International Journal of Tea Science
Vol. 10 (3&4), 2014

Effects of location of production, nitrogenous fertilizer rates and plucking intervals on tea clone TRFK 6/8 tea in East AFRICA: II. Mature leaf nutrients

Bowa O. Kwach,[a*] David M. Kamau,[b] Solomon W. Msomba,[c] Christine Muhoza[d] and Philip O. Owuor[a]

[a]*Department of Chemistry, Maseno University, P.O. Box 333-40105, Maseno, Kenya*
[b]*Department of Chemistry, Tea Research Foundation of Kenya, P.O. Box 820-20200, Kericho, Kenya*
[c]*Tea Research Institute of Tanzania, P.O. Box 2177, Dar es Salaam, Tanzania*
[d]*National Agricultural Export Development Board (NAEB), P.O. Box 104, Kigali, Rwanda*

Abstract: Due to high demand for tea beverages, *Camellia sinensis* is grown under diverse climatic conditions. The demand has led to development of high yielding clones which require high nutrients amounts usually lost through continuous cropping, leaching and surface runoff due to which it is very important to replenish these nutrients through the application of fertilizers. Tissue analysis is the reliable way to predict nutritional status leading to time migitation through supplementation of nutrients through fertilizer. To guide fertilizer requirements in East Africa, first mature leaf type analysis is done and the same analysis was adopted for clonal tea. It is not known, the standard set for the seedling tea are relevant for clonal tea and how the levels are influenced by nitrogen fertilizer rates or plucking intervals in different locations. This study assessed effects of location of production, nitrogen rates and plucking intervals on mature leaf nutrients of clone TRFK 6/8, the most widely cultivated cultivar in East Africa. The trials were set up in Kenya, Tanzania and Rwanda, as factorial two in randomized complete block design at each site. Leaf N, P, K, Ca, Mg, Mn, Zn, Cu and Fe were determined using standard methods. All nutrients significantly ($P<0.05$) varied with locations. At all locations leaf N increased ($P<0.05$) while K, Mg and Ca declined ($P<0.05$) with increase in nitrogen rates. Plucking intervals did not influence leaf nutrient levels. The nutrients levels did not match those set for seedling tea even when nutrients were supplied adequately. Diagnostic limits set for seedling tea may therefore not be suitable for clone TRFK 6/8, hence there is need to develop region specific tissue analysis diagnostic norms for clonal tea. The responses to applied nitrogen demonstrate that nitrogen deficiency can be managed through nitrogen fertiliser application. However, such applications trigger decline in potassium levels in the leaf. The applications of the two nutrients should be staggered to increase their uptake efficiency. Continuous application of high rates of nitrogenous fertilisers could cause deficiency of K, Ca, and Mg while causing toxicity of Mn.

Keywords: Clone TRFK 6/8; Nitrogen rates; Plucking interval; Location of production; Nutrients; Kenya; Tanzania; Rwanda

Introduction

Camellia sinensis L. is an important commodity crop commercially grown in many countries for processing of various tea beverages. The tea growing areas fall in several agro-ecological regions widely ranging in environmental factors,[1] geographical locations,[2–4] latitudes, from 45⁰N (Russia) to 30⁰S (South Africa), and longitudes, from 150⁰E (New Guinea) to 60⁰W (Argentina)[5] and altitudes ranging from sea level in Japan to 2,700 m above mean sea level (amsl) in Olenguruone, Kenya and Gisovu, Rwanda.[6] However, such differences affect its growth and nutrients availability and uptake, leading to yields and quality variations. The tea beverages are very popular and are claimed to be the most extensively consumed fluids after water.[7–9] The high demand for the beverages has led to development of high yielding clonal teas[10] and agronomic methods to increase productivity. With continuous cropping, the high yields together with leaching, surface run off and fixation diminish the soil nutrients supply, thus reducing plant growth and profitable yields.[11] It therefore becomes imperative to replenish the nutrients through fertiliser applications. Nitrogen (N), phosphorous (P) and potassium (K) are the most critical nutrients in the fertilization prograemme of tea.[11] In East Africa, application of NPK formulations at rates varying from 100 to 250 kg N/ha/year are recommended,[12,13] the actual rate being determined by the previous production such that higher yielding fields receive more fertiliser.

For proper growth, tea also requires magnesium (Mg), calcium (Ca), manganese (Mn), zinc (Zn), copper (Cu) and iron (Fe)[11]. Cu is important in tea since low

*Author for correspondence: Bowa O. Kwach (e-mail: okindaowuor@maseno.ac.ke)

ISSN: 0972-544X (print)

levels reduce fermentation during black tea processing as polyphenol oxidase responsible for the process is a copper-protein compound.[14,15] It is therefore necessary to supplement the availability of these nutrients to the plant for sustainable continuous high production. Deficiency of any of the nutrients reduces yields while copper deficiency impairs black tea quality.

The plant is the best indicator of its nutrients status and demand.[16] For tea, tissue analysis can be used to successfully predict the nutritional status[11,12,17] leading to timely mitigation through nutrients supplementation in form of regular or remedial fertiliser application.[12,13] Use of tissue analysis has been advocated as a reliable way of predicting possible deficiencies in tea production[12,16–18] to guide remedial applications of nutrient elements so as to alleviate deficiencies and prevent yield losses. Leaf of a defined age is necessary in tissue analysis to diagnose deficiencies. Different countries and regions use different types of leaves to predict the tea bush nutritional status.[11,18] For tea in East Africa, the first mature leaf type analysis has been adopted for tissue analysis advisory system to assess the problems in nutrients management[12,17,19] and critical nutrients levels set.[19] The development of the method was however, based on seedling tea.[17] This has been adopted to guide fertilizer application in clonal teas in East Africa without evaluation in the new environments and on clonal tea. However, most seedling tea plantations have been replaced with high yielding and good quality tea. Indeed, from mid 1970s, all new planting have used vegetatively propagated clonal tea as they are predictable in terms of yields and quality. In Kenya, for example, over 60% of tea is now clonal.[20] The situation is not different in other East African countries. Rwanda started growing tea in the 1960s and over 90% of her tea is clonal. The clonal teas, however, have different nutrients absorption abilities[21] from the soil and partitioning in the plant. Thus, a clone like high yielding AHP S15/10,[10] grown in Kericho did not accumulate above 3.5% mature leaf nitrogen even after receiving 600 kg N/ha/year[22,23] considered to be way above the recommended fertiliser level.[12] The current leaf analysis system requires application of 150 kg N/ha/year to remedy nitrogen deficiency, 50 kg K_2O/ha/year for potash deficiency and 50 kg P_2O_5 to remedy phosphate deficiency.[13]

Clone TRFK 6/8 is the most widely grown cultivar in East Africa accounting for about 80% Rwanda tea, 60% of clonal tea in Kenya,[20] and 35% to 40% in Tanzania. It is not known if the recommended rates of N, P, K applications will remedy their deficiency in all tea growing regions. There is therefore need to evaluate how location of production affect mature leaf nutrients of clonal tea in East Africa. This trial evaluated the mature leaf nutrients response of clone TRFK 6/8 to different rates on nitrogenous fertiliser and plucking intervals in different locations within East Africa. The purpose was to find out if the recommended remedial application rates can lead to recommended mature leaf diagnostic norms and if such norms are influenced by plucking intervals.

Methodology

The trials were set up in three sites in Kenya (Timbilil Estate (Upper Kericho); Changoi Estate (Lower Kericho), and Sotik Tea Company (Arroket); two sites in Rwanda (Kitabi and Mulindi Estates); and three sites in Tanzania (Katoke Tea Estate and Maruku Agricultural Research Institute (Kagera Region), Ngwazi Tea Estate (Mufindi District) all in the Lake Victoria basin, except for the trial in Ngwazi Tea Estate which in southern Tanzania, the main tea growing region in Tanzania. The details of the sites are presented in Table 1.

