Effects of Fertilizers on Tea Yields and Quality: A Review with Special Reference to Africa and Sri Lanka

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Introduction

Camellia sinensis L. O. Kuntze plants are commercially grown under different climatic conditions with latitudes ranging from 49' N (Outer Carpathians) to 33' S (Natal) (Shoubo, 1989) and altitudes from sea level in Japan and Turkey to above 2500 m a.m.s.l. in Kenya. It is planted for the production of different tea beverages including green, black and various semi-fermented teas. Over the years, production has continued to rise. In, 1980 for example world production was 1,848,016 metric tons (Anon, 1981), which rose to 2,962,590 metric tons in 1985 (Anon, 1999), a rise of 60% in 16 years. The rise in production has however, been faster than the increase in world demand, consequently tea prices have not improved with time (see Table 1). In attempts to improve profitability or to stay in business most producers have tried to use various methods to increase the quantities of tea they produce. These methods have included increasing land area under tea (Anon, 1996) and/or improving agronomic and cultural practices. Further land for more production, however, is running out leaving improvement of the agronomic practices as the most viable alternative to increase productivity per unit amount of input hence overall production. Several agronomic practices including using plants with superior yields (Banerjee, 1992), improving methods and efficiency of

Table 1: Mean export tea prices (US$ kg^{-1}) of some tea exporting countries (1980-1999)*

Year	Country					
	Kenya	India	Sri Lanka	Malawi	Indonesia	Bangladesh
1980	2.09	2.44	2.02	1.17	1.51	1.40
1981	1.79	2.07	1.79	1.10	1.42	1.31
1982	1.80	1.98	1.68	1.15	1.41	1.36
1983	1.84	2.45	2.22	1.32	1.76	1.89
1984	2.88	3.00	3.03	2.15	2.64	2.56
1985	1.85	2.63	2.22	1.43	1.65	1.56
1986	1.83	2.26	1.58	0.91	1.25	1.23
1987	1.47	2.44	1.79	0.83	1.31	135
1988	1.51	2.19	1.76	0.84	1.35	1.54
1989	1.62	2.45	1.84	0.96	1.42	1.66
1990	1.62	3.02	2.29	1.11	1.63	1.78
1991	1.58	2.44	2.02	0.97	1.30	1.50
1992	1.77	2.16	1.84	0.95	1.16	1.19
1993		2.14	1.86	1.01	1.26	1.34
1994	1.78	2.06	1.82	0.77	1.13	1.23
1995	1.54	2.16	1.97	0.83	1.11	1.26
1996	1.55	1.70	2.50	0.69	1.11	1.23
1997	2.05	2.36	2.64	0.65	1.33	1.61
1998	2.07	2.49	2.80	0.98	1.68	1.74

* Source: International Tea Committee, Annual Bulletin of Statistics (1981-1999)

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harvesting (Cloughley *et al.*, 1983; Odhiambo, 1989; Owuor and Odhiambo, 1994), improved tea nutrition (Bonheure and Willson, 1992), etc. have been used. These efforts have led to remarkable achievements in some countries and yields up to 10,995 kg made tea per hectare have been obtained under commercial tea production (Oyamo, 1992).

The mean yields obtained in various tea exporting countries are summarized in Table 2 for the period 1980 to 1998. In this period, the tea productivity in Bangladesh and Indonesia stagnated while in Malawi, Sri Lanka and India recorded marginal improvement in productivity per unit area. However, Kenya realized almost 100% increase in production per unit area.

