RESEARCH ARTICLE

Fertilizer Response and Environment Interactions of Yield and Yield Components of Clonal Tea (Camellia Sinensis) in Kenya

Karl W Nyabundi[1], P Okinda Owuor[2], Godfrey W Netondo[3], John K Bore

Abstract

Tea is an important cash crop, providing income and employment to rural populations in many countries. In Kenya, tea is the leading export commodity crop and is grown in highlands east and west of the Rift Valley at altitudes ranging from 1300 to 2700 m above mean sea level. This has significant effects on growth, productivity, tea quality and response to fertilizer and has been particularly noted for the popular, widely planted, quality clone TRFK 6/8. In East Africa, tea husbandry practices are uniform despite the variations in responses to agronomic inputs. Fertilizer is the most expensive input in tea production after plucking. In tea, nitrogen availability is the most limiting crop growth factor. However, responses of tea yields to fertilizer application vary with the region of production even with the same cultivar. The utilization of nitrogen, therefore, varies with location. The responses in growth and yield parameters of clonal tea TRFK 6/8 and their contribution to yields were investigated across different environments, in a trial setup in three locations in the east of the Rift Valley in Kenya, using clone TRFK 6/8, a popular commercial cultivar. Yield and yield components response to nitrogen rates varied with location. The highest yields were not always attained at the highest nitrogen levels and the best response to fertilizer did not translate to the highest yields. Tea crop response to fertilizer is the site-specific and universal application of fertilizer may only apply as a general guideline but will not optimize production.

Keywords: Fertilizer, Cash crop, TRFK, RCBD.

International Journal of Tea Science (2019); DOI: 10.20425/ijts1412

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[1] with an altitudinal range of 1300m to 2700m above mean sea level.[2,3] The areas lie astride the equator, and shoots are harvested every 7–14 days all year round.[4] However, yields[5,6] and quality[7-11] are influenced by weather fluctuations within and between the years in the locations. Despite the tea growing regions' proximity to the equator, differences in geographical location influence productivity,[12-16] growth rates,[15,17-19] leaf nutrients levels[20,21] tea quality parameters precursors21-28 and black tea quality.[10,11,21] Fertilizers, particularly nitrogenous fertilizers, are widely used in tea production. Indeed, fertilizer use is the second highest agronomic tea production cost item after plucking.[29-31] Nitrogenous fertilizers are beneficial to tea production[32,33] and have widely been reported to have positive tea yield responses.[16,28,34-37] In Kenya, tea yields can be enhanced by the application of nitrogenous fertilizers up to a maximum of 470 kg N/ha/year.[38] The economic rates, however, lie between 100–220 kg made tea (mt)/ha/year.[39,40] Optimal nitrogenous fertilizer rates vary with clone and geographical area of production.[2] However, the recommended nitrogenous fertilizer application rate is the same throughout Kenya.[2,39] Variations in tea yields response to fertilizers among cultivars were observed,41 but most of the results were from single clones in single sites and only a few studies have compared the same cultivar in different regions.[10,16] From the single-site studies, isolation of the effects of the 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 the ability of tea cultivars to extract nutrients from the soil have been reported.[20,42,43] This is further complicated by the large variations in soil fertility across different regions and the uniform use of fertilizer in Kenya.[39] This is partly responsible for the variations in tea yield responses[10,16,44] to nitrogenous fertilizers in different regions. The underlying mechanisms for these variations are not documented. Correlation studies and fertilizer trials have proven nitrogen to be one of the primary factors limiting plant growth. The understanding of the variations in responses in tea yield components to fertilizer in different locations may provide an explanation in the observed yield responses and lead to the development of fertilizer regimes suitable for varying locations.

[1]Tea Research Institute, Kenya Agricultural, and Livestock Research Organization, Kericho, UN

[2]Department of Chemistry, School of Physical and Biological Sciences, Maseno University, Maseno, Kenya

[3]Department of Botany, School of Physical and Biological Sciences, Maseno University, Maseno, Kenya

Corresponding Author: P Okinda Owuor, Department of Chemistry, School of Physical and Biological Sciences, Maseno University, Maseno, Kenya, email: okindaowuor@maseno.ac.ke

How to cite this article: Nyabundi KW, Owuor PO, Netondo GW, Bore JK. Fertilizer Response and Environment Interactions of Yield and Yield Components of Clonal Tea (*Camellia Sinensis*) in Kenya . International Journal of Tea Science 2019;14(1):6-13

