Quality response of clonal black tea to nitrogen fertiliser, plucking interval and plucking standard

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Abstract: Variations in the black tea quality of high-yielding clone S15/10 in response to rates of NPKS 25:5:5:5 fertiliser of 200 and 400 kg N ha^{-1} year^{-1}, plucking intervals of 7, 14 and 21 days and a selective plucking standard of up to two leaves and a bud or an unselective plucking standard were studied. Generally, quality declined with longer plucking intervals and unselective plucking. Although there was a general decline in quality with increasing nitrogen rate, only the black tea total colour declined significantly on increasing the nitrogen rate from 200 to 400 kg N ha^{-1} year^{-1}. For each nitrogen rate and each plucking interval, unselective plucking reduced the black tea quality. No significant interactions between any two of the three (nitrogen rate, plucking interval and plucking standard) or all three factors were noted, indicating that the patterns of response were similar. The results demonstrate that black tea quality changes due to the factors studied occur in the same pattern with variations in treatments. Poor black tea quality due to any of the factors studied cannot therefore be corrected by varying the other factors.

Keywords: *Camellia sinensis*; clones; black tea quality; nitrogen fertiliser; plucking standards; plucking intervals

INTRODUCTION

In the production of black tea from young shoots of *Camellia sinensis* plants, the two most costly agronomic inputs are nitrogenous fertiliser application[1,2] and plucking (harvesting).[1] Despite the high costs, these undertakings are indispensable and their incorrect operation can lead to economic losses. The application of nitrogen fertiliser is necessary as it increases yields.[3,4] However, high rates of nitrogen lower the resultant black tea quality.[5–7] The recommended rates of nitrogen fertiliser application to tea vary from country to country;[3] in Kenya they vary between 100 and 250 kg N ha^{-1} year^{-1}.[8] However, some farmers believe that the yield response is limitless and thus apply more than the recommended rates. Clone S15/10 is very high yielding in Kenya and has yielded up to 10 995 kg made tea (mt) ha^{-1} year^{-1} under commercial estate practice[9] in a year with good cropping weather. Although it was thought that such high-yielding clones might require more than the recommended rates of nitrogen,[8] recently it was demonstrated using this clone that there was no significant yield response beyond 200 kg N ha^{-1} year^{-1}, which was also the most profitable rate of nitrogen fertiliser application.[4]

Harvesting policy also affects profits in tea production. Yields[4,10,11] and black tea quality[4,11–14] decline with longer plucking intervals. Black tea quality also declines with coarser (unselective) plucking standards.[15–17] This reduction in black tea quality with coarser plucking standards has been demonstrated to be due to changes in composition of the black tea quality precursor components in green tea leaves. Catechins, which are responsible for formation of the plain black tea quality parameters (theaflavins and thearubigins), decline,[18,19] whilst chlorophyll, high levels of which reduce black tea quality,[20,21] and unsaturated fatty acids, which break down to form C_6 alcohols and aldehydes[22] responsible for the green, grassy aroma of black tea,[23] increase[24] with coarser plucking standards. The decline in black tea quality due to longer harvesting intervals was attributed to the coarse plucking standards.[4] This was due to the lack of selective plucking in previous studies,[4,10–14] contrary to what is recommended in normal tea production.[3,8]

Although there are variations in actual plucking standards from country to country and even among different tea-producing concerns within one country, plucking of up to two leaves and a bud is thought to be a good compromise between yield and quality.[3] Thus, where there is overgrowth beyond two leaves and a bud, in normal tea production, only the two leaves and the bud are harvested for processing,[8] whilst the rest is broken back and thrown away to maintain uniform plucking table height.[25] In most instances, farmers are unwilling to follow this recommendation, because the broken-back leaf is seen as waste or loss; but where the

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(*Received 7 April 1999; revised version received 20 September 1999; accepted 29 October 1999*)

