Effects of Nitrogenous Fertilizer Rates, Plucking Intervals and Geographical Location of Production on Selected Micronutrient Levels of the Black Tea

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Influence of Nitrogenous Fertilizer Rates, Plucking Intervals and Geographical Location of Production on Selected Micronutrient Levels of the Black Tea

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Abstract Micronutrients are important to both the human life and the tea plant. *Camellia sinensis* is widely grown in East Africa and its beverages are claimed to be the most widely consumed fluids after water. The changes in the levels of micronutrients with varied rates of nitrogenous fertilizer and plucking intervals three different locations were studied. All the studied micronutrients significantly ($p \leq 0.05$) varied with location of production. Mn and Se levels did not significantly ($p \leq 0.05$) change with an increase in nitrogenous fertilizer rates. Fe and Zn significantly ($p \leq 0.05$) increased with an increase in nitrogen fertilizer rates while Cu significantly ($p \leq 0.05$). The micronutrient content of the black teas did not significantly ($p \leq 0.05$) change with varied plucking intervals. There is need to strike a balance in the application of nitrogenous fertilizer rates in different locations in order to harmonize all the micronutrients. This research recommends 150 kg/ha/year of nitrogenous fertilizer rate that will strike a balance on all the studied micronutrients.

Keywords Black tea; Camellia sinensis; Nitrogenous fertilizer; Plucking interval; Micronutrients

Introduction

Elements like manganese, iron, zinc, copper and selenium among others are beneficial to the human health and the tea plant although at curtain levels may be classified as toxic. The deficiency or excess of any of these elements may cause diseases and/or be deleterious to human health (O'Dell and Sunde, 1997). Agronomic inputs influence the soil chemical parameters (Othieno, 1992) leading to changes in the absorption and hence variations in the chemical composition of the harvested leaf (Bonheure and Willson, 1992). Nitrogen, phosphorous and potassium are the main nutrients for tea. They are usually supplied in compound nitrogenous fertilizers (Bonheure and Willson, 1992). Nitrogenous fertilizer application is the second most expensive agronomic input in tea production (Ellis and Grice, 1981) after harvesting. Although nitrogenous fertilizer plays a major role in plant growth, it alters the absorption of micronutrients by the plants from the soil. That is because increasing rates of nitrogenous fertilizer generally increase soil acidity (Owuor et al., 1990; Wanyoko et al., 1990; Bonheure and Willson, 1992) and this may cause variations in availability of some of the micronutrients. The recommended rate of fertilizer application in Kenya, that is also widely used in East African countries is 100 to 250 kg N/ha/year as NPKS 25: 5: 5: 5 or NPK 20: 10: 10 (Othieno, 1988; Anon, 2002), with the actual rate being dependent on level of production. But the optimal rates for different regions vary (Owuor et al., 2010a). Nitrogenous fertilizer application influences the yield through variations in rate of shoot extension, individual shoot weight and density (Odhiambo, 1989; Owuor et al., 1997). Appropriate use of nitrogenous fertilizers leads to increase in tea production (Willson, 1975; Wanyoko, 1983; Owuor and Wanyoko, 1996) but the high rates of fertilizer application reduce black tea quality (Owuor et al., 1997; 2000) and increase the fatty acids in tea leaf (Okal, 2011). Despite the lowering of quality, application of nitrogenous fertilizer to tea is mandatory since it enhances yields (Othieno, 1988; Bonheure and Willson, 1992). These variations may be an indicator that other nutrients might also be changing due to rates of nitrogenous fertilizer application. The optimal rate of fertilizer for adequate levels of these essential minerals is not known. It is therefore necessary to establish nitrogen fertilizer rates that could enhance availability of the micronutrients in different tea growing areas in Kenya.