Sourceofsupport: Inter-UniversityCouncilofEastAfrica,LakeVictoriaResearch Initiative (VicRes) and National Council of Science and Technology (NACOSTI)

Conflict of interest: None

METHODOLOGY

Experimental treatments and design

The trial was set up in 2012 in three major tea growing geographic regions around Kericho, in the West of the Rift Valley. The geographic regions Timbilil, Changoi, and Arroket) lie at different altitudes and are located within a 42 km radius (Table 1). The slope at all the sites was gentle to slightly sloping (0–15%). The experiment was superimposed on mature tea of clone TRFK 6/8 laid out in Randomized Complete Block Design replicated three times. It was set in factorial two design with sites as the main factor and the

Table 1: Geographic location and altitude of trial study sites

Site	*Location*	*Latitude*	*Longitude*	*Altitude (mamsL)*	*Mean annual rainfall (mm)*	*Mean annual ToCMin*	*Mean annual ToCMax*	*Mean annual RH (%)*
Timbilil	TRFK, Timbilil, Kericho	0^{o} 22'S	35^{o} 21'E	2180	2154	8.8	23.3	62.4
Changoi	George Williamsons Ltd., Changoi Estate, Kericho	0^{o} 30'S	35^{o} 13'E	1860	1655	11.4	26.8	90.9
Arroket	Sotik tea Company, Arroket Estate, Sotik, Bomet	0^{o} 36'S	35^{o} 04'E	1800	1506	12.2	28.1	71.4

*Soil description after Jaetzold and Schmidt[59]; mamsL = metres above mean sea level; $T°C_{Min}$ = Minimum temperature; $T°C_{Max}$ = Minimum temperature; RH = relative humidity

fertilizer N:P:K:S (25:5:5:5) rates: 0, 75, 150, 225 and 300 kgHa^{-1} as the subfactors. Fertilizers were applied as N:P:K:S 25:5:5:5, once a year, in April. The clone TRFK 6/8 is one of the standard high black tea quality clones in most yield and quality performance evaluation trials in Kenya.[45] It is also a popular widely planted, high black tea quality clone in East Africa, constituting 30% and 80% of commercial clonal plantings in Kenya and Rwanda, respectively.11,25 Before the experiments, the tea was under standard management practices (Anonymous, 2002) and the bushes at all sites were pruned in 2007, before the start of the trial.

Site Weather Characteristics

Temperature and rainfall were, and data were recorded from weather stations located at each trial site. Accompanying meteorological data was 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 [46] . The wet and dry thermometer readings recorded as described above and the data were used to derive saturated vapour pressure deficit (SVPD) using the formula $SVPD = ew\text{-}e'$.[47]

Where:

- e = air vapour pressure
- e' = air vapour pressure at t' (Table 4)[47]
- ew = air vapour pressure at t (Table 4)[47]
- 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 an approximate diagonal line across each experiment. Samples were collected in the dry season between January and March at depths of 0–20, 20–40, 40–60 cm (56) using Jarret auger and later subjected to chemical (pH and nutrients) analysis and physical (soil texture) analysis for site characterization.

Soil Chemical and Physical Analysis

Soil pH was determined reading the pH of a soil/distilled water suspension of fresh (un-dried) soil subsamples using 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 analyzed for K, P, Ca, Mg, Mn, Na, Cu, Fe and Zn using a plasma atomic emission spectrophotometer (ICPE- 9000, Shimandzu). Subsamples from the disturbed soil samples were subjected to particle size analysis using the pipette method,[48] taking 63 ~m as the sand/silt boundary.

Yields

Green leaves consisting of mainly two leaves and a bud were plucked every 7 days and converted to made tea (mt) by multiplying by a factor of 0.225.[2]

Shoot Density (SD), and Shoot Dry Weight (SDWT)

Shoot density was determined by counting the mean of the number of mature harvestable shoots (two leaves and a bud) captured within a 0.25 m^2 grid randomly thrown on to the plucking tables (30) of five randomly selected bushes at every plucking round. Shoots falling within the grid were harvested, weighed and counted. The leaves were then oven dried at 105°C for 48 hours and weighed. The SDWT was determined by dividing the dry weight by the number of shoots harvested.

