The Status of Zn, Cu, Mn, and Fe in the Soils and Tea Leaves of Kibena Tea Estates, Njombe, Tanzania

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Abstract

A study was undertaken to assess Zn, Cu, Mn, and Fe status of the soils and tea plants at Kibena Teat Estates in Njombe, Tanzania. Low yields of tea in these estates prompted this study to identify some of the constraints to tea production. Twenty four composite soil samples were randomly collected to a depth of 0-40cm from the six divisions of the Kibena Tea Estates, namely; North, Lihogosa, Kilolelo, Central, Matombololo, and Itambo. The third leaf of the tea plants were harvested from plants close to where the soils were sampled. The soils and leaves were analyzed for available and contents of Zn, Cu, Mn, and Fe, respectively. DTPA extractable Zn and Cu were consistently low in almost all the soil samples, which ranged from 0.08 to 0.93 mg Znkg^{-1} and 0.04 to 0.34 mg Cukg^{-1} soil. On the other hands, Fe and Mn were sufficient for the tea plants and ranged from 26.88 to 60.28 mg Fekg^{-1} and 7.65 to 31.18 mg Mnkg^{-1} soil. The plant leaf Mn, and Zn were above the critical levels in most of the plant samples, a reflection of their high contents in the soils and foliar application at a rate of 2 kgha^{-1}, respectively. Although Fe was observed to be sufficient in soils, it was poorly reflected in tea leaves of which 65.22% of samples were deficient. This phenomena is explained by high levels of Zn in tea leaves which reduces the uptake of Fe from soils. The low content of Cu in leaves are consequences of low level of extractable Cu in soils and high levels of Fe in soils which induces Cu deficiency. The availability of Cu, Zn, Mn and Fe were largely controlled by the pH of the soils which ranged from 4.01 to 5.51. Application of Cu and Zn fertilizers were recommended as soil fertility management strategies for sustainable tea production at the Kibena Tea Estates.

Key words: zinc, copper, manganese, iron, critical levels, third leaf, DTPA –extractable.

Introduction

The important micronutrient elements in tea production include Zn, Cu, Mn, Fe, B and Cl (Bonheure and Wilson, 1992) with Cu and Zn being the most important based on their influence on the quality of the tea (Othieno, 1992). Micronutrient deficiencies in soils are currently common in many crops including tea (Sakal *et al.*, 1988). The introduction of high yielding crop varieties coupled with use of micronutrient-free high analysis N and P fertilizers and increased crop intensity has contributed to the depletion of the soil micronutrients (Dhane and Shukla, 1995). The available micronutrient content in soils at any given time is only a very small fraction of the total amounts present in soils; hence soils can be rich in the total contents of micronutrients but poor in amounts available to plants (Warden and Reisenauer, 1991). The available micronutrient contents in soils depend on the soil physical, chemical and biological characteristics such as pH, organic matter content, texture and nutrient interactions (Hazra and Bishapati, 1988).

In some areas where tea is grown, there have been reports on various micronutrient deficiencies. Owuor and Wanyoko (1983) reported potential deficiencies of Zn and Cu at Kericho, Kenya. In Malawi Clowes and Mitini-

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Nkoma (1987) reported deficiency of Cu and its effects on the fermentation of tea. Further, the Mufindi tea growing soils were reported to be low in Cu and Zn (Mhosole, 1995).

The Kibena Tea Project was started in 1988 as a diversification from wattle production due to wattle not fetching high prices in the world market. The highest recorded yield of made tea at Kibena Tea Estates ranged from 2,500 to 3,000 kg ha^{-1}. The situation is different in neighboring countries like Kenya and Malawi where the annual yields range from 4,500 to 6,000 kg ha^{-1} (Bonheure and Wilson, 1992). Micronutrient deficiencies may be the main constraint to tea production at Kibena Tea Estates since the macronutrients are adequately supplied to the tea plants through fertilizer applications and other inorganic soils amendments.

