spraying of nutrients in tea production

Foliar spraying of fertilizers is the application of nutrients to the plants through the leaves. Foliar spraying is of an advantage over soil application since it requires lower application rates than soil application. It also allows correction of deficiencies in less time; also uniform application is easily achieved (Fageria *et al*., 2009). Foliar spraying allows application of elements such as Copper, Zinc and Magnesium which are not mobile in both soil and the plant (Durzan, 1995). Foliar spraying is meant to raise the concentration of element directly in the leaves since in the soil nutrients are victimised by a number of processes such as mineralisation, leaching, run-off which leads to the unavailability of the nutrient to the plant (Amiri *et al*., 2009).

However, in foliar application there is a risk of leaf burn especially when a high concentration is used. Leaf scorch was reported when a concentration greater than 1% $CuSO_4$ was used (Ellis, 1971). Foliar applied nutrients have short lived effects than soil applied nutrients though it reduces the contamination of ground water with the elements. Foliar application may also be expensive since it does not have a residual effect, more spraying rounds are required than soil application (Fageria *et al*., 2009).

The effectiveness of foliar applications is influenced by factors like the rate at which the element is absorbed and transported by the plant from the leaves to other parts of the leaves that includes the roots (Haslett *et al*., 2001). Elements are transported via the phloem so their transportation depends on the mobility of element in the phloem. Some elements are not phloem mobile for example iron, manganese and calcium but elements like Copper, Zinc and Magnesium are reported to be partially phloem mobile (Newett, 2005). Absorption of foliar applied nutrients depends on the permeability of the leaf cuticle. This permeability is affected by factors such as leaf surface area, stomata

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aperture, density of the stomata and concentration of the nutrients (Durstberger *et al*., 2008).

The applied nutrients enter the plant by diffusion through the leaf cuticular membrane through the stomata. The stomata is the pathway which the nutrients enters the plant tissues therefore the stomata plays a vital role in foliar application (Fernandes and Eichert, 2009). The nutrients progresses to the plasma membrane by active transport and this has been reported to be possible with the aid of connecting tissues known as the ectodesmata (Wojcik, 2004).

Foliar application of nutrients is also affected by environmental factors such as relative humidity, light, solar radiation and pH of the nutrient solution. These factors affect the functionality of the nutrient solution. Relative humidity affects the penetration of elements through the cuticular membrane (Schonherr, 2002). High humidity favours entry of elements across the cuticle due to swelling of the cuticular membrane which loosens the components of the cuticle (Wojcik, 2004). Temperature and solar radiation affects the absorption of the nutrients in the sense that they affect active transport therefore absorption is higher in the light than in the dark (Fageria *et al*., 2009). Also a negative effect by higher temperatures has been reported since at this regime there is a higher evaporation of the elements (Pulschen, 2004). Other factors that affect foliar application includes leaf area index where the larger the leaf area index the larger the area for interception (Fageria *et al*., 2002).

CHAPTER 3: MATERIALS AND METHODS

3.0 Site description

The experiment was carried out at Southdown Estate. It is 41km east of Chipinge town along eastern border road. The site is at latitude of 20, 27° East and at a longitude of 32, 42^0 West and at an altitude of 765meters above sea level. The temperature for this area ranges from a minimum of 15^0C in winter to a maximum of 29^0C in summer. Southdown Estate is in Natural region 11; the average rainfall received is 1 305mm/annum. The dominant rock types are dolerite, quartzite, siltstone and sandstone. The area is characterised by sandy loam soils on higher slopes and black clay soils on the lower valleys. The soils are acidic, pH ranging from 3 to 5 resulting in a relatively poor nutrient status. These soils are not suitable for cultivation and are largely used for forestry and the growing of tree crops, especially tea and coffee (Nyamapfene, 1991).