In most tea growing countries, the net returns to the tea farmers have however not improved per unit of tea produced. The tea prices have remained stagnant or declined with time (see TableI) while the costs of production (Ellis and Grice, 1981) and living have increased. This lack of price improvement is partly due to the producers having increased production vastly without corresponding increase in world tea consumption or without real attempts to establish and maintain a quality yard stick for tea against which tea not meeting the standard are removed from the market. In most instances the effects of the method used to increase production on the resultant quality of the beverages have not been evaluated. Where such evaluations have been done, it seems the tea growers believe that there is more profitability in tea growing by increasing production rather than improving or maintaining quality. As a result, there have been more intensive efforts to develop technologies to increase production per unit area than to improve quality. Some of the improved technologies used to generate extra crop reduce the quality of the beverages. There have been debates on whether the extra yields obtained from such technologies compensate for the quality decline (Ellis et *al.*, 1979).

Use of fertilizers in tea production is widely practiced in tea production as it has been demonstrated to improve productivity per unit area. However, the costs of inorganic fertilizers have continued to increase. At present, fertilizer use is one of the most expensive undertakings in tea production (Owuor and Othieno, 1996). Despite the expense, farmers regularly use fertilizers in the belief that the extra crop they get due to fertilizer application actually means extra income. The most important nutrients

Table **2:** Mean productivity **(kg** made tea **ha^{-1})** of some tea exporting countries **(1980-1999)***

Year	Country					
	Kenya	India	Sri Lanka	Malawi	Indonesia	Bangladesh
1980	1174	1491	782	1637	1176	911
1981	1152	1478	858	1735	1185	928
1982	1184	1499	776	2078	1174	916
1983	1469	1468	740	1726	1036	966
1984	1393	1606	918	2115	1137	843
1985	1755	1614	929	2142	1156	932
1986	1698	1508	954	2074	1043	805
1987	1824	1607	969	1698	1054	872
1988	1890	1681	1029	2132	1068	825
1989	2065	1658	936	2133	1135	824
1990	2031	1729	1056	2144	1189	963
1991	2023	1794	1090	2215	1116	944
1992	1847	1742	806	1813	1044	1024
1993	2014	1819	**	2112	1057	1055
1994	1900	1767	1299	1869	998	1080
1995	2136	1770	**	1917	1010	992
1996	2190	1809	**	1917	1078	1052
1997	1881	1869	1430	2316	999	1101
1998	2479	1995	**	2147	1060	1131

* Source: International Tea Committee. Annual Bulletin of Statistics (1981-1999)
** Data on area were not available from the Annual Bulletin of Statistics

for tea are nitrogen, phosphorus, and potassium, although calcium, magnesium, zinc, sulphur and other micronutrients are also applied to tea. In this review an attempt is made to assess the effect of fertilizers on yields and quality of tea beverage.

Nitrogen

Nitrogen is the major nutrient for tea and is supplied to the plant in large amounts. It is the most widely used nutrient in tea production and several studies have demonstrated yield benefits (Bonheure and Willson, 1992; Owuor, 1989, Owuor and Othieno 1996, Cloughley 1983). The recommendation for nitrogenous fertilizers varies from country to country, ranging from 80 kg N ha^{-1} $year^{-1}$ for low yielding tea in Sri Lanka to 800 kg N ha^{-1} $year^{-1}$ in Japan (Bonheure and Willson, 1992). The recommended nitrogenous fertilizer rate in Kenya is 100-250 kg N ha^{-1} $year^{1}$ (Othieno, 1988), the actual rate being dependent on total yield: tea yielding up to 3000 kg mt ha^{-1} $year^{-1}$ receive 100 kg N ha^{-1} $year^{-1}$ and those yielding more than 5000 receive 200 kg N ha^{-1} $year^{-1}$. But despite the recommendations there are farmers who apply in excess of these recommended rates. In Japan, for example, farmers are known to apply up to 1200 kg N ha^{-1} $year^{-1}$ (Takeo, 1992). However, continuous application of nitrogen at rates above 165 kg N ha^{-1} $year^{1}$ in North East India stagnates or has harmful effects on the tea bush and its productivity (Barbora, 1991). High nitrogen rates cause accumulation of high amounts of amide (theanine) in the tea roots. High theanine levels are toxic to the tea roots leading to damage of feeder roots and depletion of starch in the roots. In extreme cases, this can lead to death of the tea plant.