The native levels of plant nutrient elements in soils and their replenishment through the natural recycling processes can only support certain yield levels, which in many cases are too low. Assessment of micronutrient element status in both soils and plant materials becomes mandatory when high value crops like tea are grown so as to establish the need to supplement them for increased yields. The present investigation was undertaken at Kibena Tea Estates to assess the soils' available Zn, Cu, Mn and Fe in the soils in relation to some soil properties and the contents of Zn, Cu, Mn, and Fe in the third leaf of tea shoots.

Material and Methods

Soil sampling and analysis

Twenty four composite soils samples were collected at a depth of 0-40 cm from six divisions of the Kibena Tea estate namely; the North, Lihogosa, Kilolelo, Central, Matombololo and Itambo. Each composite soil sample was constituted from 15 sub samples. The sampling depth of 0-40 cm was chosen based on ploughing depth and planting depth of tea seedlings which is slightly more than 40 cm. Also feeder roots of tea bushes tend to be concentrated in the top 0-40 cm layer (Bonheure and Wilson, 1992). The soils were air dried, ground, sieved through 2mm sieve and analyzed for some physical and chemical parameters. The soils' pH was measured in soil water suspensions (1:2.5 soil: water) based on the procedure of Dewis and Freitas (1970). Cation exchange capacity was determined by the neutral ammonium acetate saturation method (Thomas, 1982). The quantities of exchangeable Ca, Mg, K and Na ions in the ammonium acetate filtrates were measured by AAS (Thomas, 1982). Organic carbon was determined by the wet oxidation method of Walkley and Black (Nelson and Sommers, 1982). Total nitrogen was determined by the micro-Kjeldah digestion-distillation method (Bremmer and Mulvaney, 1982). Available P was determined by the Bray – 1 procedure (Kuo, 1996). The particle size analysis was carried out by the Bouyoucos hydrometer method (Day, 1965). The plant available fractions of Zn, Cu, Mn and Fe were estimated by extracting with diethlene-triamine-penta acetic acid (DTPA) adjusted to pH 7.3 (Linday and Norvell, 1978) and the amounts extracted determined by AAS.

Plant sampling and analysis

Composite samples of the third leaf were collected randomly from plants near the points where the soil samples were taken. The leaves were washed using distilled water, oven dried at 105°C for 24 hours and ground to pass through a 1mm sieve using a Tecator 1093 cyclotec sample mill prior to analysis. Total Zn, Cu, Mn, and Fe in the tea leaf samples were determined by wet digestion using H_2O_2-HNO_3-H_2SO_4 mixture followed by quantification using AAS (Juo, 1979).

Results and discussion

Soil properties

The physico-chemical properties of the soils are presented in Table 1. Based on the categorization by Landon (1991) the pH, exchangeable calcium and organic carbon contents of the soils were normal for tea production, and they are within the range found in other tea growing soils of the world (Othieno, 1992). The CEC, exchangeable magnesium and potassium of the soils ranged between low and medium (Landon, 1991). The results suggest that the soils have low inherent soil fertility status as their ability to retain all cations is low. The CEC of such highly weathered soils depend mainly on the organic matter contents because the contribution of the clay fraction in retaining cations is very low (Othieno, 1992).

Table 1. Some of the physical and chemical properties of the composite soil samples from Kibena tea estates