The sites for the trial were carefully selected such that although the plants were at different ages, all the sites had mature tea of clone TRFK 6/8. Tea at each site was pruned between April and August 2008 so that all plants were in same pruning cycle life. Subsequently the plots were demarcated and uniformity test recording were conducted between July and September. First experimental treatments commenced in September/October 2008, depending on when there was adequate soil moisture at different sites in the respective countries. In subsequent years, the trials received fertilizers in

Table 1: Site locality and history

Country	Kenya			Tanzania			Rwanda	
Site	Timbilil	Changoi	Sotik	Ngwazi	Maruku	Katoke	Kitabi	Mulindi
Altitude (m)	2180	1860	1800	1840	1488	1217	2231	1800
Latitude Longitude	0° 22'S 35°21'E	0° 30'S 35°13'E	0° 3 6' S 35°04'E	8 ° 32' S 35° 10'E	1° 23' S 31°45' E	1° 36' S 31°41' E	2° 32'S 29°26'E	1° 27'S 30°1'E
Year planted	1986	1974	1972	1994	1972	1993	1995	1994
Last prune date	2007	2007	2008	2008	2007	2007	2008	2008

September/October in single annual dose. At each site, a 5 by 3 factorial experiment was laid out in a randomized complete block design and replicated 3 times. The main treatments were the 8 sites with nitrogen rates (0, 75, 150, 225 and 300 kg N ha^{-1} $year^{-1}$ as NPKS 25:5:5:5) as a sub treatment and plucking frequency (7, 14 and 21 days intervals) the sub-sub treatment. A sub-sub plot comprises of 30 bushes of clone TRFK 6/8. The trials are analyzed as 5 by 3 factorial split design for the 8 locations.

Mature leaf samples (100gm) were sampled from each plot and oven dried at 80°C. Sampling was done during wet and cold period when water was not expected to limit nutrients uptake (April 2010). The dried leaves from each plot were milled to powdery form. A portion of the milled sample (0.5gm) was ashed for analysis of Ca, Mg, Mn, Zn, Cu and Fe using atomic absorption spectrophotometer (AAS), UV-Vis analysis of P and flame photometer analysis of K as outlined in earlier studies.[24,25] A further 1gm of the milled samples was digested for micro-Kjeldahl N analysis.[22,26]

Results and Discussion

The nutrients norms set in diagnostic tissue analysis advisory system in East Africa for seedling tea[12,17,19] is presented in Table 2. The limit levels were set for N, P. K, Mg and Zn. Whereas deficiencies of the other nutrients also limit production; their critical levels have not been set. Setting their levels require collection of more data to understand how their uptake are influenced by biotic and abiotic factors. Indeed, in a recent study,[21] these nutrients varied in different clones and even in the same clone grown in different locations. Variations in the most critical nutrients in the fertilization programme of tea N, P and K are presented in Tables 3, 4 and 5 respectively. There were significant ($P \leq 0.05$) variations in all the three nutrients with locations and nitrogenous fertilizer rates at all locations. Similar variations due to location of due to location had been observed in clones receiving same agronomic inputs.[21] Thus different regions require different NPK fertilizer application regime to realize equal leaf nutrients status. Increase in nitrogen rates significantly ($P \leq 0.05$) increased leaf N in mature leaf levels at all sites. This shows that nitrogen deficiency can be corrected by applying nitrogen fertilizer and this has also been shown in previous studies in Kenya conducted at single sites.[22,25,27] Mature leaf nitrogen level below 3.0% is considered deficient while level below 3.5% is mildly deficient for seedling tea.[12,17,19] For mean site data, there was what could be considered mild N deficiency up to 75 kg N/ha/year in Changoi and at control in Timbilil (Table 3). Indeed these two sites had the lowest mean N levels. However, despite the low levels the sites recorded higher ($P \leq 0.05$) yields than sites with high mature leaf N levels.[28] Indeed even without application of nitrogen (control) the mature leaf nutrients levels at Sotik, Ngwazi, Maruku, Katoke, Kitabi, and Mulindi were at levels considered adequately supplied despite the fact that at the time of sampling in 2010, the control plots had been without fertiliser application for three years. Similar to results from different clones receiving same agronomic inputs,[21] these results demonstrate that norms of nitrogen levels set for seedling tea may not be applicable on clonal tea and at different locations. There were significant interactions except site x N-rate which may be an indicating that the observed variations did not follow the same pattern. These results indicate that the mature leaf nitrogen norms set for seedling tea are not appropriate for clonal tea, especially in the different locations. Harvesting intervals however, did not influence mature leaf nitrogen levels.

Increasing rates of nitrogenous fertiliser had varying influences on mature leaf P at different sites. At Changoi, Sotik, Timbilil, Ngwazi, Kitabi and Mulindi, there were no significant changes in mature leaf P with higher rates on nitrogenous fertiliser despite the fact that the compound nitrogenous fertiliser used also contained P. Increase in N rates therefore automatically increased

Table 2: Critical levels of nutrients in the uppermost mature tea leaf in East Africa

Nutrient	Deficient	Borderline	Adequate
Nitrogen	Below 3.0%	3.0 to 3,5%	Above 3.5%
Phosphorous	Below 0.15%	0.15 to 0.17%	Above 0.17%
Potassium	Below 1.20%	1.20 to 1.50%	Above 1.50%
Magnesium	Below 0.10%	0.10 to 0.13%	Above 0.13%
Zinc	Below 10 ppm		

Source: Owuor and Wanyoko, 1983

Table 3: Variations in mature leaf N (%) levels of TRFK 6/8 with location, N rates and plucking frequency

Site (S)	Plucking Frequency (PF) (days)	N-rates (N) in kg N/ha/yr					PF mean	Site Mean	C.V. %
		0	75	150	225	300			
Changoi	7	2.97	3.48	3.61	3.87	3.52	3.49		
	14	3.45	3.58	3.55	3.75	3.59	3.58	3.53	4.90
	21	3.36	3.31	3.22	3.34	4.35	3.52		
Mean N-rate		3.26	3.46	3.46	3.65	3.82			
LSD, P ≤ 0.05				0.23			NS		
Sotik	7	3.36	3.78	3.33	3.85	3.54	3.57		
	14	3.88	3.67	3.88	3.38	3.95	3.75	3.70	4.57
	21	3.64	3.44	3.85	4.05	3.95	3.78		
Mean N-rate		3.62	3.63	3.68	3.76	3.81			
LSD, P ≤ 0.05				NS			0.27		
Timbilil	7	3.33	3.55	3.67	3.44	3.59	3.52		
	14	3.43	3.46	3.58	3.76	3.62	3.57	3.56	3.05
	21	3.66	3.56	3.41	3.60	3.74	3.59		
Mean N-rate		3.47	3.52	3.55	3.60	3.65			
LSD, P ≤ 0.05				0.14			NS		
Ngwazi	7	4.92	4.69	4.74	4.82	4.84	4.80		
	14	4.55	4.66	4.71	4.63	4.72	4.65	4.73	3.09
	21	4.55	4.68	4.68	4.93	4.80	4.73		
Mean N-rate		4.67	4.69	4.71	4.79	4.79			
LSD, P ≤ 0.05				NS			NS		
Maruku	7	4.26	4.32	4.28	4.51	4.29	4.33		
	14	4.18	4.27	4.31	4.25	4.64	4.33	4.34	3.07
	21	4.34	4.26	4.36	4.46	4.36	4.36		
Mean N-rate		4.26	4.28	4.32	4.41	4.43			
LSD, P ≤ 0.05				0.17			NS		
Katoke	7	4.88	5.11	5.27	5.28	5.51	5.21		
	14	5.01	4.77	5.11	4.98	5.16	5.00	5.07	3.33
	21	4.81	5.26	4.85	5.08	5.03	5.01		
Mean N-rate		4.90	5.05	5.08	5.11	5.23			
LSD, P ≤ 0.05				0.22			NS		
Kitabi	7	4.16	4.23	4.28	4.33	4.48	4.30		
	14	4.15	4.24	4.27	4.32	4.44	4.28		3.24
	21	4.16	4.23	4.29	4.34	4.47	4.30	4.29	
Mean N-rate		4.16	4.24	4.28	4.33	4.46			
LSD, P ≤ 0.05				0.21			NS		
Mulindi	7	4.13	4.37	4.40	4.48	4.63	4.40		
	14	4.10	4.37	4.39	4.50	4.61	4.39		3.46
	21	4.15	4.37	4.43	4.48	4.62	4.41	4.40	
Mean N-rate		4.12	4.37	4.41	4.49	4.62			
LSD, P ≤ 0.05				0.19			NS		
All 8 sites means		4.00	4.19	4.20	4.32	4.30	4.20		
		4.09	4.13	4.23	4.20	4.34	4.20		3.86
		4.08	4.14	4.14	4.29	4.42	4.21		
Mean N-rate		4.06	4.15	4.19	4.27	4.35			
LSD, P ≤ 0.05					0.09		NS	0.09	