Table 1. Raw data from the experiment

Quality indicator	Fertiliser application rate (kg $Nha^{-1}year^{-1}$)	Plucking interval (days)	Plucking standard	Replicate			
				1	2	3	4
Theaflavins	200	7	Selective	16.17	12.31	11.76	10.65
			Unselective	14.88	10.47	9.61	9.96
		14	Selective	15.43	11.80	11.25	10.60
			Unselective	12.86	10.60	9.36	9.78
		21	Selective	15.38	11.78	10.38	10.36
			Unselective	13.75	9.98	9.36	9.69
	400	7	Selective	15.16	10.76	10.05	10.29
			Unselective	14.31	9.09	9.69	9.64
		14	Selective	15.05	11.02	9.89	10.13
			Unselective	12.20	8.64	8.76	9.56
		21	Selective	15.08	10.73	9.80	10.17
			Unselective	10.90	5.64	9.79	8.93
Thearubigins	200	7	Selective	107.2	116.7	146.4	125.1
			Unselective	147.8	151.3	131.5	132.2
		14	Selective	157.7	143.0	144.9	134.4
			Unselective	168.0	136.9	163.5	135.0
		21	Selective	157.6	137.3	141.6	123.6
			Unselective	123.8	151.5	163.1	130.9
	400	7	Selective	150.2	151.1	150.1	123.6
			Unselective	171.2	149.6	153.8	128.8
		14	Selective	142.3	143.7	137.1	127.0
			Unselective	167.2	158.5	162.1	135.2
		21	Selective	145.2	154.7	138.2	126.6
			Unselective	121.7	159.8	165.9	123.3
Total colour	200	7	Selective	4.82	3.73	3.96	3.17
			Unselective	3.80	3.31	2.84	2.95
		14	Selective	3.91	3.70	3.32	3.51
			Unselective	3.78	3.35	2.64	3.18
		21	Selective	3.90	3.54	3.18	3.19
			Unselective	3.80	3.01	2.62	3.00
	400	7	Selective	3.90	3.56	3.06	3.43
			Unselective	3.58	3.02	2.65	3.10
		14	Selective	3.88	3.36	3.06	3.32
			Unselective	3.55	2.93	2.58	3.19
		21	Selective	3.94	3.31	2.80	3.36
			Unselective	3.43	2.66	2.48	2.44
Brightness	200	7	Selective	24.53	19.32	22.06	19.93
			Unselective	22.88	16.25	18.52	18.65
		14	Selective	24.06	18.71	19.39	18.75
			Unselective	21.57	16.06	17.39	18.29
		21	Selective	23.12	18.12	19.04	18.70
			Unselective	19.85	15.93	16.67	17.91
	400	7	Selective	23.30	22.07	20.64	21.00
			Unselective	21.58	19.64	16.67	18.53
		14	Selective	22.83	20.56	18.52	19.73
			Unselective	20.03	19.49	16.07	17.96
		21	Selective	21.77	20.24	17.95	18.98
			Unselective	13.26	18.93	12.67	17.94
Taster A	200	7	Selective	39	49	60	28
			Unselective	21	31	48	16
		14	Selective	33	43	54	22
			Unselective	31	37	30	18
		21	Selective	32	37	54	16
			Unselective	21	32	18	10
	400	7	Selective	33	43	36	28
			Unselective	27	19	12	16
		14	Selective	29	31	30	22
			Unselective	21	19	6	22
		21	Selective	23	19	24	20
			Unselective	9	13	2	18

Table 1. *continued*

Quality indicator	Fertiliser application rate (kg N ha^{-1} year^{-1})	Plucking interval (days)	Plucking standard	Replicate 1	2	3	4
Taster B	200	7	Selective	25	26	21	25
			Unselective	22	19	21	24
		14	Selective	19	25	20	23
			Unselective	19	20	20	22
		21	Selective	20	19	19	21
			Unselective	19	18	19	20
	400	7	Selective	24	21	18	20
			Unselective	21	17	18	20
		14	Selective	22	20	17	19
			Unselective	21	21	18	19
		21	Selective	20	20	15	18
			Unselective	18	16	16	18
Flavour index	200	7	Selective	2.13	1.65	1.21	
			Unselective	0.87	1.07	0.70	
		14	Selective	1.75	1.38	1.17	
			Unselective	0.83	0.92	0.73	
		21	Selective	1.35	1.02	1.00	
			Unselective	0.80	0.83	0.76	
	400	7	Selective	1.84	1.28	0.89	
			Unselective	0.89	1.14	0.54	
		14	Selective	1.25	1.21	1.08	
			Unselective	0.90	0.94	0.78	
		21	Selective	1.27	1.16	0.76	
			Unselective	0.85	0.83	0.37	