Several studies have examined the effects nitrogen has on tea quality. Whereas use of nitrogen improved green tea quality (Takeo, 1979), increasing rates of nitrogen impair black tea quality (Cloughley, 1983: Clowes and Mitini-Nkhoma, 1987; Malenga, 1987; Owuor *et al.*, 1987a; Ellis *et al.*, 1979; Cloughley, *et al.*, 1983; Khando, 1989). Such reductions in quality are minimal at low rates (Owuor and Othieno, 1996; Cloughley, 1983). Thus Malenga (1987) observed that there was no quality difference between applying 0 and 100 kg N ha^{-1} $year^{-1}$. Indeed, from this observation, it was suggested that yield increase from application of nitrogen more than compensates for quality loss (Malenga, 1987). In green tea, however, increasing nitrogen fertilizer improves quality and farmers apply up to 1,200 kg N ha^{-1} $year^{-1}$ (Watanabe, 1995; Takeo, 1992). Partial mechanisms have been worked out for the quality improvements in green tea and decline in black tea with nitrogen use. Increased rates increase the levels of amino acids (Takeo, 1979) and fatty acids (Owuor *et al.*, 1990b), which are beneficial for high green tea utility, while in black tea, high rates of nitrogen reduce catechins levels (Hilton *et al.*, 1973) which lead to the production of black tea with low theaflavins levels (Cloughley, 1983) and also increase the unsaturated fatty acids levels (Owuor *et al.*, 1990b) leading to high levels of undesirable aroma compounds with greenish smell (Robinson and Owuor, 1992). Deleterious quality and yield effects due to excessive use of nitrogen fertilizer, are presumably due to inhibition of key enzymes involved in the assimilation by amide amino and ammonia, which exert considerable effect on the biosynthesis of quality and yield components (Srivastava *et al.*, 1982). Black teas become grassy with increased chlorophyll levels, which also increase with high nitrogen levels (Van Lelyveld et al., 1990). Part of the grassy smell from high rates nitrogen is due to increased fatty acid levels (Owuor et al., 1990b). Indeed, high rates of nitrogen reduce green leaf to black tea out turn (Cloughley *et al.*, 1983) and lead to higher percentage of lowly priced fibrous grade black tea (Cloughley *et al.*, 1983). Thus, use of high rates of nitrogen reduces the valuation of the resultant black teas (Cloughley, 1983 Owuor and Othieno, 1996).

In different countries, sources and formulations of nitrogen vary. Indeed, variations in yields have been obtained with use of different sources and/or forms of nitrogen (Sharma and Sharma, 1990; Sharma and Jain, 1994). However, yield variations due to use of straight nitrogenous fertilizers are not large enough to cause significant production differences. Use of Urea gives marginally lower yields than Sulphate of Ammonia or Calcium Ammonium Nitrate (Grice, 1982; Sharma And Sharma, 1990; Dale, 1971a; Walia, 1993).

For nitrogen in NPK compound fertilizers in Kenya, yield response of clonal tea is the same from use of NPK 20:10:10 and NPKS 25:5:5:5 (Owuor *et al.*, 1990; Owuor and Othieno, 1996). In Malawi, however, better yield responses were obtained with higher amounts of phosphorus and potassium compound nitrogenous fertilizers (Clowes, 1986).

Although all forms of nitrogen exerted significant influence on total colour and brightness of tea infusion, at 180 kg N ha^{-1} $year^{-1}$, Calcium Ammonium

Nitrate produced better quality tea than Sulphate of Ammonia , Urea and Urea plus NPK 25:5:5:5 (Sharma and Sharma, 1993; Jayaratnam, 1980). But in general increasing rates of nitrogen decreased quality irrespective of the form of nitrogen (Dale, 1971a). For NPK 20:10:10 and NPKS 25:5:5:5, quality deterioration with rates of nitrogen was similar (Owuor *et al.*, 1987a, 1995; Owuor, 1989, 1992; Owuor and Othieno, 1996).