3.2 Experimental design and treatments

The experiment was laid in a Randomised Complete Block Design (RCBD) with 4 replicates and slope was the blocking factor. The experiment consisted of 5 treatments (Table 3.1)

Table 3.1: Treatment combinations of different foliar fertilisers used

Treatment	Description
1	No fertiliser application (control)
2	1% Copper sulphate(4.35kg Cu ha^{-1})
3	1.25kg/ha Zinc oxide(1kgZn ha^{-1})
4	1.25kg/ha Magnesium oxide(1kgMg ha^{-1})
5	1% Copper sulphate (4.35kgCu ha^{-1}), 1.25kg/ha Zinc oxide (1kgZn ha^{-1}), 1.25kg/ha Magnesium oxide, 1kgMg ha^{-1})

3.3 Tea variety used

In the experiment mature tea of variety Benjani was used. It is one of the highest yielding

tea varieties in Zimbabwe. The variety was planted in 1980.

3.4 Application of Copper, Magnesium and Zinc foliar fertilisers

Copper was applied as Copper sulphate which is soluble in water at 1% concentration; at

a rate of 4.35kg Cu ha^{-1}. Zinc was applied as zinc oxide at a rate of 1.25kg/ha, this gives

1kgZn ha^{-1}. Magnesium was applied as Magnesium sulphate at a rate of 1.25kg/ha, this

gives 1kgMg ha^{-1} (Table 3.1). Application of the different foliar fertilizers was done

using a 20litre knapsack. The knapsack was calibrated according to Rattan (1988) and

this was done to ensure the evenly distribution of the foliar fertilizers and the application

of the correct dose. Spraying was done once a month starting from July 2013 to November 2013. Spraying of the foliar fertilizers was done in the morning to prevent it from volatilization due to heat in the afternoon and was also done immediately after plucking. Spraying was not done in the rains to prevent the washing away of the fertilizers. No surfactants were used in this experiment.

3.5 Agronomic procedure

3.5.1 Plot size
There were a total of 111 bushes in each plot with an in-row spacing of 0.75m and inter-row spacing of 1.2m giving a plant population of 11 111plants/ ha. To guard against drift, there were 4 border rows which separate each plot.

3.5.1 Fertiliser application
Compound T (26:6:10) was applied twice at a rate of 500kg/ha (130kgN) as a basal fertiliser. The fertiliser was applied in November 2012 and February 2013 using the broadcasting method.

3.5.2 Irrigation
The tea was solely under rain fed conditions and the total rainfall received for the 5 months was 511mm.

3.5.3 Weed management
Mechanical weeding was done using hoes and knives. Weeding was done after every 3 weeks for the 5 months. The most problem weeds were black jack, climbers and *Lantana camara*.

3.5.4 Pruning

 The tea was under a three year pruning round so as to maintain the plucking table height (60 – 100cm). Pruning is the cutting down of all or most of the branches. This is done to prevent the overgrowing of the bush so as to maintain plucking table height. The bushes in this experiment were one year after pruning and the table height was 65cm.

3.5.5 Harvesting

Harvesting was done using shear machines. It was done on tender shoots which are 2 leaves and a bud and 3 leaves and a bud. Harvesting was done at every 12th or 13th day. The plucked shoots were weighed and transported to the factory.

3.5.6 Processing

Processing was done at Southdown Estates factory. The freshly plucked shoots were loaded in withering trough at a rate of 5 kg m^{-2}. Ambient air was passed through the leaves for 18 hours to bring about adequate physical and chemical withering. The withered leaves were passed through a mini CTC (Crush, Tear and Curl) machine for maceration (disruption of the intracellular compartments) (Muthumani and Kumar, 2007). The macerated leaf (dhool) was fermented (oxidised by an oxidative enzyme called polyphenol oxidase) for 30, 90 and 120 minutes at 20, 25 and 30 ˚C. Fermentation was done in environmentally controlled units. Fermentation was terminated by drying in a miniature fluid bed dryer to a final moisture content of 3%.