	Division					
Soil property	**North**	**Lihogosa**	**Kilolelo**	**Central**	**Matombololo**	**Itambo**
pH (H_2O)	5.28-5.51	4.01-6.24	4.60-5.17	4.34-	4.13-5.24	4.67-5.80
	(5.40)	(5.15)	(4.81)	5.45	(4.88)	(5.19)
Org. Carbon %	2.16-2.71	1.66-3.31	1.47-3.72	(4.88)	1.92-3.47	1.88.3.27
	(2.44)	(2.27)	(2.29)	2.06-	(2.67)	(2.58)
Total N, (%)	0.12-1.15	0.09-0.16	0.08-033	3.21	0.18-0.26	0.10-0.23
	(0.14)	(0.13)	(0.17)	(2.61)	(0.23)	(0.16)
Available P	3.13-3.70	5.23-42.74	2.16-14.13	0.1-0.29	3.39-20.89	2.39-6.15
($mgkg^{-1}$)	(3.42)	(16.77)	(8.15)	(0.17)	(9.75)	(4.08)
	13.20-	6.00-13.80	5.40-17.80	4.35-	7.60-19.60	9.80-18.80
CEC (Cmol	14.00	(11.08)	(11.67)	28.88	(10.85)	(14.00)
kg^{-1})	(13.60)	1.63-3.40	0.58-3.48	(15.59)	0.39-2.10	0.45-2.54
	0.92-3-41	(2.18)	(1.62)	5.60-	(0.51)	(1.59)
Exchangeable	(2.67)	0.11-1.24	0.37-1.12	14.80	0.12-0.91	0.12-0.91
Ca	0.90-1.31	(0.83)	(0.65)	(11.48)	(0.51)	(0.58)
(Cmol kg^{-1})	(1.11)	0.15-0.97	0.47-1.20	0.28-376	7.35-0.52	0.13-0.69
Exchangeable	0.52-055	(0.50)	(0.73)	(1.50)	(0.87	(0.43
Mg	(0.54)	0.35-5.00	1.75-3.00	0.37-	0.95-7.35	2.45-5.26
(Cmol kg^{-1})	0.90-1.65	(2.20)	(2.42)	1.12	(4.35)	(4.2)
Exchangeable	(1.28)	-	-	(0.50)	-	-
K	-	26.50-	18.00 –	0.20.077	32.20-38.70	36.20-39.20
(Cmol kg^{-1})	27.00-	38.00	38.00	(0.46)	(36.45)	(38.75)
Exchangeable	30.00	(32.90)	(30.50)	1.10-	52.70-60-20	54.80-62.20
acidity	(28.50)	57.10-	60.10-71.10	6.75	(57.08)	(58.75)
(Cmol kg^{-1})	57.10-	67.10	(64.60)	(4.59)	5.20-9.70	4.20-9.20
Particle size	67.10	(62.00)	1.90-1-.90	-	(6.45)	(6.45)
(%)	(67.10)	3.40-6.90	(4.90)	18.00-		-
	2.90-5.90	(5.10)		38.00		
Clay	(4.40)			(30.50)		
				60-10-		
				71.10		
Sand				(64.60)		
				3.80-		
				9.70		
Silt				(7.06)		

Note: Numbers in paranthes represent averages

Zinc

The amounts of DTPA-extractable Zn for the soils are presented in Table 2, and ranged from 0.08 to 0.93 $mgkg^{-1}$. Lindsay and Novel (1978) suggested the critical range of DTPA-extractable Zn to be between 0.5 to 1.0 mg $Znkg^{-1}$. Based on these critical levels the soils of Kibena Tea Estates are considered to be deficient in available Zn. The low level of extractable Zn is probably due to high contents of free Fe and Mn ions which enhance transformation of Zn to nonexchangeable forms on their hydrated oxide surfaces (Phogat *et al.*, 1994). The presence of divalent or trivalent cations such as Ca^{2+}, Fe^{3+} and Mn^{3+} greatly reduces the efficiency of heavy metal adsorption by permanent charged soil colloids. Since these soils are high in Fe^{3+} and Mn this could partially account for the low extractable Zn contents in these soils.

Table 2. DTPA extractable Zn, Cu, Mn, and Fe in the soils of Kibena tea estates

Division	Zn (mgkg^{-1} soil)	Cu	Mn	Fe
North	0.1-0.23 (0.17)	0.17-0.18 (0.18)	19.82-31.18 (25.50)	31.29-53.52 (42.41)
Lihogosa	0.13-0.93 (0.42)	0.19-0.34 (0.27)	15.03-29.31 (23.25)	27.65-54.63 (40.24)
Kilolelo	0.08-0.44 (0.20)	0.04-0.15 (0.09)	10.99-22.84 (16.37)	26.88-44.56 (34.42)
Central	0.12-0.43 (0.20)	0.20-0.17 (0.08)	7.65-29.77 (14.07)	39.68-60.28 (48.38)
Matombololo	0.18-0.60 (0.36)	0.13-0.26 (0.19)	13.30-21.72 (15-49)	31.18-54 (43.72)
Itambo	0.15-0.42 (0.28)	0.11-0.21 (0.14)	8.13-14.16 (11.96)	36.48-55.36 (43.70)