In some countries, a seasonal variation in tea production is an effect, which causes management and operations difficulties as a lot of tea is produced within a very short duration. In Malawi, for example, 80% of crop is produced in five months between December and April (Cloughley *et al.*, 1983). This leads to a situation whereby there is a period when factories work over capacity and others when the factories are under capacity. These seasonal variations in yields cannot be redistributed with use of nitrogen (Owuor *et al.*, 1990c). Seasonal variation in tea quality following nitrogen fertilizer application has been studied and found to persist irrespective of nitrogen fertilizer application (Hilton *et al.*, 1973; Owuor, 1992; Owuor *et al.*, 1991).

It has been speculated that the seasonal variations in crop distribution could be partially overcome by splitting the annual nitrogenous fertilizer application. In Kenya yields are not, however, redistributed by splitting the annual nitrogenous fertilizer application (Owuor *et al.*, 1991; 1992; 1994; Owuor and Othieno, 1996) whereas in Malawi, splitting annual nitrogenous fertilizer slightly redistributed seasonal yields, but caused an overall yield decline (Dale, 1971a; Malenga and Wilkie, 1994) except with irrigation when between 5 and 15% yield improvement was obtained (Mkwaila, 1993). However, such splitting of annual nitrogen fertilizer did not have effect on quality of black tea (Malenga and Eilkie, 1994; Nyirenda, 1993; Owuor, 1992; Owuor *et al.*, 1995; Owuor and Othieno, 1996), except in the eastern highlands of Kenya where splitting nitrogenous fertilizer application improve black tea aroma (Owuor *et al.*, 1995; Owuor and Othieno, 1996).

Yield response has been obtained by use of reasonable rates of nitrogen even at various plucking intervals (Owuor and Odhiambo, 1994; Cloughley *et al.*, 1983, Owuor *et al.*, 1997; 2000). At every rate of nitrogen application however, there is quality improvement with shorter plucking intervals. Such quality improvement was attributed to fine plucking standards with short plucking intervals. Indeed, in a separate study, it was shown that at any nitrogen fertilizer rate, quality improved with fine plucking standard (Cloughley, 1983; Cloughley *et al.*, 1983; Owuor *et al.*, 1997; 2000). Short plucking intervals is therefore one of the few agronomic practices which enhance yields (Odhiambo, 1989; Owuor et *al.*, 1997) and quality (Owuor and Odhiambo, 1994; Owuor *et al.*, 1997; 2000).

Variations in yields have been observed in different cultivars of tea (Khando, 1989; Owuor and Othieno, 1996). Such responses are also manifested in tea quality such that the extents of decline in quality with increasing nitrogen fertilizer vary with cultivars (Owuor and Othieno, 1996; Owuor and Wanyoko, 1996; Khando, 1989; Malenga and Wilkie, 1994). Although both nitrogen rate and increasing plant population improve yields, there is no quality benefit/loss from increased plant population irrespective of nitrogen rate (Owuor *et al.*, 1995).

The quality decline with increasing rates of nitrogen persists even in tea at different periods from previous prune (Owuor, 1994). The observation that quality and yields do not respond in similar pattern to increased rates of nitrogen fertilizer suggest that there is need to use rational rates of nitrogen which are a compromise between the two factors (Owuor and Othieno, 1996; Owuor and Wanyoko, 1996).