Interactions*: SxPF = 0.13, NxPF = 0.12, SxNxPF = 0.26, NS= not significant

Table 4: Variations in mature leaf P (%) levels of TRFK 6/8 with location, N rates and plucking Frequency

Site (S)	Plucking Frequency (PF) (days)	N-rates (N) in kg N/ha/yr					PF Mean	Site mean	C.V.%
		0	75	150	225	300			
Changoi	7	0.22	0.27	0.26	0.26	0.23	0.25		
	14	0.25	0.22	0.27	0.23	0.22	0.24	0.24	8.19
	21	0.23	0.24	0.22	0.22	0.22	0.23		
Mean N-rate		0.23	0.24	0.25	0.24	0.22			
LSD, P ≤ 0.05				NS			NS		
Sotik	7	0.18	0.19	0.19	0.19	0.18	0.19		
	14	0.18	0.22	0.19	0.20	0.16	0.19	0.19	8.62
	21	0.20	0.19	0.20	0.18	0.21	0.20		
Mean N-rate		0.18	0.20	0.19	0.19	0.18			
LSD, P ≤ 0.05				NS			NS		
Timbilil	7	0.18	0.19	0.19	0.17	0.17	0.18		
	14	0.18	0.18	0.18	0.19	0.18	0.18	0.18	8.80
	21	0.18	0.17	0.19	0.19	0.16	0.18		
Mean N-rate		0.18	0.18	0.19	0.18	0.17			
LSD, P ≤ 0.05				NS			NS		
Ngwazi	7	0.32	0.31	0.33	0.33	0.30	0.32		
	14	0.36	0.31	0.34	0.31	0.31	0.33	0.32	4.96
	21	0.29	0.33	0.32	0.31	0.30	0.31		
Mean N-rate		0.32	0.32	0.33	0.32	0.30			
LSD, P ≤ 0.05				NS			0.02		
Maruku	7	0.36	0.29	0.34	0.27	0.22	0.30		
	14	0.25	0.26	0.32	0.32	0.27	0.28	0.29	5.69
	21	0.24	0.32	0.27	0.31	0.24	0.28		
Mean N-rate		0.28	0.29	0.31	0.30	0.24			
LSD, P ≤ 0.05				0.02			NS		
Katoke	7	0.28	0.36	0.33	0.31	0.30	0.32		
	14	0.22	0.33	0.34	0.30	0.24	0.29	0.30	6.89
	21	0.26	0.32	0.27	0.29	0.24	0.28		
Mean N-rate		0.25	0.34	0.31	0.31	0.26			
LSD, P ≤ 0.05				0.02			0.03		
Kitabi	7	0.20	0.23	0.20	0.20	0.18	0.20		
	14	0.23	0.19	0.21	0.20	0.19	0.21	0.21	9.30
	21	0.20	0.22	0.21	0.21	0.20	0.21		
Mean N-rate		0.21	0.21	0.21	0.20	0.19			
LSD, P ≤ 0.05				NS			NS		
Mulindi	7	0.19	0.18	0.21	0.18	0.18	0.19		
	14	0.19	0.20	0.17	0.18	0.15	0.18	0.19	8.06
	21	0.18	0.21	0.21	0.20	0.19	0.20		
Mean N-rate			0.20	0.19	0.19	0.17			
LSD, P ≤ 0.05				NS			NS		
All 8 sites means	7	0.24	0.25	0.26	0.24	0.22	0.24		
	14	0.23	0.24	0.25	0.24	0.22	0.24		7.46
	21	0.22	0.25	0.38	0.24	0.22	0.23		
Mean N rate		0.23	0.25	0.25	0.24	0.22			
LSD, P ≤ 0.05				0.01			0.01	0.01	

Interactions: SxN = 0.02, SxPF = 0.01, NxPF = 0.01, SxNxPF = 0.03; NS = Not significant

Table 5: Variations in mature leaf K levels (%) of TRFK 6/8 with location, N rates and plucking frequency

Site (S)	Plucking Frequency (PF) (days)	N-rates (N) in kg N/ha/yr: 0	75	150	225	300	PF Mean	Site Mean	C.V.%
Changoi	7	1.43	1.82	1.62	1.70	1.59	1.63		
	14	1.47	1.61	1.88	1.61	1.51	1.62	1.61	2.27
	21	1.43	1.68	1.52	1.69	1.62	1.59		
Mean N-rate		1.44	1.70	1.67	1.67	1.57			
LSD, P ≤ 0.05				0.05			NS		
Sotik	7	1.81	1.62	1.72	1.52	1.62	1.66		
	14	1.67	1.69	1.62	1.55	1.55	1.62	1.62	2.86
	21	1.70	1.56	1.54	1.65	1.46	1.58		
Mean N-rate		1.72	1.62	1.62	1.58	1.54			
LSD, P ≤ 0.05				0.06			NS		
Timbilil	7	1.62	1.70	1.66	1.63	1.45	1.61		
	14	1.54	1.51	1.60	1.43	1.59	1.53	1.57	2.67
	21	1.65	1.53	1.46	1.61	1.61	1.57		
Mean N-rate		1.60	1.58	1.57	1.56	1.55			
LSD, P ≤ 0.05				NS			0.07		
Ngwazi	7	1.39	1.43	1.43	1.40	1.38	1.41		
	14	1.41	1.42	1.40	1.39	1.39	1.40	1.41	1.63
	21	1.41	1.43	1.40	1.40	1.41	1.41		
Mean N-rate		1.40	1.43	1.41	1.40	1.39			
LSD, P ≤ 0.05				0.03			NS		
Maruku	7	1.35	1.31	1.35	1.27	1.27	1.31		
	14	1.31	1.35	1.32	1.30	1.27	1.31	1.32	1.97
	21	1.32	1.36	1.35	1.34	1.31	1.34		
Mean N-rate		1.33	1.34	1.34	1.30	1.28			
LSD, P ≤ 0.05				0.03			NS		
Katoke	7	1.22	1.26	1.25	1.22	1.27	1.24		
	14	1.26	1.26	1.25	1.26	1.19	1.24	1.25	1.50
	21	1.28	1.27	1.25	1.25	1.24	1.26		
Mean N-rate		1.25	1.26	1.25	1.24	1.23			
LSD, P ≤ 0.05				0.02			NS		
Kitabi	7	1.26	1.26	1.26	1.22	1.22	1.24		
	14	1.22	1.26	1.23	1.23	1.22	1.23	1.23	1.29
	21	1.25	1.24	1.21	1.23	1.22	1.23		
Mean N-rate		1.24	1.25	1.23	1.23	1.22			
LSD, P ≤ 0.05				0.02			NS		
Mulindi	7	1.22	1.22	1.22	1.21	1.19	1.21		
	14	1.19	1.22	1.21	1.19	1.20	1.20	1.21	1.26
	21	1.27	1.24	1.21	1.20	1.19	1.22		
Mean N-rate		1.23	1.22	1.21	1.20	1.19			
LSD, P ≤ 0.05				0.02			NS		
All 8 sites means	7	1.41	1.45	1.44	1.40	1.37	1.42		
	14	1.38	1.42	1.44	1.37	1.37	1.40		2.21
	21	1.41	1.41	1.37	1.42	1.38	1.40		
Mean N-rate		1.40	1.43	1.42	1.40	1.37			
LSD, P ≤ 0.05				0.01				0.02	