In Kenya, tea grows at different rates in different locations. The effect of region on growth is a known factor in determining the micronutrient content in tea (Mokgalaka et al., 2004). The level of micronutrient in teas has been demonstrated to change with locations in India (Kumar et al., 2005). In recent studies, tea quality parameters (Jondiko, 2010; Owuor et al., 2008, 2009, 2010b) and quality precursors (Okal, 2011) were demonstrated to change with geographical area of production. Indeed even the yields (Wickremaratne, 1981; Wachira et al., 2002; Owuor et al., 2009; 2010b) and quality (Gulati and Ravichranath, 1996; Fernandez et al., 2002; Moreda-Pineiro et al., 2003; Peterson et al., 2004; Owuor et al., 2008, 2010b) vary with geographical area of production, the variation occurring in unpredictable patterns. Such changes were attributed to many factors including non-use of single cultivar and different agronomic inputs. However when the studies on single cultivar were used under same agronomic inputs, quality (Owuor et al., 2009; 2010a; 2010b) and yield (Wachira et al., 2002; Owuor et al., 2009; 2010a) variations persisted. It is not known if the micronutrients levels in black tea of same cultivar grown in different regions vary.

Plucking is an important step in tea production and the most expensive agronomic input in tea production. During the plucking operation, young leaves are removed (Willson, 1992) for processing into various tea beverages. The recommended plucking standard is two leaves and a bud that gives desirable good black quality teas (Owuor et al., 1987; 1997; 2000) and acceptable yields (Othieno, 1988; Willson, 1992). Tea grows at different rates in different locations (Obaga et al., 1988; 1989; Squire et al., 1993; Ng'etich and Stephens, 2001a; 2001b; Ng'etich et al., 2001), leading to the achievement of recommended two leaves and a bud (Othieno, 1988) after different time lengths. Recommended plucking interval in Kenya varies from 7 to 14 days (Othieno, 1988). Short plucking intervals remove the leaves when the pluckable shoots are still young and are mostly two leaves and a bud (Odhiambo, 1989; Owuor and Odhiambo, 1994). Short plucking intervals reduce "breaking-back" (Mwakha and Anyuka, 1984), a process that reduces yields, but improves quality (Owuor et al., 2000). Aroma quality precursors especially fatty acids whose degradation products reduce tea quality, were demonstrated to increase with longer plucking intervals (Okal, 2011). The changes in the various quality attributes may also suggest there may be variations in the micronutrient content of tea with varying plucking intervals. Such variations have not been established in different tea growing areas. It is necessary to establish plucking intervals leading to optimal micronutrient levels in different regions.

1 Materials and Methods

1.1 Sites and sample collection

Trials were set on clone 6/8 plantations that are uniformly managed and with known past cultivation history planted at Changoi in lower Kericho, Timbilil Estate (Tea Research Foundation of Kenya) in upper Kericho, and Sotik Highlands (Arrocket) Tea Estate in Sotik whose altitude, latitude, longitude and year of plantation are given in Table 1.

Table 1 Site locality and history for clone 6/8 cultivar

Site Locality/history	Changoi	TRFK Timbilil	Sotik Highlands (Arrocket)
Altitude (m above sea level)	1982	2198	1767
Latitude Longitude	0°31'S 35°16'E	0°22'S 35°21'E	0°36'S 35°4'E
Year planted	1989	1986	1974
Plantation age*	22	25	37

Note: * As at year 2011.
Source: Individual/ estates records.

At each site, the experiment was set as a factorial two arrangement laid out in a randomised complete block design with five fertilizer rates (0, 75, 150, 225 and 300 kgN/ha/yr) and three plucking frequencies (7, 14 and 21 day rounds) and treatments replicated three times. Each effective plot comprised of 48 plants surrounded by a line of tea bushes that served as guard rows. On the day the three plucking intervals coincided in each experiment, a mass of one kilogram of tea was harvested from each plot and taken for miniature black tea processing (Owuor and Reeves, 1986). Unsorted black tea samples were subjected to analysis of the micronutrients.

1.2 Analytical measurements

A modified standard procedure described in AOAC (2000) was followed for the preparation of samples for analysis of the micronutrients. The unsorted black tea samples were weighed on a digital analytical balance (Mettler Toledo, Switzerland) with ±0.0001 g precision. Accurately weighed 1.0000 g black tea for analyzing Mn, Fe, Zn and Cu while 2.0000 g black tea for Se analysis were transferred into ashing tubes and kept in a muffle furnace for ashing at 460℃ for 12 hours. The ashed samples were digested using double acid (concentrated hydrochloric and nitric acids in a1:1 ratio) and hydrogen peroxide in the ratio of 2: 3. Care was taken to ensure that all ash came into contact with the acid. All the chemicals used were of analytical grade obtained from Sigma Aldrich. Further the crucible containing acid solution was kept on a hot plate and evaporated to dryness. The final residue was dissolved in 0.05 M hydrochloric acid solution for extraction and made up to 25 mL for Mn, Fe, Zn and Cu analysis and to 10 mL for Se analysis. Working standard solutions were prepared by diluting the stock solution with 0.05M hydrochloric acid. The Mn, Fe, Zn, Cu and Se in made tea samples was analyzed using atomic absorption spectrophotometer (Shimadzu AA-6200 Model, Japan) under standard instrumental conditions.