In Malawi, it was observed that despite the decline in quality with higher rates of nitrogen, use of reasonable amounts of nitrogen produced yields, which more than compensated for quality losses (Malenga, 1987). Such reasonable rate of nitrogen varies with cultivars (Khanso, 1989; Owuor and Otheno, 1996; Owuor and Wanyoko, 1996). Whereas, many tea growers have calculated the reasonable rates based on the total yields, this can be misleading as there are some low yielding tea with better nitrogen use efficiency than higher yielding cultivars (Owuor and Othieno, 1996). The reasonable rates therefore should be based response rather than total yields *per se.*

Phosphorus

Phosphorus is an important nutrient in tea nutrition together with nitrogen and potassium. Several studies have recorded improvement of tea yields following phosphate fertilizers application (Othieno, 1973; Gogoi *et al.*, 1994; Barbora, 1991). In North

East India, the yield benefits were only recorded on application of up to 50 kg P_2O_5 ha^{-1} $year^{1}$, the effect being attributed to ability of phosphorus to enhance uptake and translocation of nitrogen (Gogoi *et al.*, 1994). However, application of more than 50 kg P_2O_5 ha^{-1} $year^{-1}$ was not beneficial and did not increase yields (Barbora, 1991). This lack of yield response was attributed to adverse effects such rates have on activities of enzymes responsible for nitrogen assimilation (Barbora, 1991).

Rates of phosphorus fertilizers up to 50 kg P_2O_5 ha^{-1} $year^{-1}$ improved black tea quality (Barbora, 1991; Gogoi *et al.*, 1993) by enhancing the levels of major catechins and caffeine in tea shoots, and theaflavins, thearubigins, brightness and total colour in made tea (Gogoi *et al.*, 1993). However, there are no additional quality benefits from application of higher rates.

Application of phosphatic fertilizers has also been reordered to reduce the total amount of amino acids in tea shoots (Dev Chaudhury and Bajaj, 1988). Of the individual amino acids, application of phosphorus reduced the levels of aspartic acid, glutamic acid and theanine but marginally increased leucine, iso-leucine and phenylalanine levels. These could affect the quality of black tea as the amino acids (except theanine) break down to form volatile flavour compounds that contribute to quality (Robinson and Owuor,1992). Phosphate fertilizers do not affect the levels of fatty acids in tea leaves (Bajaj *et al.*, 1984), which breakdown to form volatile flavour compounds with green grassy smell, thus reducing quality of black tea (Robinson and Owuor, 1992).

Combination of phosphorus and potassium was shown to be beneficial to quality (Willson and Choudhury, 1968). Although it was speculated that use of compound nitrogenous fertilizer with higher ratio of phosphorus could enhance quality (Willson and Choudhury, 1968), there was no difference in quality response in the use of NPKS 25:5:5:5 and NPK 20:10:10 on clonal tea (Owuor *et al.*, 1987a, Owuor and Othieno, 1996).

Potassium

Application of potassium is a recommended practice in tea production. Indeed, potassium is an important nutrient for tea together with nitrogen and phosphorus. In most countries, it is now applied in the compound fertilizer as NPK formulations. However, where deficiency is suspected or exists, remedial doses of the nutrients are applied as straight fertilizers to top up the amount supplied in the compound fertilizers. As straight fertilizers, yield response to potassium has been observed in some countries. In North East India, for example, yield response to potash was quadratic reaching a point of maxima at about 170 kg K_2O ha^{-1} $year^{1}$ (Dey, 1971; Barbora, 1991). Based on the yield increases, potash application has been shown to be economical and an extra three-kg made tea was obtained from application of 1 kg K_2O (Rahman and Roy, 1970). Response of tea to potash fertilizer was higher in non-prune years than in the year of prune (Malenga, 1986). In some countries like Kenya, however application of potash fertilizer does not improve yields (Willson, 1966; 1975a). This lack of response of potash fertilizer is attributed to adequate potassium reserve in the soils in those tea-growing regions (Willson, 1966; 1975a).

The effects of potash fertilizers on tea quality have been evaluated in a few studies. Using sensory evaluation method, Willson and Choudhury (1968) noted that for Kenya tea, straight application of potash fertilizer does not affect black tea quality. These results have been corroborated through chemical analysis which there were no responses in black tea quality parameters with increasing rates of potash fertilizer (Owuor *et al.*, 1994). However, when combined with phosphatic fertilizer, potash fertilizer improved sensory evaluation of black tea (Willson and Choudhury, 1968).