Shoot Growth Rate (SGR)

The rate of shoot growth (mmd^{-1}) was determined from five tagged shoots from each of three randomly selected bushes. Two leaves and a bud were plucked and the length from the tip of the auxiliary bud to the base measured at 3-day intervals until the new shoot developed into harvestable two leaves and a bud. The growth rate (mmd^{-1}) was calculated by dividing the shoot length measured at each interval by the number of days between two successive measurements.

Internode Extension Rate (Extension Rate).

Three bushes from each plot were selected at random and five shoots, each with a fully opened leaf and a terminal bud tagged. The internode length, above the first leaf, was measured every three days using vernier calipers until the development of a full mature shoot of two leaves and a bud above the first leaf. The total length measured at each interval was divided by the number of days between two successive measurements to determine the extension rate (mmd^{-1})

Shoot Water Potential (SWP)

The shoot water potential of harvestable shoots was measured using the pressure chamber technique[49] between 11.00 am and 2.00pm. Fifteen shots from every plot, comprising three shots from each of five randomly selected bushes were sampled. The shoots were cut, sealed in a polythene bag then transferred one by one to a pressure chamber where one centimeter was cut off the stalk and the shoot immediately inserted into the gas chamber. The key of the compressed nitrogen gas turned on until the first gas bubbles were released from the cut shoot stalk surface and the pressure reading taken. SWP measurements were taken twice per season and averaged to get the mean for each season.

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 a location as the main factor and fertilizer rates as the subfactors. Correlations between yields, fertilizer rates, and nitrogen use efficiency, were done using SPSS (Version 17.0) statistical software.

Results and discussion

Soil variations and suitability

The soil characteristics of the experimental sites are presented in Tables 3 and 4. There were variations the soil textural. Timbilil soils had a coarser texture than Changoi and Arroket soils (Table 2).

Changoi soils had the highest clay while Timbilil soils had the highest sand content. Porosity ranged from 38–51%, but with little variation between the sites. Arroket had the highest porosity (averaging 45.77%), due to the higher silt content. The soils from all the sites were of volcanic origin.[50] Tea is cultivated in soils of varying texture and also grows in soils with clay content as in Kericho (83%), Kenya and also very clay content low as in Taiwan (1.7%).[51,52] The soils in this study were well within these ranges and were also similar to those observed in Kericho.[51] These results demonstrate the suitability of these for tea growing albeit the variability. Soil pH at the three sites ranged from 5.0–3.8. Arroket soils had the highest mean pH at 4.7 (Table 3). Tea grows in soils of optimal pH of 4.0 to 6.0,[2] but can grow in soils with pH below 4.0.52 Indeed, optimal growth of tea has been reported at pH ranges between 3.8 and 5.7 inland newly cleared from primary, secondary forests and tree plantations.[51] The soil mineral contents (Table 3) were within the ranges earlier observed in the major tea growing areas.[53] The successful growing of tea in a wide variety of soils makes it difficult to put tea soils into any general classification.

In Kenya, tea is grown mostly on volcanic soils[52-54] which are classified as nitosols in the FAO-UNESCO classification system 52 but there are also pockets of acrisols and ferralsols. There were evident site variations in the soil nitrogen contents. However, the

Table 2: Soil physical characteristics of the trial sites, 2012

Location	*Depths (cm)*	*% 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) topsoil (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[50]

Table 3: Soil chemical characteristics of trial sites, 2012

Location	Depth.	pH (1:1)*	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	22.9	10.7	212.0	516	130.0	145.7	1.0	1.0	74.7	3.0
	20-40	3.69	52.4	6.0	70.3	249	86.0	105.7	1.0	1.0	76.0	3.0
	40-60	3.95	57.0	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

* 5g soil : 5 mL distilled water

nitrogen levels were adequate for tea growth despite the higher nitrogen levels recorded in Timbilil. The results demonstrate that the soils were suitable for tea growing. These results illustrate that though tea can be viable commercially grown in a wide variety of soil types, the variations in soil types could contribute significantly to locational yield variations. Soil differences between sites and even considerably significant differences between sites across East Africa tea growing regions have been recorded. Furthermore, soil water deficits and compaction could restrict the productivity of tea in different locations.[51,55] The noticeable differences in clay content in Changoi and pH and base elements in Arroket are likely to contribute to differences in yields and yield responses between the sites. Similar differences in clay content have been reported to contribute to yield differences.[55]

Weather and Geographical Locations

Table 4 shows the weather components from the three trial locations during the duration of the trial. There were sites differences in all the weather parameters measured and derived (rainfall, rain days, ambient temperatures, relative humidity, and vapor pressure deficit).