3.5.7 Leaf analysis

Leaf samples from 120 bushes were collected in prior to the trial. The leaf samples comprised of the 2nd and the 3rd leaf from the selected shoots. The samples were sent to TRFCA and were analysed for macro (N, P, K and Mg) and micro nutrients (B, Cu, Fe

and Zn). The nutrients were analysed using standard methods of analysis adopted from the Laboratory (Alloway, 2008).

3.6 Measurements taken

3.6.1 Shoot weight (kg/ha)

From the 111 bushes, total mass of the harvestable shoots (2 leaves and a bud and 3 leaves and a bud shoots) from each plot was measured using a 50kg scale at every plucking round and recorded. A total of 11 plucking rounds were done in this experiment. The weighed mass was converted to made tea yield by multiplying the unprocessed tea weight by 22%, according to methods by Grice (1990)

3.6.2 Shoot density (shoots m^{-2})

The number of shoots was measured using a 50cm^2 quadrant. The quadrant was thrown randomly on the plucking table in each plot and the number of shoots in the quadrant was counted. The shoots which were counted consist of 2 and 3 leaves and a bud (harvestable shoots). The quadrant was thrown 4 times in each plot and the average number of shoots was calculated. Shoot density was calculated by the following formula:

$$\text{Shoot density/m}^2 = \frac{\text{number of shoots}}{\text{land area}}$$

3.6.3 Made tea quality

A sample of 2kg green leaf from each plot was collected every month from July to November. Each of the samples was processed into black tea in the Mini Processing Unit at Southdown estate factory. From the processed tea a sample of 100g from each plot was taken for sensory evaluation and this was done by professional tea tasters of Southdown Estate. The parameters that were evaluated are: brightness, briskness, colour of infusion,

colour with milk and strength of the tea. The evaluation was done using a tea tasters

scoring scale which ranges from 1 to 5, 1 being the lowest grade and 5 being the highest

grade (Table 3.2) (Clowers and Mitini-Nkhoma, 1987)

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Table 3.2 Black Tea Score Sheet (Adapted from Clowers and Mitini-Nkhoma, 1987)

Briskness	5. Very brisk
	4. Brisk
	3. Fairly brisk
	2. Not brisk
	1. Coarse
Brightness	5. Very bright
	4. Bright
	3. Fairly bright
	2. Dull
	1. Greenish
Strength of Liquor	5. Pungent
	4. Strong
	3. Fair strength
	2. Soft
	1. Harsh
Colour of Liquor	5. Coppery
	4. Very bright
	3. Bright

	2. Fairly bright
	1. Dull
Milk take	5. Creamy
	4. Very thick
	3. Thick
	2. Fairly thick
	1. light

3.7 Data analysis

Analysis of variance was done on yield data (shoot weight and shoot density) using Genstat 14th edition. Score data on quality (briskness, brightness, strength of liquor and milk take) was first transformed using the square root transformation prior to analysis. Separation of means was done using Least Significance Difference (LSD) at 5% level of significance.

CHAPTER 4: RESULTS

4.1 Effects of different foliar fertilisers on shoot weight

There was a significant difference ($p < 0.05$) on the effects of different foliar fertilisers on the shoot weight of tea. Zinc oxide resulted in the highest yield of 1362kg/ha. Yields from the control (no fertiliser application), Magnesium oxide and a combination of Magnesium oxide, Zinc oxide and Copper sulphate were statistically similar. Copper sulphate produced the lowest yield of 800kg/ha (Figure 4.1).

Figure 4.1 Effects of different foliar fertilisers on shoot weight.