Better yield response to nitrogen is obtained when there is adequate supply of phosphorus and potassium (Ellis, 1976). Thus application of both phosphatic (Chennery, 1963) and potash fertilizers pay.

In summary, it has been noted that nitrogen reduces quality, phosphrous enchances quality, while potassium has no effect of quality. Splitting nitrogen application will not impair quality as much as application in single dose, and the effects of sources of nitrogen are minimal on quality (Hilton, 1970).

Other nutrients

Although nitrogen, phosphorus and potassium are the main nutrients of the tea plant, other nutrients like zinc, manganese, calcium, molybdenum, boron and magnesium are also important for high productivity.

Zinc has positive effect on plant metabolism as it mobilises photosynthates towards pluckable tea shoots. Again inadequate zinc levels in the plant adversely affect some physiological functions like chlorophyll content and stomatal conductance. Availability of zinc to tea plant is influenced by presence of other nutrients, growing conditions and physical and chemical properties of the soil (Barbora *et al.*, 1993). Several studies have shown yield benefits of up to 15% increase from foliar application of 1 to 2% zinc (Tolhurst, 1973; Barua and Dutta, 1972). Although the foliar application of zinc lead to 10-15% yield gain, such gains are short lived and last only up to 8 weeks, but ground zinc application does not lead to any yield gain (Dale, 1971b; Dootson, 1970). Inadequate zinc levels in tea plants can be corrected by foliar zinc application (Dev Chaudhury *et al.*, 1989). Foliar application of up to 4% zinc also improves the uptake of nitrogen by up to 20% (Dev Chaudhury *et al.*, 1989). However, although zinc application is widely practiced in some countries, there are no significant yield responses from the applications (Wanyoko *et al.*, 1992a). Thus, zinc application is only beneficial to yield if the nutrients are limiting. Where there is adequate supply by the soil, application of zinc does not give any yield benefit.

Application of zinc does not affect quality of black tea (Barbora *et al.*, 1993) as measured by the theaflavins, thearubigins or sensory evaluation (Dev Chaudhury *et al.*, 1989) and has no effect on strength, briskness and valuation of CTC black teas and strength, briskness, quality, colour of tips and valuation of orthodox black teas (Rahman and Sharma, 1974). Despite the noted lack of effect on black tea quality, processing leaf immediately after foliar zinc application leads to very high levels above that recommended by various health regulatory bodies. The levels however revert to acceptable limits after two to three plucking rounds (Owuor, unpublished).

Yield increases have also been reported from foliar application of manganese, and molybdenum, whereas and ground application of magnesium decreased yields (Barua and Dutta, 1972). Contradicting results have been recorded from foliar application of boron. Whereas Barua and Dutta (1972) did not observe any yield grains from foliar application of boron, recently Gohain *et al.* (2000) recorded significant yield increase averaging 12% from foliar applied boron as boric acid. Such yield increase was higher in unpruned teas compared to tea that had skiffed or light pruned. Few studies have monitored the effects of some of the micronutrients on quality of black tea. Foliar application of 1% maganese reduced the theaflavins and tasters evaluation of black tea (Dev Chaudhury *et al.*, 1989). Soil application of manganese at 20 kg Mn ha^{-1} $year^{-1}$ along with nitrogen and phosphorus produced better black tea (Kalita, 1995). The theaflavins to thearubigins ratio was high in black teas from plots treated with manganese. Manganese and nitrogen applied in absence of phosphorus, however, resulted in poorer quality black teas. Boron application did not significantly affect black tea quality (Gohain *et al.*, 2000).

