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Yields and Nitrogenous Fertiliser Use Efficiency Responses of Clonal Tea (*Camellia Sinensis*) to Locations of Production

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ABSTRACT

Tea husbandry practices in Kenya are uniform despite variations in responses to agronomic inputs with locations. Nitrogen availability is the most limiting tea/crop growth factor. However, tea yields vary with region of production even with the same cultivar, suggesting responses to nitrogen fertiliser and nitrogen utilisation may vary with locations. Nitrogen use efficiency (NUE) of clone TRFK 6/8 was investigated across three different locations/environments in western Kenya. Yields responded significantly (pd"0.05) to nitrogen fertiliser rates, but the responses varied with location of production. The responses to nitrogen rates were significantly lower (pd"0.05) in Timbilil than in Arroket and Changoi. This suggests that optimal nitrogenous fertiliser application rates should vary with locations. Nitrogen application rates between 75-300Kg N did not cause significant variation in harvestable shoots nitrogen contents. However, there were large differences in the amounts of nitrogen removed with crop. The NUE of tea decreased as nitrogen fertiliser rates increased and was low in areas where yield responses were low. Such areas need low nitrogen fertiliser application rates to justify return on investment. Quantity of nitrogen removed with crop followed same pattern. On replacement basis, nitrogen removed with crop did not exceed the recommended rate of application (150 kg N/ha/year) at any location or nitrogen rate. Shoot nitrogen contents suggest that soil applied nitrogen may not be responsible for locational variations in yield realisation. Results demonstrate that fertiliser management practices, especially nitrogen rates need to be location specific.

INTRODUCTION

Tea (*Camellia sinensis* (L). O Kuntze) is an important commodity crop in Kenya being a significant contributor to the fiscal economy (*1*). The crop is grown in the medium to high rainfall areas of Kenya majorly in the foothills of the Aberdare Ranges and Mt Kenya, in the east and the Mau Ranges; Nandi, Kisii and Kakamega hills and slopes of Mt. Elgon in the west of the Rift Valley (*2*). The altitudinal range of the regions lie from 1300m to 2700m above mean sea level (*3, 4*). These areas straddle the equator, and shoots are harvested at 7 to 14 days intervals throughout the year (*5*). Yields (*6, 7*) and quality (*8-12*) however, are influenced by weather fluctuations within and between the years in the locations. Despite proximity of the tea growing regions to the equator, differences in geographical locations influence growth rates (*13-16*), leaf nutrients levels (*17, 18*), precursors to tea quality parameters (*19-26*), black tea quality (*11, 12, 25, 27*) and productivity (*28-31*).

Fertilizers, especially nitrogenous fertilizers, are widely used in tea production. Indeed, fertilizer use is the second highest agronomic tea production cost item after plucking (*32-34*). Nitrogenous fertilizers are beneficial to tea production (*35, 36*), as positive tea yield responses have been widely reported (*26, 28, 37-40*). In Kenya, tea yields can be increased by application of nitrogenous fertilizers up to a maximum of 470 kg N/ha/year (*41*), although the economic rates lie between 100-220 kg made tea (mt)/ha/year (*42, 43*). Optimal nitrogenous fertiliser rates vary with clone and geographical area of production (*44*). However, the recommended nitrogenous fertilizer application rate remains the same throughout Kenya (*3, 43*). Though variations in tea yields response to fertilizers among cultivars were observed (*41, 45, 46*), most of the results were from single clones in single sites and only few studies have compared the same cultivar in different regions (*11, 28*). From the single site studies, isolation of the effects of environment from that of cultivars is impossible. Evaluation of a single cultivar under similar management in different environments may provide insights into the causes of the variations.