Interactions: SxN = 0.03, SxPF = 0.02, NxPF = 0.02, SxNxPF = 0.05, NS = Not significant

the amount of P applied. But at Katoke and Maruku there was significant ($P \leq 0.05$) response in mature leaf P to nitrogenous fertiliser application. The response however, appeared quadratic with low levels at control and at the highest nitrogen rate. That trend was repeated for the mean data for all locations. The increase observed is attributed to the additional P applied in the nitrogenous fertiliser. However, the data from Katoke and Maruku were at variance with previous data from Kericho, where application of high rates of nitrogenous fertiliser reduced mature leaf P levels.[22-24] The decline at the highest nitrogenous fertiliser level could be due to soil pH reduction[24] causing phosphorous fixation in the soil. The data from Katoke and Maruku suggest that in some locations within East Africa, uptake of P can be improved by application of nitrogenous fertiliser containing the nutrient. Such responses are limited to not more that 225 kg N/ha/year. Beyond this, extra nitrogen fixed P making it unavailable. It may be necessary to do soil analysis to establish how these nutrients interact in the soils where there were responses and to establish if the responses were influenced by the soil acidity levels. Like nitrogen, there were significant variations in mature leaf mean P with locations (Tables 4), demonstrating the supply and absorption status of the nutrients are influenced by varying environmental factors. In all areas the levels were above those considered deficient for seedling tea.[12,17,19] Even where fertiliser had not been applied, the levels were higher than the deficient limit level. The results imply that either these soils were well supplied with the nutrient or the recommended levels for seedling tea are not suitable for clonal tea, and that different locations need specific guideline to guide the nutrient application. There were significant interactions between locations and nitrogen rates indicating that the observed variations were unique and did not follow same pattern. These results suggest that seedling tea norms set for this nutrient do not seem to apply to clone TRFK 6/8 at all locations. There was no response on mature leaf phosphorus levels to plucking frequency except at Ngwazi and Katoke and in all site means. It is unclear what caused this difference since analysed leaf was of the same age.

The amounts of leaf K monitored at all sites support the early observations[29] that East African soils are rich in the nutrient and there is little likelihood of obtaining tea yield response to the nutrient.[30,31] Although there were no significant variations ($P \leq 0.05$) in mature leaf potassium levels with increasing rates of nitrogenous (Table 5), the general trend was that there was decline in clone TRFK 6/8 K levels. This was despite the concurrent increase in applied K with increase in nitrogenous fertiliser rates in the fertiliser formulation used. The decrease in mature leaf K with rise in nitrogenous fertiliser can be attributed to leaching triggered by excess ammonium ions in the NPK fertiliser.[32] The ionic size of potassium cation (K^+) (1.33A) and ammonium ion (NH_4^+) (1.43A) are very similar.[33] Excess ammonium ions in the soil therefore triggers off replacement of potassium cations in the soil exchange sites, causing potassium leaching. This causes antagonistic soil availability relationship between N and K in the soils.[34,35] These results suggest that application of K and N may need to be staggered so that at any time there is only availability of one of the nutrients. Such applications can be staggered by at least 3 months for a perennial crop like tea. There were no significant responses in mature leaf K to intervals of harvesting, except at Mulindi, and in all sites means. However, the response appeared sporadic. There were significant ($P \leq 0.05$) interactions effects between locations and nitrogen rates and locations and plucking intervals, demonstrating that extents of the responses varied with site. This indicates that factors controlling the absorption of nutrients were varied from site to site.

Mature leaf Mg levels of clone TRFK 6/8 significantly ($P \leq 0.05$) changed with location of production (Table 6). The levels were particularly low at Katoke and Kitabi, where the levels were equivalent to borderline levels for seedling tea.[12,17] In other areas, the levels were equivalent to adequate supply. At all locations, the clone TRFK 6/8 mature leaf mg levels declined with increase in nitrogenous fertiliser rates (Table 6) and this reached significant levels at Timbilil, Maruku, Katoke and Kitabi. Similar decline in mature leaf Mg with increase in nitrogenous fertiliser rates had been observed in earlier studies.[24-26,36,37] Indeed, Kamau[38] argued that as long as tea fields are well nourished with NPK, responses to magnesium in acid tea soils are unlikely. The significant interactions indicate that the leaf Mg variations did not follow same pattern. The magnesium levels did not change due to plucking intervals except at Maruku.

The zinc levels (Table 7) were much higher than the set limits levels for seedling tea in Kericho[12,17,19]. This is despite the fact that the fields on which these trials were set up had been subjected to foliar zinc application as recommended when there is deficiency.[12] Thus, the set limits set for seedling tea seem inappropriate for clone TRFK 6/8 at all locations in East Africa. There were significant ($P \leq 0.05$) differences in mature leaf Zn levels with

Table 6: Variations in mature leaf Mg levels (%) of TRFK 6/8 with location, N rates and plucking frequency

Site (S)	Plucking Frequency (PF) (days)	N-rates (N) kg N/ha/yr 0	75	150	225	300	PF mean	Site Mean	C.V.%
Changoi	7	0.19	0.19	0.16	0.18	0.17	0.18		
	14	0.18	0.16	0.18	0.19	0.18	0.18	0.17	9.70
	21	0.18	0.17	0.17	0.13	0.14	0.16		
Mean N-rate		0.18	0.17	0.17	0.17	0.16			
LSD, P ≤ 0.05				NS			NS		
Sotik	7	0.17	0.19	0.18	0.19	0.19	0.18		
	14	0.17	0.17	0.19	0.16	0.17	0.17	0.18	11.23
	21	0.21	0.17	0.16	0.17	0.16	0.18		
Mean N-rate		0.18	0.18	0.18	0.17	0.17			
LSD, P ≤ 0.05				NS			NS		
Timbilil	7	0.20	0.17		0.17	0.11	0.16		
	14	0.19	0.13	0.19	0.15	0.13	0.16	0.17	13.03
	21	0.13	0.17	0.20	0.15	0.16	0.16		
Mean N-rate		0.18	0.16	0.17	0.16	0.13			
LSD, P ≤ 0.05				0.03			NS		
Ngwazi	7	0.20	0.25	0.21	0.22	0.22	0.22		
	14	0.21	0.20	0.23	0.20	0.21	0.21	0.21	7.73
	21	0.20	0.20	0.20	0.21	0.21	0.20		
Mean N-rate		0.21	0.22	0.21	0.21	0.22			
LSD, P ≤ 0.05				NS			NS		
Maruku	7	0.15	0.11	0.11	0.12	0.13	0.13		
	14	0.14	0.16	0.13	0.13	0.14	0.14	0.14	10.19
	21	0.19	0.15	0.15	0.15	0.13	0.15		
Mean N-rate		0.16	0.14	0.13	0.13	0.13			
LSD, P ≤ 0.05				0.02			0.02		
Katoke	7	0.10	0.13	0.09	0.10	0.07	0.10		
	14	0.13	0.12	0.14	0.09	0.08	0.11	0.11	13.39
	21	0.15	0.10	0.10	0.10	0.12	0.11		
Mean N-rate		0.13	0.12	0.11	0.10	0.09			
LSD, P ≤ 0.05				0.02			NS		
Kitabi	7	0.12	0.09		0.10	0.11	0.11		
	14	0.12	0.10	0.11	0.10	0.10	0.11		11.77
								0.11	
	21	0.11	0.11	0.10	0.10	0.10	0.10		
Mean N-rate		0.12	0.10	0.11	0.10	0.10			
LSD, P ≤ 0.05				0.02			NS		
Mulindi	7	0.14	0.15	0.17	0.15	0.15	0.15		
	14	0.18	0.16	0.15	0.15	0.16	0.16	0.16	8.65
	21	0.14	0.16	0.17	0.18	0.15	0.16		
Mean N-rate		0.16	0.16	0.16	0.16	0.15			
LSD, P ≤ 0.05				NS			NS		
All 8 sites means	7	0.16	0.16	0.15	0.15	0.14	0.15		
	14	0.17	0.15	0.17	0.15	0.15	0.16		10.71
	21	0.16	0.15	0.16	0.15	0.15	0.15		
Mean N-rate		0.16	0.16	0.15	0.15	0.15			
LSD, P ≤ 0.05				0.01			NS		