1.3 Statistical analysis

The data was analyzed using a randomized complete block design in a 3×5×3 factorial design with location as main treatments, nitrogen NPKS 25: 5: 5: 5 fertilizer rates as sub-treatments and harvesting intervals as sub-sub treatments. MSTAT-C statistical package (Michigan State University, MI) was used for ANOVA, while linear regressions were performed using Ms-Excel statistical package.

2 Results and Discussions

Influence of nitrogenous fertilizer rates, plucking intervals and location of production on the micronutrient levels of the black tea.

Nitrogenous fertilizer application rates and harvesting intervals (Owuor et al., 1997; 2000; 2010b) are known to influence the chemical quality parameters of tea. Indeed high rates of nitrogenous fertilizer and long plucking intervals impair black tea quality. Similarly the chemical composition and hence quality of tea has been demonstrated to change with geographical area of production even when one cultivar was used (Owuor et al., 2009; 2010a; 2010b). Using clone 6/8, the influence of these factors was evaluated on micronutrients content. Clone 6/8 used in this study is a popular cultivar grown widely in Kenya (Wachira, 2002) and East Africa in general for manufacture of black tea.

2.1 Changes in the levels of micronutrients due to location of production

The changes in micronutrients levels in black tea due to location of production are presented in Table 2. All the five micronutrients significantly ($p \leq 0.05$) varied with locations of production, therefore it is not possible to make black teas with similar micronutrient contents in all the three locations. This can be attributed to the differences in the soil pH in the three sites as observed in the earlier studies (Kamau et al., 2008a). Some of these micronutrients like Fe, Zn and Cu are known to be more bioavailable in strongly acidic soils (Yemane et al., 2008), thus the levels of the micronutrients inversely followed that of pH (Kamau et al., 2008b). Equally mature leaf Fe and Zn levels were high in locations with lower pH (Kamau et al., 2005). The changes in the levels of micronutrients Mn, Fe, Zn, Cu and Se could be due to several factors including temperature (Tanton, 1982a), rainfall and rainfall distribution (Othieno et al., 1992), altitude (Obaga et al., 1989; Squire et al., 1993) and sporadic hail damage experienced in the tea growing locations (Othieno et al., 1992; Ng'etich et al., 2001; Ng'etich and Stephens, 2001b) observed in different locations in Kenya. Although these factors were not monitored in the present study, the extents of their variations may be large at the various geographical locations. Equally past crop husbandry and management may also play a bigger role in micronutrient variations in the different geographical locations.

2.2 Changes in the levels of micronutrients due to varied rates of nitrogenous fertilizer

The changes in micronutrient levels in black tea due to application of nitrogenous fertilizer rates are presented in Table 2 and Table 3. Mn levels did not significantly ($p \leq 0.05$) vary with an increase in nitrogenous fertilizer rates. These results were similar to the report by Kamau et al. (2005) on the first mature leaf Mn levels where there was no significant (p≤ 0.05) difference by increasing nitrogenous fertilizer rates. This was attributed to the high acidic nature of the tea soils which make Mn to be in excess and thus luxurious uptake may be expected ending up with no specific pattern (Kamau et al., 2005).