Temperatures

Mean monthly temperatures generally increased as altitude declined from Timbilil to Arroket with Timbilil recording the lowest and Arroket the highest temperatures (Table 1 and Table 4). Whereas temperatures in Timbilil and Changoi dropped with the onset of the April rains, in Arroket the temperatures rose with the onset of the April rains. This could be ascribed to the influence proximity of Timbilil and Changoi to the Mau forest complex which may have contributed to the lowering of ambient temperatures. The Timbilil and Changoi Sites were reported to have been previously under natural forest.[51] The mean temperature difference between Timbilil and Changoi was 1.8°C while between Changoi and Arroket and Timbilil and Arrroket were 1.9 and 3.7°C, respectively. These results were similar to those obtained earlier15 where temperature difference between high and lower altitude (below 2000 m) was higher than between locations at high altitude (over 2000 m). The temperature difference between Changoi and Arroket was similar to that between Timbilil and Changoi though the difference in altitude between the former was only 60 m as compared to the over 300 m differences between Timbilil and Changoi and Timbilil and Arroket. Location differences due to temperature have been earlier observed.[12,51,56,57]

Rainfall

Rainfall pattern in Timbilil was unimodal, and rains commenced in April and continuing through to December. Changoi and Arroket rainfall was weakly bimodal with two peaks, between April to July and in December (Table 4) as had been reported earlier for Kericho.[58] Total rainfall declined with altitude from Timbilil to Arroket (Tables 1 and 4). These relationships, however, were not significant. In the January- March season Arroket and Timbilil received less rain than Changoi despite more rain days. The seasonal variations are likely to influence the total annual yields variations between the sites as has also been reported earlier.[55,59]

Relative Humidity (Rh) and Vapour Pressure Deficit (VPD)

Relative humidity (Rh) and vapor pressure deficit (VPD) also showed variations between sites. Mean monthly relative humidity did not follow any altitudinal pattern. The lowest VPD was recorded in Changoi. The Highest VPDs were recorded in the January March

Table 4: Monthly weather parameters at three study locations, Jan–Dec 2012

	Timbilil							Changoi							Arroket						
	Temp (°C)							Temp (°C)							Temp (°C)						
	Max	Min	Mean	Rain (mm)	Rdays (d)	Rh(%)	Svpd (KPa)	Max	Min	Mean	Rain	Rdays (d)	Rh (%)	Svpd (KPa)	Max	Min	Mean	Rain	Rdays (d)	Rh (%)	Svpd (KPa)
Jan	25.7	7.7	16.7	0.0	0	62	15.14	27	11	19.0	0.4	0	88	1.5	27.8	11.2	19.5	2.5	1	62	11.05
Feb	26.3	9.1	17.7	26.8	7	55	15.52	28	11	19.5	26.4	3	86	1.9	29.1	9.9	19.5	31.6	8	67	12.90
Mar	27.5	8.5	18.0	27.7	6	63	14.08	27	11	19.0	76.3	6	86	1.9	28.6	10.0	19.3	56.9	7	70	9.67
Apr	23.3	7.2	15.3	398.4	25	62	5.43	26	11	18.5	423.3	17	88	1.6	29	11.0	20.0	337.7	26	74	5.93
May	22.9	9.8	16.4	391.1	24	71	3.61	25	10	17.5	429.0	21	85	1.7	28.2	13.5	20.9	236.0	23	69	6.08
Jun	22.2	9.7	16.0	226.9	20	80	4.37	25	10	17.5	231.2	20	85	1.7	26.8	12.8	19.8	153.8	20	74	4.88
Jul	21.7	9.7	15.7	160.9	13	70	5.14	25	10	17.5	140.9	13	82	2.1	25.8	13.4	19.6	82.2	9	76	5.50
Aug	22.8	9.4	16.1	298.9	18	71	5.14	25	10	17.5	35.0	3	79	2.2	27.8	13.8	20.8	78.0	12	72	6.59
Sept	22.7	8.7	15.7	239.1	24	71	6	25.4	10.2	17.8	152.5	6	74	3.2	27.6	13.5	20.6	135.5	16	72	6.58
Oct	23.7	10.0	16.9	269.4	24	73	7.39	25.3	10.4	17.9	78.9	4	94	0.6	29.6	12.6	21.1	74.0	14	74	6.33
Nov	24.1	9.7	16.9	227.6	22	80	6.56	26	11.4	18.7	139.3	8	94	0.6	27.7	12.8	20.3	87.0	19	75	5.14
Dec	22.9	9.9	16.4	172.3	15	62	7.44	26.9	10.4	18.7	185.1	11	94	0.7	29.3	12.2	20.8	230.8	17	72	5.46
Total				2439	198						1918	112						1506	172		
Mean	23.8	9.1	16.5			68.3	8.0	26.0	10.5	18.3			86.3	1.6	28.1	12.2	20.2			71.4	7.2