Interactions: SxN = 0.02, SxPF = 0.01, NxPF = 0.01, SxNxPF = 0.03, NS = Not significant

Table 7: Variations in mature leaf Zn levels (ppm) of TRFK 6/8 with location, N rates and plucking frequency

Site (S)	Plucking Frequency (PF) (days)	N-rates (N) kg N/ha/yr					PF mean	Site (S) Mean	C.V.%
		0	75	150	225	300			
Changoi	7	16.00	16.00	19.67	20.67	19.67	18.4		
	14	16.00	18.00	17.00	19.33	19.67	18.00	17.98	10.88
	21	15.67	18.33	17.67	17.67	18.33	17.53		
Mean N-rate		15.89	17.44	18.11	19.22	19.22			
LSD, P ≤ 0.05				2.56			NS		
Sotik	7	19.00	21.67	20.67	28.00	31.33	24.13		
	14	18.00	20.00	21.00	27.67	28.00	22.93	23.62	7.59
	21	18.67	21.00	22.33	28.00	29.00	23.80		
Mean N-rate		18.56	20.89	21.33	27.89	29.44			
LSD, P ≤ 0.05				2.35			NS		
Timbilil	7	21.33	21.00	20.33	22.67	23.00	21.67		
	14	22.00	21.00	22.33	22.00	21.67	21.80	21.51	1.21
	21	20.33	20.33	22.33	21.00	21.33	21.07		
Mean N-rate		21.22	20.78	21.67	21.89	22.00			
LSD, P ≤ 0.05				1.21			NS		
Ngwazi	7	29.00	29.33	27.67	34.00	37.00	31.40		
	14	29.33	34.00	30.67	30.00	33.67	31.53	31.82	8.55
	21	31.00	29.67	35.00	34.00	33.00	32.53		
Mean N-rate		29.78	31.00	31.11	32.67	34.56			
LSD, P ≤ 0.05				3.56			NS		
Maruku	7	44.33	44.33	48.00	44.00	45.67	45.27		
	14	44.33	44.67	42.00	45.00	46.00	44.40	45.36	4.97
	21	45.33	45.33	44.67	48.00	48.67	46.40		
Mean N-rate		44.67	44.78	44.89	45.67	46.78			
LSD, P ≤ 0.05				NS			NS		
Katoke	7	38.00	42.33	34.67	44.33	43.67	40.40		
	14	43.67	40.00	46.00	42.33	45.00	43.40	42.13	6.70
	21	38.00	40.33	46.33	43.00	45.33	42.60		
Mean N-rate		39.89	40.89	42.33	43.22	44.33			
LSD, P ≤ 0.05				3.69			4.44		
Kitabi	7	28.33	27.00	28.33	28.67	31.00	28.67		
	14	26.67	29.33	28.67	30.00	29.33	28.80	28.49	5.10
	21	26.33	27.67	29.00	27.33	29.67	28.00		
Mean N-rate		27.11	28.00	28.67	28.67	30.00			
LSD, P ≤ 0.05				1.90			NS		
Mulindi	7	31.67	31.67	32.67	34.67	33.33	32.80		
	14	32.33	32.00	32.33	32.33	33.67	32.53	32.91	3.89
	21	32.67	33.67	34.00	32.00	34.67	33.40		
Mean N-rate		32.22	32.44	33.00	33.00	33.89			
LSD, P ≤ 0.05				NS			NS		
All 8 sites means	7	28.46	29.17	29.00	32.13	33.08	30.34		
	14	29.04	29.88	30.00	31.08	32.13	30.43		6.74
	21	28.50	29.54	31.42	31.38	32.50	30.67		
Mean N-rate		28.67	29.53	30.14	31.53	32.53			
LSD, P ≤ 0.05					0.95		NS	1.02	

Interactions: SxN = 1.98, SxPF = 1.61, NxPF = 1.37, SxNxPF = 3.39, NS = Not significant

Table 8: Variations in mature leaf Ca levels (%) of TRFK 6/8 with location, N rates and plucking frequency

Site (S)	Plucking Frequency (PF) (days)	N-rates (N) kg N/ha/yr					PF mean	Site Mean	C.V.%
		0	75	150	225	300			
Changoi	7	1.15	1.24	1.09	1.04	0.92	1.09		
	14	1.18	1.11	1.03	1.21	1.11	1.13	1.10	12.92
	21	1.17	1.05	1.06	1.12	1.03	1.09		
Mean N-rate		1.16	1.13	1.06	1.12	1.02			
LSD, P ≤ 0.05				NS			NS		
Sotik	7	1.68	1.89	1.79	1.69	1.54	1.72		
	14	1.67	1.65	1.77	1.81	1.71	1.73	1.71	4.17
	21	1.90	1.73	1.52	1.67	1.65	1.70		
Mean N-rate		1.75	1.76	1.70	1.73	1.63			
LSD, P ≤ 0.05				0.09			NS		
Timbilil	7	0.89	0.73	0.84	0.80	0.73	0.80		
	14	0.79	0.81	0.82	0.74	0.70	0.77	0.81	4.94
	21	0.96	0.98	0.68	0.83	0.84	0.86		
Mean N-rate		0.88	0.84	0.80	0.79	0.76			
LSD, P ≤ 0.05				0.04			NS		
Ngwazi	7	0.38	0.41	0.41	0.41	0.43	0.41		
	14	0.39	0.41	0.41	0.43	0.41	0.41	0.40	6.01
	21	0.38	0.40	0.42	0.42	0.42	0.41		
Mean N-rate		0.38	0.40	0.41	0.42	0.42			
LSD, P ≤ 0.05				0.05			NS		
Maruku	7	0.21	0.27	0.22	0.16	0.17	0.21		
	14	0.21	0.17	0.19	0.21	0.21	0.20	0.20	6.08
	21	0.28	0.16	0.17	0.19	0.13	0.19		
Mean N-rate		0.24	0.20	0.19	0.19	0.17			
LSD, P ≤ 0.05				0.02			0.02		
Katoke	7	0.32	0.28	0.33	0.36	0.33	0.33		
	14	0.35	0.37	0.39	0.34	0.18	0.33	0.33	5.53
	21	0.38	0.39	0.31	0.32	0.34	0.35		
Mean N-rate		0.35	0.35	0.34	0.34	0.29			
LSD, P ≤ 0.05				0.02			NS		
Kitabi	7	0.46	0.54	0.32	0.35	0.32	0.40		
	14	0.37	0.49	0.41	0.34	0.27	0.38	0.42	6.25
	21	0.54	0.39	0.58	0.47	0.36	0.47		
Mean N-rate		0.46	0.47	0.44	0.39	0.32			
LSD, P ≤ 0.05				0.03			0.04		
Mulindi	7	0.71	0.63	0.68	0.62	0.59	0.65		
	14	0.71	0.66	0.61	0.63	0.53	0.63	0.62	3.99
	21	0.55	0.62	0.65	0.60	0.56	0.60		
Mean N-rate		0.66	0.63	0.65	0.62	0.56			
LSD, P ≤ 0.05				0.03			0.04		
All 8 sites means	7	0.73	0.75	0.71	0.68	0.63	0.70		
	14	0.71	0.71	0.70	0.71	0.64	0.69		7.49
	21	0.77	0.72	0.67	0.70	0.67	0.70		
Mean N-rate		0.74	0.73	0.69	0.70	0.64			
LSD, P ≤ 0.05				0.03			NS	0.03	

Interactions: SxN = 0.06, SxPF = 0.05, NxPF = 0.04, SxNxPF = 0.10, NS = Not significant

Table 9: Variations in mature leaf Mn levels (%) of TRFK 6/8 with location, N rates and plucking frequency