4.2 Effects of different foliar fertilisers on the mean shoot density of tea.

There was a significant difference ($p < 0.05$) on the effects of different foliar fertilisers on the shoot density of tea. Zinc oxide produced the highest shoot density of 25.75shoots/m^2. Shoot density from the control (no fertiliser application), Magnesium oxide and a combination of Magnesium oxide, Zinc oxide and Copper sulphate were statistically similar. Copper sulphate produced the lowest shoots density (20.25shoots/m^2) (Figure 4.2).
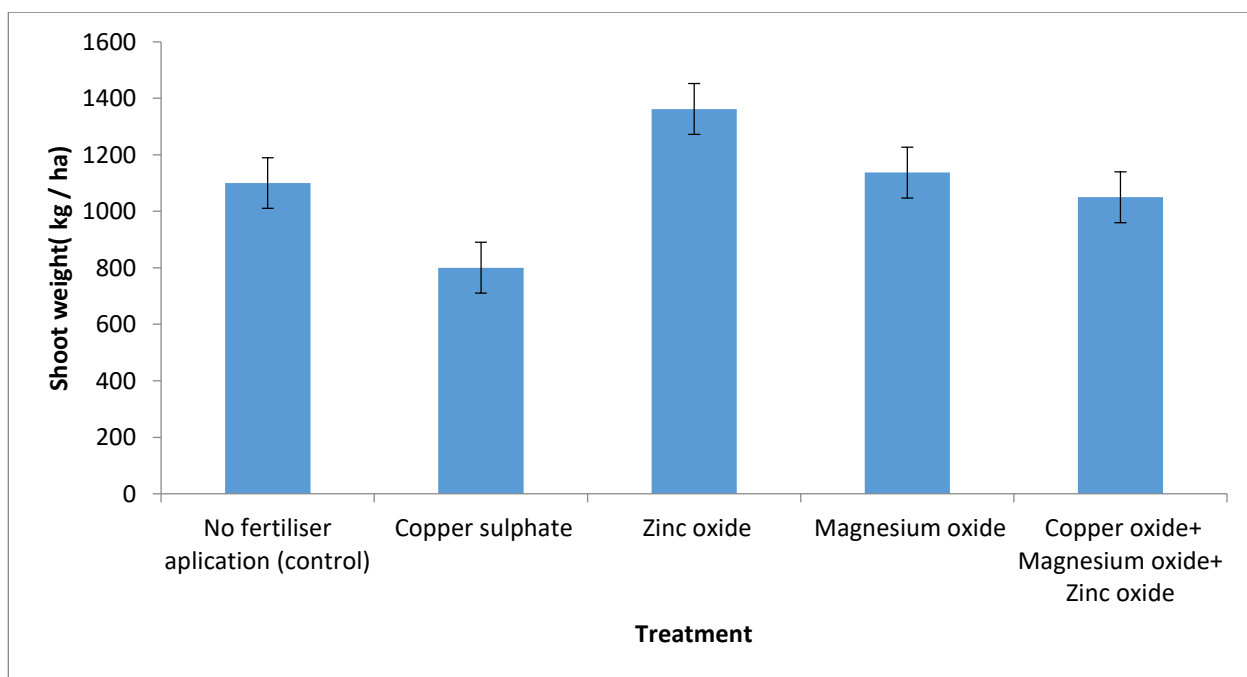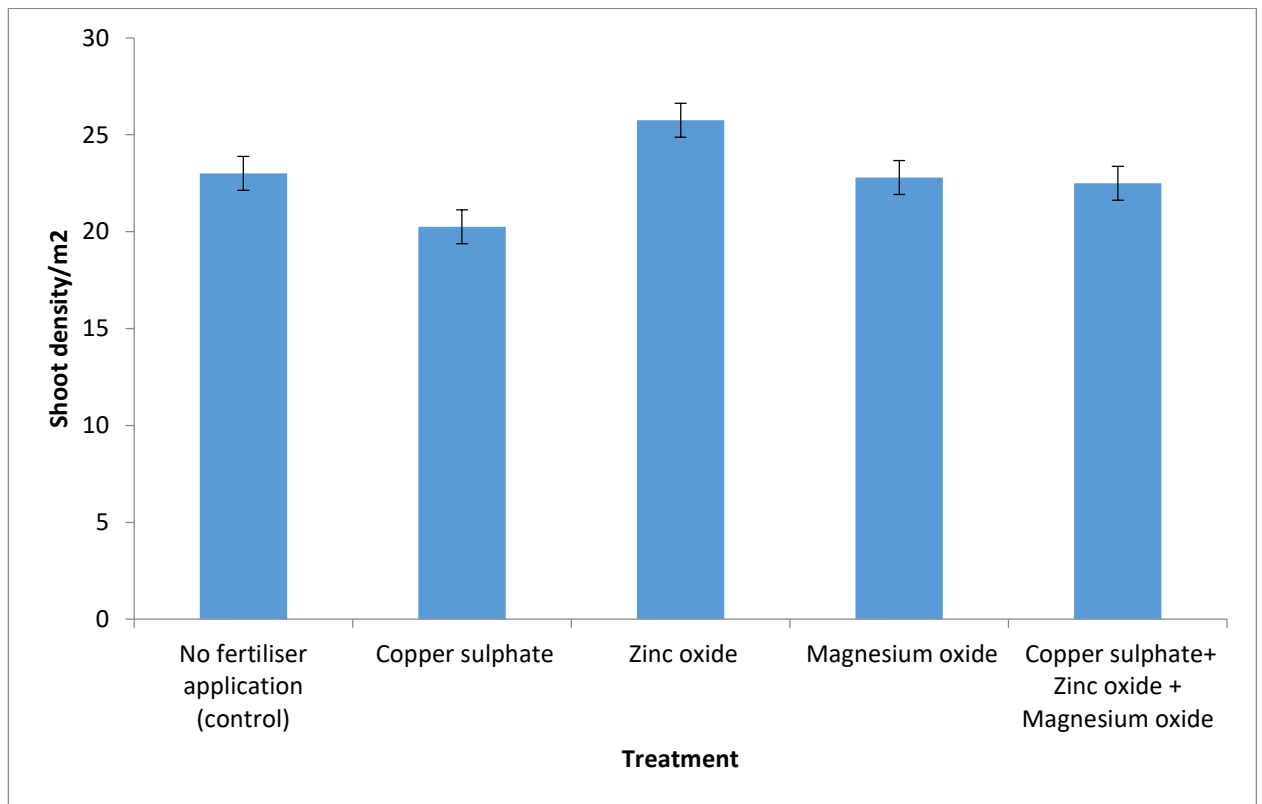