season in Timbilil and Arroket but were highest at Timbili. This suggests a more severe drought in Timbilil. Similar weather effects, with more severe drought at a higher altitude, have been recorded before.55 Such droughts have also been recorded to give rise to high soil water deficits, and occur around Kericho area on average once every three years.[55,59] Results revealed seasonal variations of weather parameters within and between sites. Soil water deficits and similarly, shoot water potential (SWP) is determined by ambient temperatures and humidity. Atmospheric humidity is inversely related to vapor pressure deficits.[29,60] An inverse linear relationship between VPD and SWP in tea has been reported[6,61,62] although SWP of tea shoots were more closely related to VPD than to soil moisture [62]. Variations in soil water deficits between sites in Kericho affected the difference in yield variations.[17] These may explain locational yield difference, but not the variations in response to nitrogenous fertilizer observed.

Relationships between tea yield components and varying environment parameters under different N:P:K (25:5:5) Fertilizer Rates.

Yield Components

The recorded yield components; shoot growth rates, shoot dry weights, shoot densities and shoot water potentials are presented in Table 5.

Shoot growth rate

The shoot growth rates (SGR) showed significant ($p \leq 0.05$) responses to locations of production (sites) and nitrogen rates (Table 5). Mean SGR increased significantly with increasing nitrogen rate up to 225 kg N ha^{-1} $year^{-1}$. Shoot leaf lengths had been reported to increase with the application of fertilizer over the control.[63] This may be an indication that shoot growth rate has a maximum threshold for nitrogen at about 225 kg N ha^{-1} $year^{-1}$. Table rise was also proven to be faster in fertilizer-applied plots than the control.[19] These observations are the indications of the effect of fertilizer on tea plant growth. Significant ($p \leq 0.05$) site differences in shoot growth rate were in the order Arroket > Changoi > Timbilil which also followed the order of temperature increase with a decline in altitude. Effects of temperature on tea shoot growth have been discussed earlier.[13]

Fertilizer rate x location interactions were also significant ($p \leq 0.05$), indicating that yield components response to nitrogen rates varied with location. Indeed, though significant responses to nitrogen rates were observed in Changoi and Arroket there were no significant responses in Timbilil. These findings suggest that fertilizer requirements, even for the same cultivar, may vary from one location to the next. Fertilizer recommendations, therefore, may be site-specific even for a single cultivar planted in different locations.

Internode Extension Rate

Internode extension rates (IER) also varied significantly ($p \leq 0.05$) with location and nitrogen rates. Changoi had significantly ($p \leq 0.05$) the highest internode extension rates recorded and Arroket the lowest. Mean internode extension rates increased significantly with rising rates of nitrogen and continued increasing even at 300kg N ha^{-1} $year^{-1}$. This suggests that IER may have a higher threshold for nitrogen than SGR. The locational differences in IER were significant ($p \leq 0.05$), in order Arroket < Timbili < Changoi. This was different from the order location differences of SGR and suggests that IER may vary between locations in response to some factor other than altitude or temperature. Rate x location interactions were significant ($p \leq 0.05$). The response of IER to fertilizer rates varied with location.