Table 2 Effects of location of production and nitrogen fertilizer rates on micronutrients

Micronutrient	Location	N-Rates (kg N/ha/year)					Mean locations
		0	75	150	225	300	
Mn (μg/g)	Timbilil	652.33	685.89	654.78	660.56	678.11	666.33
	Sotik Highlands	557.56	554.78	586.11	576.56	572.22	569.44
	Changoi	662.22	648.56	655.89	631.44	655.11	650.64
	Mean N-Rate	624.04	629.74	632.26	622.85	635.14	-
	C.V (%)				5.12		
	L.S.D (P≤0.05)		NS				29.22
Fe (μg/g)	Timbilil	110.33	121.89	121.78	148.22	128.44	75.17
	Sotik Highlands	69.89	75.22	71.89	75.33	83.56	68.44
	Changoi	60.67	71.56	70.22	69.67	70.11	-
	Mean N-Rate	80.3	89.56	87.96	97.74	94.04	-
	C.V (%)				16.10		13.13
	L.S.D (P≤0.05)		10.93				
	Interactions (SxN)				15.73		
Zn (μg/g)	Timbilil	18.11	25.11	29.00	31.11	29.89	22.64
	Sotik Highlands	19.44	20.78	21.00	22.78	29.22	23.02
	Changoi	20.33	22.22	22.44	24.89	25.22	-
	Mean N-Rate	19.30	22.70	24.15	26.26	28.11	-
	C.V (%)				20.60		
	L.S.D (P≤0.05)		3.75				3.51
	Interactions (SxN)				5.40		
Cu (μg/g)	Timbilil	23.67	22.78	21.11	17.44	12.67	5.51
	Sotik Highlands	9.00	7.22	4.56	3.67	3.11	15.16
	Changoi	19.00	15.22	13.33	13.67	14.56	-
	Mean N-Rate	17.22	15.07	12.96	11.70	10.11	-
	C.V (%)				24.46		
	L.S.D (P≤0.05)		2.78				2.97
	Interactions (SxN)				3.56		
Se (μg/g)	Timbilil	1.58	1.91	1.56	1.93	1.62	1.55
	Sotik Highlands	1.48	1.46	1.66	1.56	1.60	2.25
	Changoi	2.50	2.03	2.49	1.96	2.28	-
	Mean N-Rate	1.86	1.80	1.90	1.82	1.83	-
	C.V (%)				23.60		
	L.S.D (P≤0.05)		NS				0.39

Mn levels are high in strongly acidic soils and that the nutrient can be accumulated highly in the leaves to an extend that application of fertilizer or manure might not affect the levels (Ishibashi et al., 2004). Irrespective of location of production, nitrogenous fertilizer rates does not significantly (p≤0.05) affect the Mn content of black teas. Thus for optimal Mn in black tea for alleviation of hidden hunger nitrogenous fertilizer rates do not dictate the levels of this micronutrient in black teas.

Fe levels significantly (p≤ 0.05) increased with the increase in nitrogenous fertilizer rates in the three locations (Table 2 and Table 3). Increasing the rates of nitrogenous fertilizer is known to reduce the soil pH (Kamau et al., 2008b) and thus increases the bioavailability of this nutrient. Increasing the rates of nitrogenous fertilizer generally increase soil acidity (Owuor et al., 1990) and this may cause variations in the metal content of teas. The increase in Fe concentrations by increasing the rates of nitrogenous fertilizer is demonstrated in Figure 1 where the increase had a positive gradient with high R^2 values indicating the magnitude of increase was high.

Table 3 Effect of plucking intervals and fertilizer rates on micronutrients in black tea

Micronutrient	P-Freq	N-Rates					Mean P-Freq
		0	75	150	225	300	
Mn (μg/g)	7	623.11	629.22	630.89	608.67	622.67	622.91
	14	626.44	636.44	632.44	613.33	639.11	629.56
	21	622.56	623.56	633.44	646.56	643.67	633.96
	Mean N-rate	624.04	629.74	632.26	622.85	635.14	-
	CV (%)			5.12			
	LSD (P≤0.05)	NS					NS
Fe (μg/g)	7	80.56	89.33	85.44	96.56	94.44	89.27
	14	82.44	86.78	90.33	102.00	91.89	90.69
	21	77.89	92.56	88.11	94.67	95.78	89.80
	Mean N-rate	80.30	89.56	87.96	97.74	94.04	-
	CV (%)			16.10			
	LSD (P≤0.05)	10.93					NS
Zn (μg/g)	7	19.56	19.56	24.89	26.22	30.00	24.04
	14	20.33	23.78	23.56	26.56	27.22	24.29
	21	18.00	24.78	24.00	26.00	27.11	23.98
	Mean N-rate	19.30	22.70	24.15	26.26	28.11	-
	CV (%)			20.60			NS
	LSD (P≤0.05)	3.75					
Cu (μg/g)	7	14.33	12.67	14.44	13.11	10.11	12.93
	14	17.33	17.89	12.89	13.89	10.00	14.40
	21	13.78	13.00	13.33	14.00	10.22	12.87
	Mean N-rate	15.15	14.52	13.56	13.67	10.11	-
	CV (%)			24.46			
	LSD (P≤0.05)	2.78					NS
Se (μg/g)	7	1.87	1.78	1.74	1.64	1.74	1.76
	14	1.76	1.72	1.93	2.00	1.88	1.86
	21	1.93	1.90	2.02	1.80	1.88	1.91
	Mean N-rate	1.86	1.80	1.90	1.82	1.83	-
	CV (%)			23.60			
	LSD (P≤0.05)	NS					NS