Figure 4.2 Effects of different foliar fertilisers on the mean shoot density of tea.

4.3 Effects of different foliar fertilisers on made tea quality

There was a significant difference (p<0.05) on the effects of different foliar fertilizers on the quality of made tea (Table 4.1). On brightness tea treated with copper sulphate had the highest average score of 1.85. Zinc oxide, Magnesium oxide and a combination of Copper sulphate, Magnesium oxide and Zinc oxide had statistically similar average scores. The control (no fertilizer application) had the least average score of 1.5 (Table 4.1).

Table 4.1 Effects of different foliar fertilisers on made tea quality

Treatment	Quality parameters					
	Briskness	Brightness	Colour of liquor	Strength of liquor	Colour with milk	Total
No foliar application (control)	(1.510) 2.551[ab]	(1.500) 2.549[a]	(4.100) 3.017[a]	(4.000) 3.000[ab]	(4.200) 2.669[ab]	15.31[a]
Copper sulphate	(2.462) 2.732[c]	(1.850) 2.617[c]	(4.752) 3.123[d]	(3.900) 2.983[a]	(4.710) 2.664[a]	17.68[d]
Zinc Oxide	(1.545) 2.558[b]	(1.625) 2.574[b]	(4.515) 3.085[b]	(4.100) 3.017[bc]	(4.408) 2.673[bc]	16.19[b]
Magnesium oxide	(1.475) 2.545[a]	(1.475) 2.545[a]	(4.607) 3.100[c]	(4.225) 3.037[c]	(4.535) 2.678[c]	16.42[c]
Copper sulphate + Zinc Oxide + Magnesium oxide	(1.500) 2.550[ab]	(1.575) 2.564[ab]	(4.600) 3.098[c]	(4.150) 3.025[bc]	(4.500) 2.675[bc]	16.32[bc]
LSD	0.00893	0.02100	0.01018	0.18230	0.00799	0.20150

P	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
%CV	6.2	4.3	5.1	3.9	5.9	4.8

Means without brackets are the transformed means.