Site (S)	Plucking Frequency (PF) (days)	N-rates (N) kg N/Ha/yr 0	75	150	225	300	PF mean	Site Mean	C.V.%
Changoi	7	0.34	0.41	0.44	0.40	0.45	0.41		
	14	0.43	0.41	0.43	0.37	0.41	0.41	0.41	6.84
	21	0.36	0.40	0.42	0.49	0.45	0.42		
Mean N-rate		0.38	0.40	0.43	0.42	0.44			
LSD, P ≤ 0.05				0.04			NS		
Sotik	7	0.30	0.28	0.29	0.30	0.30	0.29		
	14	0.26	0.30	0.30	0.31	0.29	0.29	0.29	9.26
	21	0.25	0.25	0.32	0.28	0.31	0.28		
Mean N-rate		0.27	0.28	0.30	0.30	0.30			
LSD, P ≤ 0.05				NS			NS		
Timbilil	7	0.23	0.27	0.24	0.26	0.25	0.25		
	14	0.24	0.24	0.22	0.27	0.24	0.24	0.25	8.62
	21	0.25	0.26	0.21	0.25	0.27	0.25		
Mean N-rate		0.24	0.25	0.23	0.26	0.26			
LSD, P ≤ 0.05				0.03			NS		
Ngwazi	7	0.17	0.17	0.16	0.16	0.18	0.17		
	14	0.16	0.17	0.16	0.17	0.18	0.17	0.17	6.69
	21	0.14	0.17	0.17	0.16	0.18	0.17		
Mean N-rate		0.16	0.17	0.16	0.17	0.18			
LSD, P ≤ 0.05				0.01			NS		
Maruku	7	0.14	0.16	0.16	0.15	0.16	0.15		
	14	0.11	0.15	0.15	0.14	0.15	0.14	0.15	9.75
	21	0.14	0.15	0.13	0.14	0.16	0.15		
Mean N-rate		0.13	0.15	0.15	0.14	0.16			
LSD, P ≤ 0.05				0.02			NS		
Katoke	7	0.13	0.13	0.13	0.16	0.15	0.14		
	14	0.14	0.15	0.14	0.15	0.17	0.15	0.15	9.74
	21	0.13	0.16	0.12	0.15	0.16	0.15		
Mean N-rate		0.14	0.15	0.13	0.16	0.16			
LSD, P ≤ 0.05				0.02			NS		
Kitabi	7	0.13	0.13	0.14	0.13	0.14	0.13		
	14	0.14	0.12	0.14	0.13	0.13	0.13	0.13	5.92
	21	0.13	0.13	0.13	0.13	0.13	0.13		
Mean N-rate		0.13	0.13	0.14	0.13	0.13			
LSD, P ≤ 0.05				NS			NS		
Mulindi	7	0.19	0.21	0.21	0.21	0.23	0.21		
	14	0.26	0.22	0.18	0.20	0.21	0.22	0.21	7.75
	21	0.18	0.20	0.21	0.21	0.23	0.20		
Mean N-rate		0.21	0.21	0.20	0.21	0.22			
LSD, P ≤ 0.05				NS			NS		
All 8 sites means	7	0.20	0.22	0.22	0.22	0.23	0.22		
	14	0.22	0.22	0.22	0.22	0.22	0.22		8.88
	21	0.20	0.22	0.21	0.23	0.24	0.22		
Mean N-rate		0.21	0.22	0.22	0.22	0.23			
LSD, P ≤ 0.05				0.01			NS	0.01	

Interactions: SxN = 0.02, SxPF = NS, NxPF = 0.01, SxNxPF = 0.03, NS = Not significant

Table 10: Variations in mature leaf Cu levels (ppm) of TRFK 6/8 with location, N rates and plucking frequency

Site (S)	Plucking Frequency (PF) (days)	N-rates (kg N/ha/yr) 0	75	150	225	300	PF mean	Site Mean	C.V.%
Changoi	7	9.33	10.67	11.67	12.67	13.00	11.47		
	14	11.67	11.00	10.33	10.33	13.00	11.27	11.29	17.61
	21	10.67	10.67	11.33	12.33	10.67	11.13		
Mean N-rate		10.56	10.78	11.11	11.78	12.22			
LSD, P ≤ 0.05				2.60			NS		
Sotik	7	9.33	10.00	9.33	10.33	10.67	9.93		
	14	9.33	9.00	10.00	10.00	10.33	9.73	9.91	11.02
	21	9.00	9.00	11.00	11.00	10.33	10.07		
Mean N-rate		9.22	9.33	10.11	10.44	10.44			
LSD, P ≤ 0.05				1.43			NS		
Timbilil	7	7.67	7.33	8.00	7.67	10.33	8.20		
	14	7.67	7.33	8.00	8.67	7.33	7.80	7.84	10.73
	21	6.67	8.33	7.00	7.67	8.00	7.53		
Mean N-rate		7.33	7.67	7.67	8.00	8.56			
LSD, P ≤ 0.05				1.10			NS		
Ngwazi	7	8.67	9.00	9.00	8.33	9.00	8.80		
	14	8.33	9.00	9.00	9.00	9.00	8.87	9.00	10.08
	21	9.00	8.33	8.67	10.00	10.67	9.33		
Mean N-rate		8.67	8.78	8.89	9.11	9.56			
LSD, P ≤ 0.05				NS			NS		
Maruku	7	17.67	19.00	19.00	16.67	18.67	18.20		
	14	18.00	17.33	17.00	20.00	20.00	18.47	18.56	6.68
	21	18.67	18.33	20.00	19.67	18.33	19.00		
Mean N-rate		18.11	18.22	18.67	18.78	19.00			
LSD, P ≤ 0.05				NS			NS		
Katoke	7	15.33	14.33	15.00	13.00	14.67	14.47		
	14	13.00	13.00	13.33	14.67	15.00	13.80	14.20	7.97
	21	13.33	15.00	14.00	15.00	14.33	14.33		
Mean N-rate		13.89	14.11	14.11	14.22	14.67			
LSD, P ≤ 0.05				NS			NS		
Kitabi	7	8.00	10.67	9.33	8.67	12.67	9.87		
	14	10.67	9.00	15.33	13.00	11.67	11.93	11.07	13.69
	21	10.67	12.00	8.00	13.67	12.67	11.40		
Mean N-rate		9.78	10.56	10.89	11.78	12.33			
LSD, P ≤ 0.05				1.98			2.38		
Mulindi	7	6.00	6.33	7.67	8.00	7.33	7.07		
	14	8.67	8.00	9.67	7.00	8.00	8.27	7.78	16.94
	21	6.00	8.33	6.33	9.33	10.00	8.00		
Mean N-rate		6.89	7.56	7.89	8.11	8.44			
LSD, P ≤ 0.05				NS			NS		
All 8 sites means	7	10.25	10.92	11.13	10.67	12.04	11.00		
	14	10.92	10.46	11.58	11.58	11.79	11.27		12.97
	21	10.50	11.25	10.79	12.33	11.87	11.35		
Mean N-rate		10.56	10.88	11.17	11.53	11.90			
LSD, P ≤ 0.05				0.67			NS	0.72	

Interactions: SxN = NS, SxPF = 1.14, NxPF = 0.97, SxNxPF = 2.40, NS = Not significant

Table 11: Variations in mature leaf Fe levels (ppm) of TRFK 6/8 with location, N rates and plucking frequency