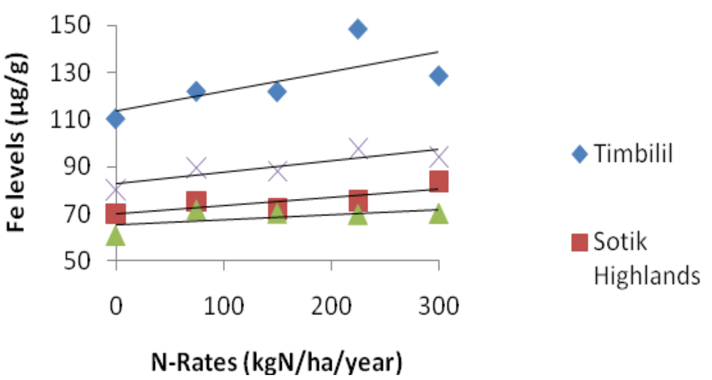

Figure 1 Effects of N-rates on iron levels in the unsorted black teas

Note: $Fe_{(Timbilil)} = 0.163x + 107.6$ (R^2=0.916); $Fe_{(Changoi)} = 0.049x + 63.04$ (R^2=0.816); $Fe_{(Sotik\ Highlands)} = 0.036x + 69.68$ (R^2=0.890); $Fe_{(Mean\ N\text{-}Rates)} = 0.074x + 80.78$ (R^2= 0.919)

Thus for increasing the Fe content in black tea, high levels of nitrogenous fertilizer should be used. This is also same with yields where they increase with increased fertilizer application but not exceeding 250 kg N/ha/year (Owuor et al., 2009; 2010a; 2010b). Similar yield responses to rate of nitrogen had been widely recorded for trials conducted on single locations (Ranganathan and Natesan, 1987; Bonheure and Wilson, 1992; Owuor et al., 1997;

2000; 2008; Kamau et al., 1998; Kamau, 2008). On the other hand, irrespective of geographical area of production, high rates of nitrogenous fertilizer is deleterious to quality (Owuor et al., 2009; 2010a; 2010b) hence levels of nitrogenous fertilizer rates should be used that is a compromise between yield, quality and micronutrient content of the black teas.

Zn levels significantly ($p \leq 0.05$) increased with the increase in nitrogenous fertilizer rates (Table 2 and Table 3). This was also attributed to the increased acidity of the soils when nitrogenous fertilizers rates are increased (Kamau et al., 2008b) which makes extractable Zn to be more bioavailable (Lasat et al., 1996). This is elaborated in Figure 2 which has positive gradient with very high R^2 values. Just like the micronutrient Fe, a higher rate of nitrogenous fertilizer maximizes Zn content in black teas.