Note: Numbers in parentheses represent averages

The contents of Zn in the third leaves of the tea plants are presented in Table 3, and ranged from 17.40 to 97.20 mg Znkg^{-1}. Owuor and Wanyoko (1983) reported that Zn deficiency occurred when Zn content in the third leaf is below 10 mg Znkg^{-1}. In view of this categorization 100% of the leaf samples contained more than 10 mg Znkg^{-1} and therefore rated as sufficient in Zn content. Bonheure and Wilson (1992) categorized the Zn nutritional status as follows: <20 mg Znkg^{-1} is deficient, 20-25 mg Znkg^{-1} is sub normal, 25-50mg Znkg^{-1} is normal and 50. g Znkg^{-1} excess. Based on this categorization, the Zn nutritional status at Kibena Tea Estates is rated as deficient to excess. The high contents of Zn in the third leaves of the tea plants might be attributed to the routine foliar application of Zn at a rate of 2kg Znha^{-1} per year which is carried out in two splits.

Table 3. Micronutrient contents in the third leaf of the tea shoots from Kibena tea estates

Division	Zn (mgkg^{-1})	Cu	Mn	Fe
North	17.40-38.20 (27.80)	1.00-2.40 (1.70)	459.40-503.40 (481.40)	23.80-384 (31:10)
Lihogosa	39.20-75.20 (56.96)	5.40-15.60 (9.24)	439.80-626.20 (523.80)	3.00-569.60 (141.56)
Kilolela	23.20-72.60 (41.20)	3.40-12.80 (7.60)	185.40-680.20 (492.87)	21.40-176.20 (112.12)
Central	28.60-87.40 (46.96)	2.00-6.60 (4.95)	209.80-1074.60 (548.00)	16.40-984.00 (229.96)
Matombololo	33.40-97.20 (53.195)	0.40-9.00 (4.65)	295.80-552.60 (410.65)	24.80-91.80 (59.30)
Itambo	33.60-91.00 (52.60	1.60-2.60 (2.10)	254.2-446.80 (374.90)	36.20-73.20 (51.75)

Note: Numbers in parentheses represent averages

The simple correlations between DTPA extractable Zn and some of the soil properties are presented in Table 4. The results show negative and significant relationship with pH, organic carbon and CEC, but a non significant relationship with available phosphorus. The increase in Zn with low pH probably is due to high dissolution of Zn favoured by the low pH (Vadivelu and Banyopadhyaya, 1995; Maji *et al.,* 1993; Saha *et al.,* 1996). Negative correlation between DTPA extractable Zn with organic carbon and CEC have been observed elsewhere (Mhosole, 1995). The negative correlation between available Zn and organic carbon could be attributed to large amounts of Zn being retained as highly stable organo-Zn complexes which are not immediately available to plants.

Table 4. Correlation between DPTA – extractable micronutrient cations and some selected soil properties

Soil property	Zn	Cu	Mn	Fe
pH	-0.598**	-0.363**	-0.214^{ns}	-0.522**
Avail P	-0.143^{ns}	-0.053^{ns}	0.057^{ns}	-0.027^{ns}
Org. Carbon	-0.311**	-0.134^{ns}	0.139^{ns}	0.097^{ns}
CEC	-0.401**	-0.199^{ns}	0.177^{ns}	-0.018^{ns}

Note: * P < 0.05; ** P < 0.01; ns = non significant

The stepwise regression analysis (Table 5) show that pH alone accounted for 34.90% of the variation in the DTPA Zn content. Further, inclusion of organic carbon and available phosphorus improved the prediction to 39.00%. However, inclusion of CEC slightly lowered the prediction to 38.80%. From the regression analysis, the availability of Zn in the soils is largely controlled by the pH of the soils. However, with partial correlation, pH, organic carbon and CEC showed significant effect on the availability of Zn. But with multiple regression, when all soil properties were included in the model only pH was found to contribute significantly to Zn availability variations in the soils.