Means with the same letters in each column are not statistically different at 95% CI

On briskness, tea treated with Copper sulphate scored the highest average score of 2.462. Zinc oxide, Magnesium oxide and the control (no fertilizer application) and the combination of Copper sulphate, Magnesium oxide and Zinc oxide have statistically similar scores. A combination of Copper sulphate, Magnesium oxide and Zinc oxide had the least average score of 1.5 (Table 4.1).

On the colour of liquor, tea treated with Copper sulphate had the highest average score of 4.752, Magnesium oxide and a combination of Copper sulphate, Magnesium oxide, Zinc oxide produced statistically similar scores whilst the control (no fertilizer application) had the least score of 4.1 (Table 4.1).

On the strength of liquor, tea treated with Magnesium oxide, Zinc oxide and a combination of Copper sulphate, Magnesium oxide and Zinc oxide had statistically similar scores, Magnesium oxide having the highest score of 4.225. Copper sulphate and the control (no fertilizer application) had statistically similar scores while Copper sulphate had the lowest score of 3.9 (Table 4.1).

On the milk take, tea treated with Copper sulphate had the highest average score of 4.71 whilst the control (no fertilizer application) had the least score of 4.2 (Table 4.1).

Overally tea treated with copper sulphate had the highest average score of 17.68, therefore the highest quality. The control (no fertilizer application) had the least average score of 15.31 (Table 4.1), therefore the poorest quality.

CHAPTER 5: DISCUSSION

5.1 Effects of different foliar fertilisers on shoot weight

Results from this study showed that there was a significant difference on the effects of the different fertilisers on shoot weight ($P<0.05$) (Fig 4.1). Tea treated with Zinc oxide had the highest score, 23.82% higher than the control (Fig 4.1). This could be attributed to the fact that Zinc is responsible for the synthesis of the enzyme IAA which is responsible for the growth of shoots in tea (Sedaghathoor *et al*., 2009). Also zinc increases the rate of carbohydrate metabolism in photosynthesis in tea therefore increase growth and development of tea. Zinc also mobilises photosythates towards the harvested shoots in tea this increases the mass of harvestable shoots (Alloway, 2008).

Shoot weight was significantly reduced by applications of copper sulphate at a concentration of 1%, 27.3% lower than the control (Fig 4.1). This could be because the concentration of 1% copper sulphate caused the accumulation of copper to toxic levels in tea plants therefore reducing yield. Excess copper levels in tea plants inhibit

photosynthesis as a result there will be an altered source –sink relationship when carbohydrate accumulate in tea leaves due to excess copper levels. This produces a feedback inhibition on photosynthesis leading to production of insufficient photosythates for growth and development of tea shoots (Alaoui-Sosse *et al*., 2004).

In this experiment application of Magnesium oxide didn't have a significant effect on shoot weight (Fig 4.1). This may be because the application rate was too low to correct the deficiencies of magnesium in the experiment. Magnesium has been reported by several authors to increase yield in tea (Barua and Dutta, 1972; Grice, 1990; Sedaghathoor *et al*., 2009). Magnesium is a mineral constituent in the chlorophyll molecule that regulates photosynthesis; it also acts as an activator of many enzyme systems. Magnesium also plays specific roles in dry matter formation and carbon partitioning to sink organs (Ding *et al*., 2006).

The applications of a mixture of Copper sulphate, Zinc oxide, Magnesium oxide also didn't show a significant effect on shoot weight. This could be because of the complexity of the mixture where Zinc oxide increased the yield whilst Copper sulphate reduced the yield.