Differences in ability of tea cultivars to extract

Table 1: Study sites geographic location

Site	Location	Latitude	Longitude	Altitude
Timbilil	Tea Research Institute (Kenya), Timbilil, Kericho	0° 22’S	35° 21’E	2180 m amsl
Changoi	George Williamsons Ltd., Changoi Estate, Kericho	0° 30’S	35° 13’E	1860 m amsl
Arroket	Sotik Tea Company, Arroket Estate, Sotik, Bomet	0° 36’S	35° 04’E	1800 m amsl

nutrients from the soil have been reported (*17, 47, 48*). This is complicated by the large variations in soil fertility across different regions and the uniform use of fertilizer in Kenya (*43*). This in part causes variations in tea yield responses (*11, 28, 31*) and mature leaf nutrients contents (*17, 49*) to nitrogenous fertilizers in different regions. The mechanisms leading to these variations are not documented. Correlation studies and fertiliser trials have proven that nitrogen is one of the primary factors limiting plant growth. The question of which physiological and morphological features of plants serve as adaptations to nitrogen deficient environments and which features lead to high fitness in nitrogen rich environments can only be answered by defining the parameters that measure efficiency of uptake, allocation, residence time and use by the plant. Nitrogen use efficiency (NUE) was developed as such a parameter (*50*). NUE has several definitions that relate to plant dry matter accumulated, stored or lost per unit of nitrogen applied (*50*). It also refers to the unit of harvest per unit of nitrogen applied. Usually, NUE decreases with increasing abundance of nitrogen as plants lose their ability to mine and utilize nitrogen more efficiently (*50-52*) especially under dry conditions (*53*). Plants in nitrogen deficient environments develop ability to mine and utilize the scarce nitrogen more efficiently (*50*). Clone TRFK 6/8 is the most widely cultivated tea cultivar in East Africa (*28*). It is necessary to understand whether the NUE of TRFK 6/8 varies with locations and nitrogenous fertiliser rates. Determination of NUE of tea in different environments is critical in understanding the variations in yield responses to fertilisers and optimising production in varying environments. This study evaluated the NUE of clone TRFK 6/8 in different locations to determine whether the NUE is influenced in similar manner at all locations.

METHODOLOGY

Experimental Treatments and Design

The trial was set up in three major tea growing geographic regions (Timbilil, Changoi and Arroket) in western Kenya at different altitudes and within a radius of about 42 km (Table 1). The slopes at all sites were gentle to slightly sloping (0-15%). The experiment consisted of mature tea of clone TRFK 6/8 laid out as factorial two trial in randomized complete block design layout replicated three times, with sites as main factor and nitrogenous fertilizer N:P:K:S (25:5:5:5) rates : (0, 75, 150, 225 and 300 kg/ha/year) as sub factor.

Site Weather Characteristics

Rainfall and temperature data were recorded from weather stations located at each trial site and accompanying meteorological data derived as follows: Rainfall was recorded daily using a standard rain gauge. Maximum, minimum, wet and dry bulb temperatures were recorded at 09.00 h and 15.00 h local time daily using mercury in glass thermometers (Cassella (London) Ltd., UK). Relative humidity (RH %) was derived from wet and dry bulb temperature readings using relevant tables (*54*). The wet and dry thermometer readings recorded as described above and the data were used to derive saturated vapour pressure deficit (SVPD) using the

Location	Depth	%sand	% clay	% silt	Textural class	% porosity	Soil description*
Timbilil	0-20	41.37	49.75	10.96	Clay	37.56	Volcanic dark red (10R 3/2), deep friable clays with a dusky red (2.5YR 3/6) top soil (0-0.1m), with Kaolinite as the predominant , classified as humic nitosols
	20-40	42.15	44.13	13.28	Clay	45.22	
	40-60	38.08	48.36	15.57	Clay	47.00	
Changoi	0-20	23.75	70.79	11.52	Clay	43.33	volcanic derived, deep, free draining, dark red (2.5 YR 3/6) with a dark reddish brown (2.5YR 3/4) top soil (0-0.1m), classified as nitosols
	20-40	22.28	72.08	11.67	Clay	31.67	
	40-60	23.07	70.32	12.86	Clay	31.67	
Arroket	0-20	29.84	48.59	21.57	Clay	51.33	Dark reddish brown (2.5YR 3/4), moderately deep, firm clay loam with humic top soils on, classed as chromoluvic phaeozems
	20-40	27.84	49.59	22.57	Clay	42.00	
	40-60	28.20	50.23	21.57	Clay	44.00	

formula $SVPD = e_w - e'$ (*55*).