Table 5. The effect of soil properties on the predictability of DTPA extractable micronutrient cations

DPTA extractable nutrient	Regression equation	Contribution to variation (R^2x100)
Zn	X^1	34.90*
	$X^1 + X^2$	34.90*
	$X^1 + X^2 + X^3$	39.90*
	$X^1 + X^2 + X^3 + X^4$	38.80*
	X^1	12.00*
Cu	$X^1 + X^2$	11.20*
	$X^1 + X^2 + X^3$	12.60*
	$X^1 + X^2 + X^3 + X^4$	11.40*
Mn	X^1	3.20*
	$X^1 + X^2$	2.90*
	$X^1 + X^2 + X^3$	2.20^{ns}
	$X^1 + X^2 + X^3 + X^4$	1.20^{ns}
Fe	X^1	26.20^{ns}
	$X^1 + X^2$	29.00*
	$X^1 + X^2 + X^3$	28.50*
	$X^1 + X^2 + X^3 + X^4$	29.70*

*** = P= 0.05**

X^1=Soil pH, X^2=available P, X^3=organic carbon, X^4=CEC

Copper

The amounts of DPTA extractable Cu are presented in Table 2, and varied from 0.04 to 0.34 mg Cukg^{-1}. Lindsay and Novell (1978) suggested 0.2 mg Cukg^{-1} soil of DTPA extractable Cu as the critical limit of Cu for normal plant growth. Based on this critical limit, the soils under study were considered deficient in available Cu, with the exception of the soils of Lihogosa. The observed low levels of extractable copper could be due to heavy phosphate fertilization and high levels of Fe which have been reported to induce

Cu deficiencies (Landon, 1991) and probably low Cu contents in the parent materials from which the soils were formed.

The Cu contents of the leaf samples ranged from 1.00-15.60mg $Cukg^{-1}$ plant material (Table 3). Bonheure (1992) reported critical level of Cu in the third leaves to be 15mg $Cukg^{-1}$. These results indicate that 98% of the samples fall under the deficiency level. The low levels of copper in the leaves are a consequence of the low levels of extractable Cu in the soils and high levels of Fe in soils (Table 2) which have been reported to induce Cu deficiency (Landon, 1991). Considering the importance of copper in the fermentation of tea during processing, foliar application would improve the contents of copper in the tea plants (Clowes and Mitini-Nkoma, 1987) hence the quality of made tea.

The simple correlations between DTPA extractable Cu and some selected soils properties are presented in Table 4. The results show a negative and significant relationship with pH but a non significant relationship with organic carbon, available phosphorus and CEC. The increase in Cu with decreasing pH of the soils is a result of high dissolution of Cu under low soil pH (Vadivelu and Bandyopadhyaya, 1995; Maji *et al.*, 1993; Saha *et al.*, 1996).

From the stepwise regression analysis (Table 5) the pH alone account for 12% of the variation in the DTPA- Cu content. Further, inclusion of organic carbon and available phosphorus slightly improved the prediction to 12.6%. However, inclusion of CEC slightly reduced the prediction to 11.4%. From the regression analysis the availability of Cu in the soils was largely controlled by the pH of the soils.

Manganese

The DTPA extractable Mn for the soils are presented in Table 2, and ranged from 7.65 to 31.18 mg $Mnkg^{-1}$. Lindsay and Novell (1978) and Arora and Sekhon (1981) suggested 1.0 $mgkg^{-1}$ of DTPA extractable Mn in soil as the critical limit for plant available Mn. Based on the above-mentioned critical limits, the soils of Kibena Tea Estates contain high levels of plant available Mn. The high levels of Mn in the soils could be due to the low soil pH which favours the dissolution of Mn compounds in soils as well as inherently high contents of Mn in the parent materials of these soils.