5.2 Effects of different foliar fertilisers on shoot density.
Results from this study showed that shoot density was significantly affected by the different foliar fertilisers ($P<0.05$). Density of tea shoots were significantly increased by application of Zinc oxide, 12% higher than the control (Fig 4.2). Since Zinc is responsible for the healthy development of the tea shoots that are to be harvested for processing (Gondwe, 1969) and zinc is important on the synthesis of RNA, proteins and tryptophan (precursor of IAA) therefore contribute to the growth of plants, this could be

the reason for the increase in shoot density. Also Zn increases the rate of carbohydrate metabolism in photosynthesis in tea therefore increase growth and development of new shoots in tea (Alloway, 2008). A number of reports have indicated positive yield response to zinc in tea Dootson, 1976, Barboora *et al*., 1992 and Fung and Wang, 2001).

Shoot density was significantly reduced by applications of copper sulphate, 11.9% lower than the control (Fig 4.2). Copper sulphate foliar fertilisers could have had an inhibitory effect on the development of shoots which has caused the decline in the number of shoots and therefore yield in plots where copper sulphate was applied. Copper has been reported to be a photosynthesis inhibitor which influences electron transport, photophosphorylation and the dark reactions of photosynthesis (Fernandes and Henriques, 1991). The inhibitory effect of copper was also found on the activity of several enzymes responsible for the dark reactions of photosynthesis such as ribulose 1, 5 biphosphate carboxylase in barley and phospho enolpyruvate carboxylase in maize (Stiborova *et al*., 1986).

 Also a reduction in shoot density was also observed by Barua and Dutta (1972) due to copper application on tea. Leaf scorch was observed in copper treatments which also lead to reduction in shoot population showing that the concentration of copper sulphate was detrimental to shoot development. Excess copper accumulation leads to the production of reactive oxygen species which react with cellular components leading to the oxidation of nucleic acids and peroxidation of lipids which results in enzyme inactivation, mutation and cell death (Halliwell and Gutteridge, 1999).

In this study application of Magnesium oxide did not have a significant effect on shoot density of tea (Fig 4.2). This could be attributed to the fact that the concentration at

which magnesium was applied in this experiment failed to meet the requirements for the Benjani variety or there was another factor limiting the role of magnesium in tea plants. Magnesium has been reported by several authors to increase shoot density in tea (Barua and Dutta, 1972; Grice, 1990; Sedaghathoor *et al*., 2009). Magnesium is a mineral constituent in the chlorophyll molecule that regulates photosynthesis; it also acts as an activator of many enzyme systems.

The applications of a mixture of Copper sulphate, Zinc oxide, Magnesium oxide also did not show a significant effect on shoot density (Fig 4.2), this could be due to the complexity of the mixture.

5.3 Effects of foliar fertilisers containing copper, magnesium and zinc on made tea quality
Application of the different fertilisers had significant effects ($p<0.05$) on the quality of tea.

Application of Copper sulphate resulted in the highest overall score of 17.68 and this implies highest quality. The least was the control with an overall score of 15.31 and this implies the lowest quality (Table 4.1). The increase in quality by copper sulphate and Zinc oxide could be due to the increase in the levels of theaflavins and thearubins. Theaflavins (TF) and thearubins (TR) are the chemicals responsible for the taste and appearance of black tea. TF is responsible for the astringency, brightness, and briskness of the black tea, while TR contribute to the mouth feeling (thickness) and strength of the tea (Wang *et al*., 2000; Owuor and Obanda, 2001). Copper and Zinc have been reported to increase the levels of flavins and polyphenol oxidase in tea leaves. Polyphenol oxidase is the enzyme that catalyses the transformation of flavonols to

theaflavins during the fermentation of black tea in the manufacturing process. Copper and Zinc are vital components of polyphenol oxidase therefore they are important elements in the formation of theaflavins and thearubins during fermentation of black tea and this could explain their significant effect on quality. A positive correlation of copper and total phenol content which improves tea quality in tea was also found in tea samples of Nigerian tea (Ogunmoyela *et al*., 1994). Copper and Zinc were also found to raise tea quality in Iranian tea (Sedaghathoor *et al*., 2009).