Table 5: Effects of geographical location and nitrogen rates on yield components

	SGR				IER				SDWT				SD				SWP			
	Tmbl	Chgi	Arrkt	Rate mean	Tmbl	Chgi	Arrkt	Rate mean	Tmbl	Chgi	Arrkt	Rate mean	Tmbl	Chgi	Arrkt	Rate mean	Tmbl	Chgi	Arrkt	Rate mean
0	0.03	0.03	0.68	0.25	2.02	2.24	0.81	1.69	0.44	0.37	0.14	0.31	107	119	74	100	5.79	6.22	7.21	6.41
75	0.03	0.03	0.99	0.35	1.86	2.45	1.09	1.80	0.49	0.36	0.12	0.32	108	129	80	106	5.68	6.33	7.21	6.41
150	0.03	0.03	1.06	0.37	2.00	2.37	1.20	1.86	0.45	0.36	0.14	0.32	107	132	83	108	6.03	5.83	7.43	6.40
225	0.04	0.28	1.17	0.50	1.90	2.34	1.28	1.84	0.51	0.38	0.13	0.34	105	129	83	106	5.89	6.14	7.23	6.40
300	0.03	0.03	1.17	0.41	1.95	2.46	1.22	1.88	0.47	0.36	0.13	0.32	106	134	85	108	5.76	6.18	7.17	6.37
site mean	0.03	0.08	1.01		1.95	2.37	1.12		0.47	0.37	0.13		107	129	81		5.83	6.14	7.25	
CV%	29.86				13.5				20.12				8.56							
LSD (p ≤0.05)	Rate	Site	RxS		Rate	Site	RxS		Rate	Site	RxS		Rate	Site	RxS		Rate	Site	RxS	
	0.049	0.038	0.09		0.11	0.09	0.2		NS	0.01	NS		4	3	NS		NS	0.23	NS	

NS = Not Significant Tmbl = Timbilil; Arrkt = Arroket; Chgi = Changoi; Ste = site = location; sgr = shoot growth rate; ier = internode extension rate; sdwt = shoot dry weight; sd = shoot density

Indeed, whereas the response to fertilizer was not significant in Timbil, responses were significant ($p \leq 0.05$) in Changoi and Arroket. Further, in Arroket and Changoi internode extension rates significantly increased with the application of nitrogen fertilizer rates. In Timbilil, however, though not significant, use of nitrogen resulted in a decline in internode extension rates. The variation in internode extension rate response to fertilizer varied with location, similar to SGR, is an indication that fertilizer requirements for a single cultivar of tea may vary with location.

These elicit the variations shoot growth rates and internode extension rates response to the environment, contrary to the expectation that these should follow the same pattern, especially when measured in the same clone. Tea shoots from the same population may grow at different rates at different stages of growth.[6] The two parameters represent different growth phases of the shoot and may respond differently to temperature and relative humidity due to the variations in the shoot metabolism with the growth phase.

Shoot Dry Weight and Shoot Density

Shoot dry weights showed only significant ($p \leq 0.05$) response to location but not nitrogen rates (Table 5). Higher rates of nitrogen were observed to increase the photosynthetic rate,[64] improve shoot fresh weight but reduce the dry matter.[65] Earlier studies showed nitrogen rates to not affect shoot mass of clone TRFK 6/8.[19] The shoot densities, however, showed significant variations ($p \leq 0.05$) with nitrogen rates and location. Mean shoot density increased significantly ($p \leq 0.05$) with the application of fertilizer over the control but further increase in fertilizer dosage did not result in any significant response to shoot density. Studies on the same cultivar in a single site had given similar results but with the continued increase in shoot density up to 400 kg N ha^{-1} $year^{-1}$.[19] The highest mean shoot density was recorded in Changoi (129 shoots m^{-2}) and lowest at Timbilil (81 shoots m^{-2}). The varying clonal response of shoot density with altitude had been earlier reported.[14] The findings demonstrate the variation in responses of yield components to fertilizer application and the variation of these responses with the geographic location of production.

Shoot Water Potential

Shoot water potential only significantly varied with the site but not nitrogen rates (Table 5). This could be attributed to the differences in the locational vapor pressure deficits. Shoot water potential of tea shoots has been demonstrated to be more closely related to vapor pressure deficits than to soil moisture.[61] Shoot water potential influences shoot growth by determining the cellular turgidity required for cell expansion.[66] These findings suggest a threshold of plant water status for tea shoot survival and growth, which does not vary with the application of nitrogen fertilizer but varies with location. This suggests that the tea plant maintains an internal water balance despite the application of fertilizer, as long as no other factors are limiting.