Where:

e = air vapour pressure

e' = air vapour pressure at t',

e_w = air vapour pressure at t,

t' = dry bulb temperature (°C)

t = wet bulb temperature (°C)

Soil Characteristics

Disturbed soil samples were collected from two sites from each trial location in approximate diagonal line across each experiment. Samples were collected in dry season between January and March at depths of 0-20, 20-40, 40-60 cm (*56*) using Jarret auger. The samples were subjected to chemical (pH and nutrients) analysis and physical (soil texture) analysis for site characterization.

Soil chemical and physical analysis

Soil pH was determined by making a soil/distilled water suspension of fresh (un-dried) soil sub samples and reading the pH of the suspension off a Jenway 3305 pH meter. Nitrogen content was determined using the Kjeldahl method. For the mineral nutrient analysis, soil samples were air dried, ground and sieved through a 2 mm sieve. The ground samples were then extracted using the Mehlich III method then analysed for K, P, Ca, Mg, Mn, Na, Cu, Fe and Zn using a plasma atomic emission spectrophotometer (ICPE-9000, Shimandzu). Sub samples from the disturbed soil samples were subjected to particle size analysis using the pipette method (*57*), taking 63 ìm as the sand/silt boundary.

Yields

Green leaves comprising mostly two leaves and a bud were plucked every 7 days and converted to made tea (mt) by multiplying by a factor of 0.225 (*3*).

Shoot nitrogen content

To determine the nitrogen levels in the shoot, a sample of 300g of fresh harvestable two leaves and a bud shoots per plot was sampled twice every quarter, starting January to December. These were transferred to the laboratory, dried in an oven at 105°C for 48 hours, allowed to cool then milled to powder. The shoot nitrogen content was then determined using the Kjeldahl method.

Nitrogen Use Efficiency (NUE)

The NUE was estimated by determining the amount of yield dry matter produced per unit of nitrogen fertilizer applied (*58*).

(i.e. NUE = $(Yield\ at\ Yi - Yield\ at\ Y0)/Yi,$

$Where\ Yi\ is\ the\ ith\ nitrogen\ rate\ and\ Y0\ is\ yield\ at\ 0\ kg\ N/ha/year$)

The yield dry matter was determined by applying the ratio of dry weight to fresh weight as determined from dry matter of a sample of 300g of fresh harvestable two leaves and a bud shoots sampled twice every quarter during the year. Shoot dry matter was determined by drying the 300 g sample of fresh harvestable shoots in an oven at 105°C for 48 hours and then weighing. Quantity of nutrients harvested with crop due to nitrogen rate was determined as yield due to the nitrogen rate x harvestable leaf nutrient content.

Data analysis

Collected data were subjected to analysis of variance (ANOVA) using MSTAT-C (Version 2.10) statistical package, as factorial two in RCBD layout, with location as the main factor and fertilizer rates as the sub factors. Correlations between yields, fertiliser rates and nitrogen use efficiency, were done using SPSS (Version 17.0) statistical software.

RESULTS AND DISCUSSION

Soil variability and suitability

Soil characteristics of the experimental sites are given in Tables 2 and 3. There were variations in soil textural properties. Timbilil soils had coarser texture than Changoi and Arroket soils. Timbilil soils had the highest sand content while Changoi soils recorded highest clay content. The porosity ranged from 38% to 51% with little variation between the sites. Arroket had the highest porosity (averaging 45.77%) due to the higher silt content. All the soils were of volcanic origin (*59*). Tea grows in soils of varying texture, with clay content as high as 83% in Kericho, Kenya and as low as 1.7% in Taiwan (*60*). Soils in this study fell within these ranges and were similar to those observed in Kericho (*61*). These results demonstrate suitability of these soils for tea growing. The soil pH at the sites ranged from 5.0 to 3.8. Arroket soils had the highest mean pH at 4.7. Tea grows in soils of optimal pH of 4.0 to 6.0 (*3, 61*), but can grow in soils with pH below 4.0 (*43, 60*). Soil mineral contents (Table 3) were within the ranges observed in the tea growing areas (*60*). In Kenya, tea is grown on volcanic soils (*60, 62*) classified as nitosols in the FAO-UNESCO classification system (*60*) but with pockets of acrisols and ferralsols. Site variations in the soil nitrogen contents were evident. However, the soil nitrogen levels were adequate for tea growth despite the higher nitrogen levels recorded in Changoi.