Magnesium oxide significantly raised the quality of tea (Table 4.1). This could be attributed by the fact that sufficient supply of Magnesium in nutrient solution increased biomass production and concentrations of free amino acids, notably theanine in young shoots and roots of tea, without affecting total nitrogen in the leaves, absorption rates of inorganic nitrogen and glutamine synthetase activity (Ruan *et al.,* 2012). The free amino acids in young tea shoots are important chemical constituents, remarkably influencing the quality of tea (Ruan *et al*., 2012). This could be the reason for the significant effect of magnesium sulphate on quality.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

From the study it can be concluded that:
- Zinc oxide foliar fertiliser significantly increases the yield (shoot weight and shoot density) of tea.

- Copper sulphate foliar fertiliser significantly reduces the yield (shoot weight and shoot density) of tea.

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- Magnesium oxide foliar fertiliser did not increase the yield (shoot weight and shoot density) of tea.

- Copper, Magnesium and Zinc foliar fertilisers significantly increase the made tea quality.

Recommendations are:

• It is recommended to the farmers to use Zinc oxide since it increases both yield of tea.

• It is also recommended that farmers should use Copper sulphate, Magnesium oxide and Zinc oxide since they improve the quality is required of tea.

• There is need to further research on the effects of varying the different foliar fertilisers concentrations in order to determine best concentration which improves both yield and quality of tea.

• There is also need for repeated evaluations of the different foliar fertilizers in different sites so as to come up with conclusive results.

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APPENDICES

Appendix 1: ANOVA table for shoot weight of different foliar fertiliser applications

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	3	20740.	6913.	2.29	
Treatment	4	660750.	165188.	54.74	<.001
Residual	12	36210.	3018.		
Total	19	717700.			

Appendix 2: ANOVA table for shoot density of different foliar fertiliser application

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	3	10.800	3.600	3.40	
Treatment	4	61.700	15.425	14.57	<.001
Residual	12	12.700	1.058		
Total	19	85.200			

Appendix 3: ANOVA table for brightness of different foliar fertiliser application

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	3	0.0005156	0.0001719	0.93	
Treatment	4	0.0106591	0.0026648	14.34	<.001
Residual	12	0.0022293	0.0001858		
Total	19	0.0134040			

Appendix 4: ANOVA table for briskness of different foliar fertiliser application

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	3	0.00007297	0.00002432	0.72	
Treatment	4	0.10496179	0.02624045	781.72	<.001
Residual	12	0.00040281	0.00003357		
Total	19	0.10543758			

Appendix 5: ANOVA table for colour of liquor of different foliar fertiliser application

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	3	0.00028338	0.00009446	2.16	
Treatment	4	0.02602087	0.00650522	148.91	<.001
Residual	12	0.00052423	0.00004369		
Total	19	0.02682848			

Appendix 6: ANOVA table for strength of liquor of different foliar fertiliser application

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	3	0.0002613	0.0000871	0.23	
Treatment	4	0.0071812	0.0017953	4.65	0.017
Residual	12	0.0046330	0.0003861		
Total	19	0.0120755			

Appendix 7: ANOVA table for milk take of different foliar fertiliser application

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	3	0.00001814	0.00000605	0.23	
Treatment	4	0.00050070	0.00012518	4.66	0.017
Residual	12	0.00032239	0.00002687		
Total	19	0.00084123			

Appendix 8: ANOVA table for the total score of different foliar fertiliser application

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	3	0.01302	0.00434	0.25	
Treatment	4	11.49745	2.87436	168.07	<.001
Residual	12	0.20523	0.01710		
Total	19	11.71570			