Site (S)	Plucking Frequency (PF) (days)	N-rates (N) kg N/ha/yr					PF mean	Site mean	C.V.%
		0	75	150	225	300			
Changoi	7	96.67	123.67	156.33	172.33	185.00	146.80		
	14	102.00	109.00	147.33	142.67	190.00	138.20	141.82	6.99
	21	97.33	110.67	159.67	154.00	180.67	140.47		
Mean N-rate		98.67	114.44	154.44	156.33	185.22			
LSD, P ≤ 0.05				12.98			NS		
Sotik	7	151.33	145.67	148.67	156.67	176.67	155.80		
	14	145.67	157.00	158.00	162.67	167.00	158.07	155.11	6.85
	21	135.33	148.67	160.00	150.67	162.67	151.47		
Mean N-rate		144.11	150.44	155.56	156.67	168.78			
LSD, P ≤ 0.05				13.90			NS		
Timbilil	7	154.67	179.00	185.67	181.33	201.67	180.47		
	14	161.67	177.33	181.67	188.33	182.67	178.33	180.04	6.04
	21	174.67	183.00	178.33	182.67	188.00	181.33		
Mean N-rate		163.67	179.78	181.89	184.11	190.78			
LSD, P ≤ 0.05				14.24			NS		
Ngwazi	7	76.33	76.67	74.33	77.67	87.67	78.53		
	14	78.33	78.67	86.33	89.33	82.33	83.00	80.49	6.58
	21	73.33	75.00	76.00	85.00	90.33	79.93		
Mean N-rate		76.00	76.78	78.89	84.00	86.78			
LSD, P ≤ 0.05				6.93			NS		
Maruku	7	78.33	75.33	87.00	80.33	88.33	81.87		
	14	82.33	81.33	80.00	81.33	89.33	82.87	82.20	7.29
	21	84.33	88.33	78.67	87.00	71.00	81.87		
Mean N-rate		81.67	81.67	81.89	82.89	82.89			
LSD, P ≤ 0.05				NS			NS		
Katoke	7	134.00	146.00	145.00	132.33	140.67	139.60		
	14	128.00	127.67	128.33	133.67	136.00	130.73	135.31	4.69
	21	136.67	130.00	131.00	139.00	141.33	135.60		
Mean N-rate		132.89	134.56	134.78	135.00	139.33			
LSD, P ≤ 0.05				NS			9.97		
Kitabi	7	129.33	127.00	162.67	166.67	184.33	154.00		
	14	161.00	164.67	142.33	195.33	190.67	170.80	156.18	4.33
	21	138.33	140.33	165.33	130.67	144.00	143.73		
Mean N-rate		142.89	144.00	156.78	164.22	173.00			
LSD, P ≤ 0.05				8.85			NS		
Mulindi	7	77.33	71.00	79.00	93.33	100.00	84.13		
	14	75.33	102.00	99.33	89.33	88.00	90.80	87.58	7.56
	21	68.33	91.33	87.67	87.00	104.67	87.80		
Mean N-rate		73.67	88.11	88.67	89.89	97.56			
LSD, P ≤ 0.05				8.67			NS		
All 8 sites means	7	112.25	118.04	129.83	132.58	145.54	127.65		
	14	116.79	124.71	127.92	135.21	140.75	129.10		6.88
	21	113.54	120.92	129.58	127.00	135.33	125.28		
Mean N-rate		114.19	121.22	129.11	131.64	140.54			
LSD, P ≤ 0.05				4.05			NS	4.37	

Interactions: SxN = 8.46, SxPF = 6.87, NxPF = 5.84, SxNxPF = 14.46, NS = Not significant

location of production, possibly demonstrating the zinc reserves in the soils were widely varying with locations and/or environmental factors controlling zinc absorption were not constant in different locations. These tea areas were unlikely to suffer from zinc deficiency. Generally, increasing rates of nitrogenous fertiliser application increased the mature leaf zinc levels, reaching significant ($P \leq 0.05$) levels at all locations except at Maruku and Katoke. The significant ($P \leq 0.05$) interactions between nitrogen rates and locations suggested that patterns of changes in mature leaf Zn levels were different from location to location. However plucking intervals had no significant influence on mature leaf zinc levels in clone TRFK 6/8 mature leaf.

Diagnostic mature leaf limit levels for Ca, Mn, Cu and Fe have not been set. However, these nutrients are beneficial to proper growth of plants. The changes in these nutrients with locations, nitrogenous fertiliser rates and plucking intervals are presented in Tables 8, 9, 10 and 11, respectively. All the mature leaf contents of these nutrients changed ($P \leq 0.05$) with location of production, further emphasising how the nutrients reserves in the soils are variable. Similar data were recently recorded on clones grown in different locations[21] and nitrogen rates[37] in Kenya. Ca and Mn levels in mature leaf more than doubled their variations. While Ca levels declined ($P \leq 0.05$), the levels of Mn, Cu, and Fe increased ($P \leq 0.05$) with rise in nitrogenous fertiliser rates at all sites. Similar results for Ca had been observed in earlier studies.[26,37,39-41] These patterns follow closely those observed in the soils where available soil Ca levels decline[31,37] while Mn levels rise.[26,31,37] There were significant interactions effects, except site and plucking frequency for Mn and site and N-rate for Cu indicating differences in patterns of change in the observed variations of mature leaf C, Mn, Cu and Fe. Generally, the mature leaf Ca, Mn, Cu and Fe were not influenced by harvesting intervals.

In conclusion, the amount of mature leaf nutrients significantly ($P \leq 0.05$) varied with location of production (Tables 3-11). The results indicate that due to variations in environmental factors at the sites, even with application of the same agronomic inputs, the level of the nutrients will be different. This in part could be due to variations in the levels of micronutrients in the soils at different locations, especially for the nutrients not supplied and/or due to past agronomic inputs in the fields. Such observation requires soil analytical data to confirm. There were large variations in the mean values for sites for N, K, Ca, Mn, Zn, Cu and Fe. These large variations maybe the cause in part of the variations in yields;[42-45] quality[43-45] and quality precursors[46-49] of clonal tea due to locations observed in the past. These results further reveal that the nutrients norms set even in a single cultivar may vary with location.

The results presented herein demonstrate that diagnostic limits set for seedling tea may not be suitable for clone TRFK 6/8. There is therefore need to develop tissue analysis diagnostic norms for clonal tea. Deficiency of nitrogen can be conveniently cured through application of nitrogen fertiliser as there is response in mature leaf to nitrogen application. However, such application triggers decline in potassium levels in the leaf. The application of the two nutrients need to be staggered in East Africa so that at any time the plant is exposed to only one nutrient in high amounts. Continuous application of high rates of nitrogenous fertilisers could trigger deficiency of K, Ca, and Mg while causing toxicity of Mn. Plucking intervals had minimal effects on mature leaf nutrients.

Acknowledgements

This research has been supported by The Lake Victoria Research (VicRes) initiative. The authors are grateful to the Tea Research Foundation of Kenya, Tea Research Institute of Tanzania and Office Des Cultures Industrielles du Rwanda The' (OCIR The') for availing their field trials, facilities and personnel during the research.

References

1. Gulati A & Ravichranath SD. 1996. Seasonal variations in quality of Kangra tea (*Camellia sinensis* (L.) O. Kuntze) in Himachal Pradesh. *J Sci Food Agr* 71:231–236.
2. Fernandez PL, Fernando P, Martin J & Gonzalez AG. 2002. Study of catechin and xanthine tea profiles as geographical tracers. *J Agr Food Chem* 50: 1833–1839.
3. Li T, Yu LJ, Li MT & Li W. Comparative studies of green teas in Karst and non-Karst areas of Yichang, Hubei Province, PR China. *Food Chem* 103:71–74.
4. Maredo-Pineiro A, Fisher A & Hill SJ. The classification of tea according to region of origin using pattern recognition techniques and trace metal data. *J Food Compos Anal* 16:195–211.
5. Shoubo H. 1989. Meteorology of the tea plant in China. A review. *Agr Forest Meteorol* 47:19–30.
6. Owuor PO, Obanda M, Nyirenda HE & Mandala WL. 2008. Influence of region of production on clonal black tea chemical characteristics. *Food Chem* 108:263–271.
7. Agrawal B. 1989. Factors affecting quality of tea during processing. *Sri Lanka Journal of Tea Science* 58:64–72.

8. Gardner EJ, Ruxton CHS & Leeds AR. 2007. Black tea, helpful or harmful. A review of the evidence. *Eur J Clin Nutr* 61:3–18.