Yields

Application of nitrogen increased yields significantly (pd”0.05) over the control but with no significant yield increases beyond 75 kg N/$ha^{-1}year^{-1}$ (Table 4). Yields significantly (pd”0.05) between locations, in the order Changoi > Arroket > Timbilil. The nitrogen rates x site interactions were, significant (pd”0.05). Application of nitrogen had no effect on yields, in Timbilil, but significantly increased (pd”0.05) yields above the control in Changoi, although nitrogen application above 75 kg N/$ha^{-1}year^{-1}$ the increments were insignificant. In Arroket, increased fertilizer doses significantly increased (pd”0.05) yields up to 300 kg N/ha/year, this being better yield response to nitrogenous fertilizer rate than at the other sites. The rankings of yield increase due to nitrogen application also varied with site. Linear responses of tea yields to nitrogen up to a maximum of 375 and 300 kg 75 kg N/$ha^{-1}year^{-1}$ in irrigated and un-irrigated tea, respectively, were reported in Tanzania.[36,67] In Kenya[38] and Sri Lanka[68] however, yields of seedling tea increased with application of nitrogenous fertilizer up to 470 kg N/$ha^{-1}year^{-1}$. Responses of tea yields and growth to fertilizer are nonetheless influenced by climatic, edaphic, genotypic and managerial factors.[69] These factors vary widely between regions and sites such that tea plant responses to fertilizer regimes between regions and growing sites differ unpredictably. Similar variations were observed on clone TRFK 6/8 within seven sites in East Africa[16] and on clone BBK 35 across five sites in Kenya.[11,17] Clonal tea yields may thus, not be stable across different environments. These observations imply that to optimize yields, management practices should not be applied universally in all regions too. Further, clonal evaluations and selections need to incorporate the evaluations of the responses to nitrogen fertilizers. Some cultivars may respond better in specific environments/locations.

Yield, Yield Components, and Environment Interactions

Correlation analysis revealed that significant correlation between yields and yield components and nitrogen rates only occurred in Arroket (Table 7). Yields, shoot growth rate and shoot density showed a significantly high correlation to nitrogen rates ($r = 0.930$, 0.909, 0.919, respectively $p \leq 0.05$) (Table 7). Though correlations were not significant other locations, the magnitude of the correlations varied from one location to another. Changoi recorded the highest yields but had the lowest yield response to nitrogen rates (Tables 6 and 7).

This study's findings definitively indicate the site specificity of the tea crop response to fertilizer. Universal application of fertilizer may therefore only apply as general a guideline but production will vary between locations.

Conclusions

Yield and yield components response to nitrogen rates varied with location, resulting in the highest yields not always being attained at the highest nitrogen levels. Tea crop response to fertilizer is site-specific and universal application of fertilizer may only apply as a general guideline but will not optimize production. The highest yield response to nitrogen application in any one location may not translate to the highest yields, ever. Since tea yield response to fertilizer will vary with location, confirmatory trials need to be conducted in each location to ascertain the optimum fertilizer levels, if production is to be optimized.

Acknowledgments

The authors wish to express their gratitude to the Inter-University Council of East Africa: Lake Victoria Research (VicRes) Initiative and National Council of Science and Technology (NACOSTI) for funding of the study; the Kenya Tea Development Authority (KTDA) and Kipkebe Tea Company Ltd. for providing trial sites, and the staff of Crop Environment and Physiology section, and Kangaita station of the Tea Research Institute for data collection and sampling. This paper is published with the approval of the Director of the Tea Research Institute of Kenya.

Table 6: Effect of location and nitrogen rates on annual yields (Kg mt ha-1 year-1), yield rankings and actual response to nitrogen (Kg mt ha-1 year-1) (yields due to nitrogen application (YT-.Y0)), 2012

N Rate (kg N ha-1 year -1)	*Timbilil*	*Changoi*	*Arroket*	*Rate mean*	*Actual response to N* *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	RatexSite					
LSD0.05	281	218	483					

Yield rankings are in parentheses; (YT-.Y0) = Yield at rate T; Y0– Yield at the control

Table 7: Effects of location on correlations between nitrogen rates, yield and yield parameters (SGR, SD, SDWT)

		YLD	*SWP*	*SGR*	*SD*	*SDWT*
Timbilil	N rate	0.598	0.176	0.354	–0.693	0.442
Changoi	N rate	0.562	–0.228	0.354	0.822	0.000
Arroket	N rate	0.930*	–0.092	0.909*	0.919*	–0.189

N = 5

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