Although aluminium is not normally supplied to tea as one of the nutrients, its beneficial effects on tea growth is well recognized. It is known to stimulate tea growth (Chennery, 1955; Kinoshi,1992) leading to faster growth and high yields. Indeed, aluminium regulates the uptake of phosphorus, nitrogen, potassium, calcium and magnesium. At low phosphorus availability, aluminium stimulates absorption of phosphorus and promotes growth of the tea plant, but at high phosphorus availability aluminium alleviates the toxicity of excess phosphorus, enhances the absorption of phosphorus and promotes growth (Kinoshi *et al.*, 1985). Aluminium induced decrease in calcium and magnesium but increased nitrogen and potassium in the tea plants (Kinoshi *et al.*, 1985). Aluminium also plays regulatory role in the nutrient economy of tea with respect to toxic ions like manganese. Aluminium uptake is high in soils rich in manganese, but high levels of calcium and magnesium lower aluminium and manganese uptake (Matsuda *et al.*, 1979).

In the very acid soils that tea is grown, aluminium is adequately supplied (Owuor and Cheruiyot, 1989) to the point that sometimes it is thought it could be toxic to growth of the plant (Owuor-Gerroh, 1991). Indeed, where the soil pH is very low, aluminium toxicity has been suspected (Owino-Gerroh and Othieno, 1991) although Eden (1976) had contended that tea plant can accumulate high levels of aluminium without adverse effect. The suspected toxic effects (Owini-Gerroh and Othieno, 1991) of aluminium are through its affecting availability and/or absorption of other nutrients.

The high levels of aluminium in the acid soils led to the speculation that consumption of high amounts of tea could result into high aluminium uptake leading to Alzheimer's disease. However, although the available aluminium in the soil increase with soil acidity, under such conditions, the tea plant absorption of aluminium, as reflected in the tender shoots analysis, actually declines (Owuor and Cheruiyot, 1989). Thus increasing nitrogen fertilizer rates which normally increases soil acidity will actually reduce the amount of aluminium in made tea (Owuor *et al.*, 1990a). Despite the Alzheimer's problem, reasonable amount of aluminium is actually beneficial to tea quality. Chang and Gudnanson (1982) observed that addition of aluminium salts to tea increase the redness and brightness of the extracts of black tea and improve its taste. Although the level of aluminium may be fairly high in tea, most of it complexes in the infusion and does not get into the liquor (Owuor *et al.*, 1900c; Ananthacumaraswamy and Sivapalan, 1990). Thus although the level of aluminium in black tea could be as high as 600 ppm, only 4 ppm end in the tea cup (Ananthacumaraswamy and Sivapalan, 1990).

Copper is not normally supplied to tea in form of fertilizer. However, where there is copper deficiency, foliar application of the nutrients leads to marginal improvement in crop (Dootson, 1976). Copper is essential to the tea plant particularly for the formation of polyphenol oxidase, which is a copper containing enzyme and is indispensable in fermentation process in black tea manufacture (Alice, 1960). Foliar spray of copper, to copper deficient tea plant Improved the enzyme activity and the resultant black tea quality (Chiomba, 1971). Indeed, foliar application of copper sulphate or copper oxychloride improved the resultant black tea infusion and sensory evaluation (Clowes and Mitini-Nkhoma, 1988).

Sulphur deficiency in tea leads to low yields (Grice, 1978). In most tea growing countries, it is commonly supplied as Sulphate of Ammonia or in compound fertilizers like NPKS 25:5:5:5, thus its deficiency is rare where application of nitrogen in these forms is regular. The effects of sulphur on tea quality have not, however, been reported.

Although calcium is an essential nutrient in tea, its application does not lead to yield increase (Willson, 1975b). The effect calcium on quality has not been quantified. Magnesium is an essential nutrient for all plants with green leaves including tea. Both foliar and ground application improves plant magnesium uptake (Wanyoko *et al.*, 1991, Willson, 1975c). Its effects on quality are unknown. The effects of other nutrients like molybdenum on yields and quality have not been documented.

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