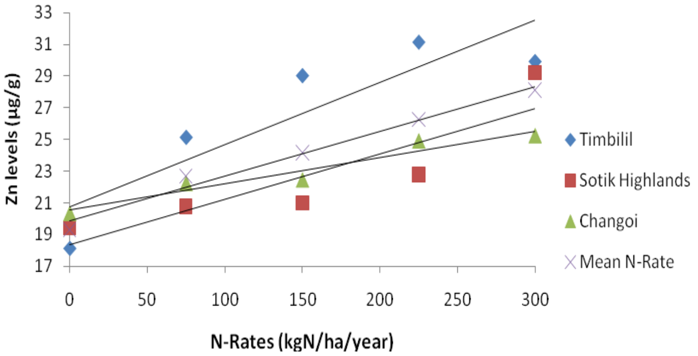

Figure 2 Effects of N-rates on zinc levels

Note: $Zn_{(Timbilil)} = 0.052x + 19.73$ (R^2=0.856); $Zn_{(Changoi)} = 0.016x + 20.53$ (R^2=0.936); $Zn_{(Sotik\ Highlands)} = 0.028x + 18.33$ (R^2=0.878); $Zn_{(Mean\ N\text{-}Rates)} = 0.028x + 19.86$ (R^2=0.980)

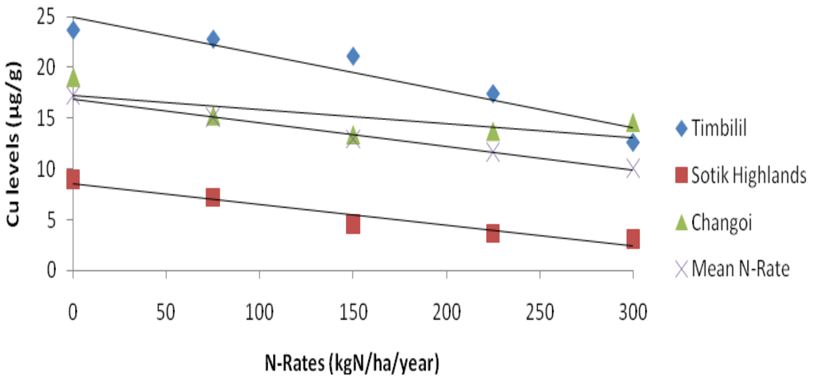

Figure 3 Effects of N-rates on Cu levels

Note: $Cu_{(Timbilil)} = -0.036x + 25.00$ (R^2=0.915); $Cu_{(Changoi)} = -0.021x + 17.84$ (R^2=0.718); $Cu_{(Sotik\ Highlands)} = -0.020x + 8.578$ (R^2=0.934); $Cu_{(Mean\ N\text{-}Rates)} = -0.014x + 15.58$ (R^2=0.988)

Cu levels in black tea significantly ($p \leq 0.05$) reduced with increased rates of nitrogenous fertilizer (Table 2 and Table 3). High concentrations of Zn causes significant reduction in the rate of Cu transport (Reeves et al., 1996). Thus the rate and kinetics of Cu transport in any cell is affected by concentration of Zn in which the mechanism involves an inhibition of Cu efflux from the cell (Reeves et al., 1996). In the current study the levels of Cu decreased with high rates of nitrogenous fertilizer rates possibly due to increase in soil acidity and rise in Zn levels which might have inhibited Cu absorption by the tea plants. This decrease is illustrated in Figure 3 where there are negative gradients with high R^2 values indicating there is a strong decrease in the Cu levels with increased nitrogenous fertilizer rates. High levels of Cu can be achieved by minimizing the rates of nitrogenous fertilizer but this will reduce the concentrations of Zn and Fe as observed earlier thus fertilizer application should be that which is a compromise between the micronutrient levels in the black teas.

Table 4 Effects of plucking intervals and location of production on micronutrients

Micronutrient	P-Freq (days)	Locations			Mean P-Freq
		Timbilil	Sotik Highlands	Changoi	
Mn (μg/g)	7	658.20	542.00	668.53	622.91
	14	672.80	574.33	641.53	629.55
	21	668.00	592.00	641.87	633.96
	Mean locations	666.33	569.44	650.64	-
	C.V (%)		5.12		
	LSD (p≤0.05)	29.22			NS
	Interactions (SxP)		32.65		
Fe (μg/g)	7	123.80	75.20	68.80	89.27
	14	129.13	74.47	68.47	90.69
	21	125.47	75.87	68.06	89.80
	Mean locations	126.13	75.18	68.44	-
	C.V (%)		16.10		
	LSD (p≤0.05)	13.13			NS
	Interactions (SxP)		14.67		
Zn (μg/g)	7	25.53	21.20	25.4	24.04
	14	28.67	22.20	22.00	24.29
	21	25.73	24.53	21.67	23.98
	Mean locations	26.64	22.64	23.02	-
	C.V (%)		20.60		
	LSD (p≤0.05)	3.51			NS
	Interactions (SxP)		5.03		
Cu (μg/g)	7	18.93	4.73	15.13	12.93
	14	20.53	5.40	17.27	14.40
	21	19.13	6.40	13.06	12.87
	Mean locations	19.53	5.51	15.16	-
	C.V (%)		24.46		
	LSD (p≤0.05)	2.97			NS
	Interactions (SxP)		3.32		
Se (μg/g)	7	1.51	1.64	2.11	1.76
	14	1.92	1.30	2.36	1.86
	21	1.73	1.71	2.28	1.91
	Mean locations	1.72	1.55	2.25	-
	C.V (%)		23.60		
	LSD (p≤0.05)	0.39			NS
	Interactions (SxP)		0.44		