Table 2: Soil physical characteristics of the trial sites

Location	Depth	%sand	% clay	% silt	Textural class	% porosity	Soil description*
Timbilil	0-20	41.37	49.75	10.96	Clay	37.56	Volcanic dark red (10R 3/2), deep friable clays with a dusky red (2.5YR 3/6) top soil (0-0.1m), with Kaolinite as the predominant , classified as humic nitosols
	20-40	42.15	44.13	13.28	Clay	45.22	
	40-60	38.08	48.36	15.57	Clay	47.00	
Changoi	0-20	23.75	70.79	11.52	Clay	43.33	volcanic derived, deep, free draining, dark red (2.5 YR 3/6) with a dark reddish brown (2.5YR 3/4) top soil (0-0.1m), classified as nitosols
	20-40	22.28	72.08	11.67	Clay	31.67	
	40-60	23.07	70.32	12.86	Clay	31.67	
Arroket	0-20	29.84	48.59	21.57	Clay	51.33	Dark reddish brown (2.5YR 3/4), moderately deep, firm clay loam with humic top soils on, classed as chromoluvic phaeozems
	20-40	27.84	49.59	22.57	Clay	42.00	
	40-60	28.20	50.23	21.57	Clay	44.00	

*Soil description after Jaetzold *et al.,* (*59*).

Yields

Overall, application of nitrogen increased yields significantly (pd”0.05) over the control but above 75 kg N/ha/year there were no significant yields increases (Table 4). There were also yield variations (pd”0.05) between locations, in the order Timbilil < Arroket < Changoi. The nitrogen rates x site interactions were, significant. (pd”0.05). In Timbilil, application of nitrogen had no effect on yields, but in Changoi nitrogen application, significantly increased (pd”0.05) yields above the control but above this rate the increments were insignificant. In Arroket, increasing nitrogen fertilizer application significantly increased (pd”0.05) yields up to 300 kg N/ha/year. This was better yield response to nitrogen fertilizer rate than at the other sites.

The rankings of yield increase due to nitrogen application also varied with site. In Tanzania (*63, 64*), linear responses of tea yields to nitrogen up to a maximum of 375 and 300 kg N/ha/year in irrigated and un-irrigated tea, respectively, were reported. Yields of seedling tea in Kenya (*41*) and Sri Lanka (*65*) however, increased with application of nitrogenous fertilizer up to 470 kg N/ha/year. Response of tea to fertilizer in terms of growth and yield is nonetheless influenced by climatic, edaphic, genotypic and managerial factors (*66*). These factors vary widely between regions and sites such that tea plant responses to fertilizer regimes differ between regions and growing sites in an unpredictable manner. Such variations were observed in clone BBK 35 across five sites in Kenya (*11, 12*) and clone TRFK 6/8 within seven sites in East Africa (*28*). Thus, clonal tea yields may not be stable across different environments. The observations imply that management practices should not be applied universally in all regions to optimise yields. In addition, clonal evaluations and selections need to incorporate the evaluations of the responses to nitrogen fertilizers. Some cultivars may respond better in specific environments/locations.

Table 3: Soil chemical characteristics of trial sites

Location	Depth	pH	N (ppm)	P (ppm)	K (ppm)	Ca (ppm)	Mn (ppm)	Mg (ppm)	Na ppm)	Cu (ppm)	Fe (ppm)	Zn (ppm)
Timbilil	0-20	3.94	53.5	8.7	239.3	297	86.3	179.7	1.0	1.0	84.7	2.3
	20-40	3.92	78.0	7.7	256.0	336	87.0	155.0	1.0	1.0	84.7	2.0
	40-60	3.96	58.5	5.3	148.3	295	94.3	103.7	1.0	1.0	74.7	2.0
Changoi	0-20	3.82	229	10.7	212.0	516	130.0	145.7	1.0	1.0	74.7	3.0
	20-40	3.69	524	6.0	70.3	249	86.0	105.7	1.0	1.0	76.0	3.0
	40-60	3.95	570	10.7	63.3	269	83.7	124.7	1.0	1.0	79.0	3.0
Arroket	0-20	4.44	34.0	11.3	579.3	1290	152.7	213.0	1.0	1.0	127.0	3.3
	20-40	5.02	33.5	10.7	407.3	1807	196.7	195.3	1.0	1.0	119.3	3.0
	40-60	4.85	24.5	9.3	450.3	1317	234.7	193.7	1.0	1.0	101.0	3.0