The Mn contents in the tea leaves from Kibena Tea Estates are presented in Table 3, and ranged from 185.60 to 1074.60 $mgkg^{-1}$. Bonheure and Wilson (1992) categorized the Mn contents in the third leaves of tea shoot as; <50 mg $Mnkg^{-1}$ deficient, 50-100 mg $Mnkg^{-1}$ subnormal and 100-500 mg $Mnkg^{-1}$ excess. In view of the above categorization, the Mn contents in the tea plants at Kibena Tea Estates are in the normal to excess range. This observation is a reflection of the abundant supply of Mn in the soils which has also been reported to be taken in large amounts from acidic soils by the tea plants (Bonheure and Wilson, 1992). The results for simple correlations between DTPA extractable Mn and some soils properties are presented in Table 4. The data showed non-significant relationship between DTPA extractable Mn with all soil properties, namely pH, organic carbon, available phosphorus and CEC. These results suggest that there might be other soils properties contributing to the availability of manganese in the soil of Kibena Tea Estates, like sesquoxides, primary minerals and total contents of the other micro-nutrients.

Iron

The DTPA extractable Fe in the soils of the Kibena Tea Estates are presented in Table 2, and ranged from 26.88 to 60.28 mg $Fekg^{-1}$. According to Arora and Sekhon (1981), 2mg of DTPA extractable $Fekg^{-1}$ soil is considered as the critical limit for normal plant growth. Lindsay and Novell (1978) suggested the critical limit of Fe as 6.0 mg kg^{-1} soil. Based on the above critical limits the soils of Kibena Tea Estates contain sufficient amounts of plant available Fe. The high levels of iron in the soils could be attributed to the low soil pH and nature of the parent materials from which the soils were formed.

The Fe contents in the third leaves from the Kibena Tea Estates are presented in Table 3, and ranged from 16.40 to 984.00 mg $Fekg^{-1}$. Bonheure and Wilson (1992) reported ranges of Fe contents of the third leaves as, <60mg $Fekg^{-1}$ deficient, 60-100mg $Fekg^{-1}$ subnormal, 100-500mg $Fekg^{-1}$ normal and >500mg $Fekg^{-1}$ excess. In light of these ranges, the Fe contents of the tea plants at the Kibena Tea Estates ranged from deficient to excess that is 65.22% of sample were Fe deficient, 17.39% had subnormal levels, 8.70% were normal, and 8.69% of samples had excess Fe. A significant proportion of the leaf samples were deficient in iron despite the high levels of iron in the soils. This observation is probably due to the high Zn content in the leaves as a result of foliar application, which reduced the uptake of Fe. A similar observation has been reported by Landon (1991).

The simple correlations between DTPA Fe and some soil properties are as presented in Table 4. The results show negative and significant relationship with pH but a non significant relationship with organic carbon, available phosphorus and CEC, explaining an increase in DTPA Fe with decrease in soil pH. Similar results have been reported by Dhane and Shukla (1995) and Hazra and Biswapati (1988).

The stepwise regression analysis (Table 5) shows that the contribution of pH alone to the variation in the DTPA Fe contents in the soils accounted for 26.20% of the variation. Adding organic carbon to the model improved the prediction to 29.00%. However, inclusion of all factors (available phosphorus and CEC) only slightly improved the prediction to 29.70%. From the stepwise multiple regression analysis it was noted that the availability of Fe in soils of Kibena Tea Estates in mainly controlled by the pH of the soils.

Conclusions

The DTPA extractable micronutrients, Zn, and Cu in the soils of Kibena Tea Estates were low but Fe and Mn were found to be sufficient for tea. However, the leaf Zn, Mn and Fe contents were found to be sufficient for normal tea growth and only Cu was consistently low in almost all the samples. The normal levels of Zn in the tea leaves as compared to the low contents in soils were attributed to the foliar application of Zn. For sustainable tea production at the Kibena Tea Estates, it is recommended that field trials need to be undertaken to establish the rates of Cu application and foliar application of Zn containing fertilizers. Application of micronutrient containing fertilizers to raise and supplement the essential micronutrient elements, especially Zn and Cu, has to be one of the soil fertility management strategies. Approaches and means to reduce or contain antagonistic interactions/relationships between the micronutrients namely Fe-Zn, Mn-Zn, Fe-Cu etc. should be investigated.

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