The Se levels in the black tea do not follow any order meaning that nitrogenous fertilizer rates have no effect on these levels. Se levels were not significantly (p≤0.05) affected by increasing rates of nitrogenous fertilizer (Table 2 and Table 3). To increase Se concentrations in tea then Se-enriched fertilizer like fertilizer of sodium selenite or sodium selenate is to be used (Xu et al., 2003). The Se levels were also very low compared to other micronutrients. It is possible Se levels in the soils are very low or the plant absorbs very little Se.

2.3 Changes in the levels of micronutrients due to plucking intervals

The changes in micronutrient levels in black tea due to plucking intervals are presented in (Table 3 and Table 4). Plucking intervals did not significantly (p≤0.05) affect the micronutrient content of the black teas. This implies that it is possible to make black teas with similar micronutrient content with varied plucking intervals. These results are similar to the yield response to plucking intervals which did not vary significantly with plucking intervals (Jondiko, 2010). Contradicting reports on yield responses to plucking intervals have been reported for example in Malawi yields decreased with increased plucking rounds (Palmer-Jones, 1977; Tanton, 1982b), but increased in Kenya with short plucking intervals (Owuor and Odhiambo, 1994). An increase in plucking intervals reduced black tea quality (Owuor et al., 2009; 2010a; 2010b) partly due to increase in green leaf fatty acid content (Okal, 2011). In recent studies quality parameters increased with shorter plucking intervals (Mahanta et al., 1988; Owuor et al., 1997; 2000; 2008) while yields increased with long plucking intervals (Owuor et al., 2008). In the present study plucking intervals do not have a significant effect on the micronutrient of black teas.

There were no significant ($p \leq 0.05$) interactions between location of production and nitrogenous fertilizer application for the micronutrients Mn and Se (Table 2) meaning that the response patterns for these micronutrients occurred in a similar manner. For the micronutrients Fe, Zn and Cu, there were significant ($p \leq 0.05$) interactions between location of production and nitrogenous fertilizer application rates (Table 2) meaning that the response patterns were different at each region. This is also evident from Figures 1, Figure 2 and Figure 3 where the lines showing the micronutrient response to nitrogenous fertilizer rates do not cross each other. On the other hand, there were no significant ($p \leq 0.05$) interactions between nitrogenous fertilizer application rates and plucking intervals for all the micronutrients (Table 3) meaning that the responses were not related to the treatments. There were significant ($p \leq 0.05$) interactions between location of production and plucking intervals for all the micronutrients (Table 4) indicating that the response patterns were different at each site.

3 Conclusions

The micronutrient levels in black tea significantly ($p \leq 0.05$) varied with the location of production. Mn and Se levels in black tea were not significantly ($p \leq 0.05$) affected by increasing the nitrogenous fertilizer rates, Fe and Zn levels significantly ($p \leq 0.05$) increased while Cu levels of the resultant black teas significantly ($p \leq 0.05$) reduced with an increase in the rates of fertilizer application. The plucking intervals did not significantly ($p \leq 0.05$) affect the levels of the micronutrients. This study recommends sources of black tea should be known if their micronutrient value is to be considerer. The nitrogenous fertilizer rates used should be the one that is a compromise of all the micronutrients and in this case we recommend 150 kg/ha/year as the rate that strikes a balance among the micronutrients. Finally, plucking intervals is not a factor to consider in optimizing the micronutrient levels of the black teas.

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