9. Sharma VK, Bhattachayg A, Kumar A & Sharma HK. 2007. Health benefits of tea consumption. *Trop J Pharmaceut Res* 6:785–792.

10. Oyamo JR. 1992. The golden clone in a golden field. *Tea* 13:1–9.

11. Bonheure D & Willson KC. 1992. Mineral nutrition and fertilizers, in *Tea: Cultivation to Consumption*, ed. by Willson KC and Clifford MN. Chapman and Hall: London, 269–329p.

12. Othieno CO. 1988. Summary of observations and recommendations from TRFK. *Tea* 9:50–65.

13. Anonymous. 2002. *Tea Growers Handbook*. Tea Research Foundation of Kenya: Kericho, Kenya.

14. Harler CR. 1971. *Tea Growing*. Oxford University Press, London.

15. Clowes MSJ & Mitini-Nkhoma SP. 1987. Copper deficiency on young clonal tea growing close to Mulanje Mountain. *Quarterly Newsletter, Tea Research Foundation (Central Africa)* 88:13–15.

16. Bhaduri D & Pal A. 2013. Diagnosis and recommendation integrated system (DRIS): Concept and applications on nutritional diagnosis of plants – A review. *JSWC* 12:70–79.

17. Tolhurst JAH. 1976. Chemical analysis as a guide to fertilizer programmes. *Tea in East Africa* 16:4–5.

18. TRFCA. 1990. *Tea Planters Handbook, Tea Research Foundation of Central Africa*. Mulanje, Malawi.

19. Owuor PO & Wanyoko JK. 1983. Fertilizer use advisory service. A reminder to farmers. *Tea* 4:3–7.

20. Wachira FN. 2002. Detection of genetic diversity and characterization of Kenyan tea germplasm. A Tea Genetic Diversity (TGD) Project. TGD Final Project Document, Ed. Tea Research Foundation of Kenya, Kericho, Kenya.

21. Kwach BO, Owuor PO, Kamau DM & Wanyoko JK. 2012. Evaluation of foliar analysis as a diagnostic tool of predicting nutrients deficiencies of clonal tea. *Asian J Biol Life Sci* 1:8–18.

22. Owuor PO, Wanyoko JK & Othieno CO. 1990. High rates of nitrogen on tea. II. Monthly changes in mature leaf nitrogen, phosphorus and potassium contents. *Tea* 11:90–95.

23. Owuor PO, Othieno CO, Kamau DM & Wanyoko JK. 2011. Effects of long term fertilizer use on a high yielding tea clone S15/10: Soil pH, mature leaf nitrogen, mature leaf and soil phosphorus and potassium. *IJTS* 8:15–51.

24. Wanyoko JK, Owuor PO & Othieno CO. 1992. Ammonium and magnesium sulphates on moribund tea. II: Effect of soil chemical properties and plant nutrient uptake. *Tea* 13:91–99.

25. Wanyoko JK, Othieno CO, Mwakha E & Cheruiyot D. 1997. Effects of types and rates of nitrogen fertiliser on leaf nutrient contents of seedling tea at Nandi Hills, Kenya. *Tea* 18:21–31.

26. Wanyoko JK, Owuor PO & Othieno CO. 1990. High rates of nitrogen on tea: III. Monthly changes in mature leaf calcium, magnesium, manganese and aluminium contents. *Tea* 11:96–100.

27. Wanyoko JK. 1988. Types and rates of nitrogen fertilisers on seedling tea. *Tea* 9:4–9.

28. Msomba SW, Kamau DM, Uwimana MA, Muhoza C & Owuor PO. 2014. Yield response of clonal tea to growing environments and nitrogenous fertiliser rates and plucking intervals in the East African countries. *IJTS* **(Submitted)**.

29. Willson KC. 1975. Studies on mineral nutrition of tea. IV. Potassium. *Plant and Soil* 43:279–293.

30. Owuor PO, Wanyoko JK, Othieno CO & Sudoi V. 1993. Effects of rates and ratios of nitrogenous and potash fertilisers on tea in the eastern highlands of Kenya: I. Yields. *Tea* 14:73–77.

31. Kamau DM, Owuor PO & Wanyoko JK. 1998. Effects of rates and ratios of nitrogen and potash fertilisers on seedling tea at Kericho. I. Soil pH, soil available calcium, magnesium and extractable manganese. *Tea* 19:84–91.

32. Owuor PO, Wanyoko JK & Othieno CO. 1987. Effects of nitrogenous fertilisers on leaf potassium contents of tea, *Camellia sinensis* (L.) O. Kuntze. *Tea* 8:4–13.

33. Buurman ET, Pennock J, Tempest DW, Teixeira de Mattos MJ & Neijssel OM. 1998. Replacement of potassium ions by ammonium ions in different micro-organisms grown in potassium-limited chemostat culture. *Arch Microbiol* 152:58–63.

34. Mulder D. 1953. *Les element mineurs en culture fruitiere*. Convegn Nazionale Frutticoltura, Montana de Saint Vincet.

35. Brady NC & Weil RR. 1996. *The nature and properties of soil*. Prentice-Hall Inc: Upper Saddle River, New Jersey.

36. Willson KC. 1975. Studies on the mineral nutrition of tea. IV. Magnesium. *Plant and Soil* 43:309–316.

37. Kibeney SJ, Kamau DM, Ng'etich WK & Owuor PO. 2010. Changes in soil chemical properties and leaf

nutrients content due to nitrogen fertilizer rates and application intervals. *Tea* 31:22–27.

38. Kamau DM. 2002. Magnesium nutrition and dynamics in tea agroecosystems. *Tea* 23:5–11.
39. Willson KC. 1975. Studies on the mineral nutrition of tea. V. Calcium. *Plant and Soil* 43:295–307.
40. Owuor PO, Wanyoko JK & Othieno CO. 1988. Effects of fertiliser on tea. II. Calcium contents in mature leaf. *Tea* 9:10–20.
41. Kamau DM. 2000. Maintenance of guard rows in fertilizer field experiments. *Tea* 21:5–8.
42. Wachira FN, Ng'etich WK, Omolo J & Mamati G. 2002. Genotype x Environment Interactions for tea yields. *Euphytica* 127:289–296.
43. Owuor PO, Kamau DM & Jondiko EO. 2009. Response of clonal tea to location of production and plucking intervals. *Food Chem* 115:290–296.
44. Owuor PO, Kamau DM & Jondiko EO. 2010. The influence of geographical area of production and nitrogenous fertiliser on yields and quality parameters of clonal tea. *Journal of Agriculture, Food and Environment* 8:682–690.
45. Owuor PO, Kamau DM, Kamunya SM, Msomba SW, Jondiko EO & Uwimana MA. 2013. The response of clone BBK 35 tea to nitrogen fertilizer rates and harvesting intervals in the Lake Victoria Basin of Kenya. *Journal of Agriculture, Food and Environment* 11:757–763.
46. Okal A, Owuor PO, Kamau D & Manguro L. 2012. Variations of Fatty Acids Levels in Young Shoots of Clonal Tea with Location of Production and Nitrogenous Fertilizer Rates in the Kenya Highlands. *Journal of Agricultural Science and Technology* 14:1543–1554.
47. Okal AW, Owuor PO, Kamau DM & Mang'uro LOA. 2012. Effects of Production Locations and Plucking Intervals on Clonal Tea Fatty Acids Levels in the Kenya Highlands. *Food Sci Tech Res* 18:351–356.
48. Kwach BO, Owuor PO, Kamau DM, Wanyoko JK & Kamunya SM. 2013. Influence of location of production, season and genotype on caffeine and flavan-3-ols in young green tea (*Camellia sinensis*) leaves in Kenya. *Journal Agricultural Science and Technology* B3:557–574.
49. Owuor PO, Okal AW, Kamau DM, Msomba SW, Uwimana MA & Kamunya SM. 2013. Influence of nitrogen fertilizer rates and harvesting intervals on clonal tea green leaf fatty acids levels in the Lake Victoria Basin of Kenya. *Journal of Agriculture, Food and Environment* 11:667–674.