Table 4: Effect of location and nitrogen rates on annual yields (kg mt/ha/year), yield rankings and Actual response to nitrogen (kg mt/ha/year) (yields due to nitrogen application $(Y_T\text{-.}Y_0)$)

					Actual response to N			
N Rate	**Timbilil**	**Changoi**	**Arroket**	**Rate mean**	**Timbilil**	**Changoi**	**Arroket**	**Rate mean**
0	1906*[4]*	3446*[5]*	2225*[5]*	2526	-	-	-	-
75	1867*[5]*	4044[*2])*	2834*[4]*	2915	-38	597	609	390
150	1944[*3*]	4288*[1]*	3339[*2*]	3190	38	842	1114	665
225	2173*[1]*	4020[*3*]	3235[*3*]	3142	267	574	1010	617
300	1978[*2*]	4009*[4]*	3596*[1]*	3195	73	563	1371	669
Site mean	1974	3961	3046		85	644	1026	
CV (%)	9.95							
	N Rate	Site	Rate x Site					
LSD ($p \leq 0.05$)	281	218	483					

Yield rankings are in parentheses; $(Y_T\text{-.}Y_0)$ = Yield at rate T ; Y_0= Yield at control

Shoot nitrogen content

Pluckable shoot nitrogen content did not vary significantly (pd”0.05) with nitrogen fertilizer rates or location (Table 5). Similar results on nitrogen rate on a single clone in one site had been reported (*67*). The nitrogen content of “two leaves and a bud” was less sensitive to nitrogen fertilisation (*41*). Thus, increase in nitrogen rates at 75 to 300 does not increase partitioning of nitrogen to the pluckable shoots. Increase in nitrogen supply improves growth up to a point beyond which nitrogen absorbed is not used for growth of shoots, but rather is accumulated as soluble compounds in the leaves (*68*). Further, high rates of nitrogen improved shoot fresh weight but reduced dry matter (*69*) The findings suggest that yield increase associated with nitrogen application in tea (Table 4), involves the enhancement of processes that lead to increase in shoot size and weight and shoot growth rates but not increase in nitrogen partitioning into individual shoots in clone TRFK 6/8.

The quantity of nitrogen removed with crop varied with location. However, the variations due to rates of nitrogen at single sites were minimal (Table 5). Where response to nitrogen was low (Timbilil), quantity of nitrogen removed with crop was lower than where responses were higher (Changoi and Arroket). Thus on replacement basis, where yield responses are low there may be no need to

Table 5: Effect of nitrogen rates and location on harvestable shoot nitrogen content (% of dwt).

	Harvestable shoot nitrogen content				Quantity of nitrogen (Kg/ha/year) harvested with crop			
N Rate	**Timbilil**	**Changoi**	**Arroket**	**Rate mean**	**Timbilil**	**Changoi**	**Arroket**	**Rate mean**
0	3.85	3.24	4.1	3.73	73	112	91	92
75	3.76	3.71	3.95	3.81	70	150	112	111
150	3.88	3.67	4.17	3.91	75	157	139	124
225	3.79	3.84	3.89	3.84	80	154	125	120
300	3.99	3.94	3.99	3.97	79	158	140	126
Site mean	3.85	3.68	4.02		75	146	121	115
CV (%)	9.72							
	N Rate	Site	Rate x Site					
LSD ($p \leq 0.05$)	NS	NS	NS					
STDev (CV%*)					4 (5.5)	19 (13.2)	21 (16.9)	14 (12.1)

*As STDev/mean x100

Table 6: **Effect of nitrogen rates and geographical location on NUE (g dwt/g N)**

N Rate	Timbilil	Changoi	Arroket	Rate mean
0	-	-	-	
75	-0.98	17.60	12.97	9.86
150	0.53	10.66	11.22	7.47
225	2.17	5.02	7.37	4.85
300	0.47	0.47	7.31	2.75
Site mean	0.55	8.44	9.72	

apply to apply in excess of 100kg N/ha/year. However, even in locations where yields and responses were higher, application of beyond 150 kg N/ha/year, the recommended nitrogen rate (*3, 43*) may not be justifiable.

Nitrogen use efficiency (NUE)

The nitrogen use efficiency (NUE) as determined in this study was calculated as per the definition of unit dry weight of harvested shoot per unit of nitrogen applied (*50, 57*), and estimates of NUE were only where external nitrogen was applied. The effect of nitrogen application was determined as yield at a given rate less yield at the control (zero). The correct term applicable in this instance should therefore be “Harvestable Applied Nitrogen Use Efficiency”. Though tea may realise yields without application of nitrogen fertiliser, the yields are commercially very low and unsustainable. The NUE (Table 6) declined with increasing nitrogen rates and varied across all sites. There was better nitrogen use efficiency at Changoi (0.47-17.6 g dry weight (dwt)/g N) and Arroket (7.31-12.97 g dwt/g N) than Timbilil (-0.98-2.17 g dwt/g N). The NUE decreased with increase in nitrogen application but rate varied with location. The decline in NUE value followed the same pattern as yield response to nitrogen rates (Table 4). The findings indicate that NUE may be environment dependent. This could lead to locational variations in fertiliser rate at which nitrogen is used most efficiently to produce harvestable tea shoots. The findings demonstrate that for maximising profits, recommended nitrogen fertiliser rates for tea should be dependent on location. Areas with low NUE should receive lower nitrogen fertiliser rates, while areas with high NUE should receive higher nitrogen fertiliser rates. From this study, there may be no justification in applying more than 100 kg N/ha/year in Timbilil and 150 kg N/ha/ year in Changoi and Arroket, to clone TRFK 6/8.

Yield, NUE and nitrogen rates interactions

Linear regression analysis between yields, nitrogen rates and NUE showed that the relationships varied with location (Table 7). Yields directly related (pd”0.001) with nitrogen rates at Arroket. At all sites inverse (pd”0.001) relationships between NUE and nitrogen rates were recorded. In Tanzania, higher nitrogen application rate increased photosynthetic rate (attributed to increased stomatal conductance and reduced leaf temperatures) and radiation interception on clone TRFK6/8 (*69*). However, increase in fertilizer beyond 375 kg N/ha/year reduced photosynthetic rate despite decline in stomatal conductance. Higher rates of nitrogen improved shoot fresh weight but reduced the dry matter and increased the proportion of waste fibre (*68*), resulting into lower prices of tea (*11, 12, 25, 68*). The responses to nitrogen application

Table 7: **Effect of location on correlation coefficients (r) of annual yield, nitrogen rate and nitrogen use efficiency**

Location		Nitrogen rate	Nitrogen Use Efficiency
Arroket	Annual yield	.836***	-.790***
	Nitrogen rate		-.915***
Changoi	Annual yield	-.113	.181
	Nitrogen rate		-.886***
Timbilil	Annual yield	.246	-.120
	Nitrogen rate		-.925***

N = 12; *** Correlation is significant at the 0.001 level;

in this study were not related to yield and were influenced by environmental factors. These results demonstrate that application of high rates of nitrogen fertilizer reduce possible profits from tea enterprise. This decline is further enhanced by reduction in tea quality due to high rates of nitrogen (*11, 12, 37, 43*).

CONCLUSIONS

Tea yield response to nitrogen and NUE varied with location of production. Though yield increased with nitrogen rates, NUE declined with increased nitrogen rates. Since shoot nitrogen content showed no variations with nitrogen rates and location, the yields variation with increasing nitrogen rates may be due influence of nitrogen on shoot growth factors and not applied nitrogen. Optimal agronomic nitrogen rates therefore vary with location. Fertiliser management practices for tea should consequently vary with locations even on the same clone.

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