recommendation is strictly enforced, it is observed despite the loss in yield. However, there is no study that has compared the effect of maintaining the recommended plucking standard[3,8] at different nitrogen fertiliser rates and plucking intervals on black tea quality. This study was carried out to establish whether there are black tea quality variations due to the application of varying rates of nitrogen, plucking intervals and plucking standards, and to assess whether there are interactions between the three black tea agronomic practices.

MATERIALS AND METHODS

The experiment, initiated in 1992, was carried out in Field 19, Soet Division, Kaproret Estate, African Highlands and Produce Company, Kericho, Kenya, situated at an altitude of 1860 m above mean sea level. The field consisted of a high-yielding clone S15/10[9] planted in 1970 at 122 cm × 61 cm rectangular spacing with a population density of 13 448 plants ha^{-1}. Before the tea was planted, the field was under natural forest. The soils are well-drained humic nitosols, very deep, dark reddish-brown to dark brown, and the texture consists of clay loam near the surface and clay (kaolinite) in the lower depths. The soil was derived from tertiary basic igneous rocks (basalt, nepheline, phonolite) which are commonly found in volcanic footbridges. The site has a dry season from mid–December to the end of March, a cool wet season from April to August and a warm wet season from September to mid-December, and receives an average annual rainfall of about 1500 mm.[26] Prior to the start of the experiment the plantation was uniformly managed and had received fertiliser at a rate of 200 kg N ha^{-1} year^{-1} as NPKS 25:5:5:5, all in one application, in the previous 6 years. NPKS 25:5:5:5 is one of the recommended N-carrying fertilisers[8] and is the most popular among tea farmers in Kenya. The experimental treatments were laid out in a split plot design with N rates as the main treatments, split for plucking intervals in four replicates. Fertiliser (NPKS 25:5:5:5) rates of 100, 200, 300, 400, 500 and 600 kg N ha^{-1} year^{-1} were split for plucking intervals of 7, 14 and 21 days. Each effective sub-plot consisted of 80 plants and was surrounded by a guard row of tea plants. Fertiliser applications were carried out in March every year. All the available leaf was harvested irrespective of the standard, ie hard unselective plucking was done.

Black tea manufacture and chemical and sensory evaluations

The recommended nitrogenous fertiliser rate for tea in Kenya is up to 200 kg N ha^{-1} year^{-1}.[8] However, prior to adoption of this rate, tea farmers in Kenya used on average 400 kg N ha^{-1} year^{-1}. Although most Kenya tea growers pluck tea at 14 day plucking intervals, there are farmers in the smallholder sector plucking after 21–28, days, while in the estate sector, plucking

Parameter	Rate of nitrogen (kg N ha^{-1} year^{-1})	Plucking interval (days) 7	14	21	Mean N rate
Theaflavins	200	11.98	11.46	11.46	11.63
(μmol g^{-1})	400	11.12	10.66	10.13	10.64
Mean interval		11.55	11.06	10.80	
CV (%)			7.56		
LSD ($P \leq 0.05$)			0.50		NS
Interactions ($P \leq 0.05$)			NS		
Thearubigins	200	132.3	147.9	141.2	140.5
(g kg^{-1})	400	147.3	146.6	141.9	145.3
Mean interval		139.8	147.3	141.6	
CV (%)			9.04		
LSD ($P \leq 0.05$)			NS		NS
Interactions ($P \leq 0.05$)			NS		
Total colour	200	3.57	3.42	3.28	3.43
(%)	400	3.29	3.23	3.05	3.19
Mean interval		3.43	3.33	3.17	
CV (%)			5.52		
LSD ($P \leq 0.05$)			0.16		0.22
Interactions ($P \leq 0.05$)			NS		
Brightness	200	20.27	19.28	18.67	19.40
(%)	400	20.43	19.40	17.72	19.18
Mean interval		20.35	19.34	18.19	
CV (%)			6.24		
LSD ($P \leq 0.05$)			0.85		NS
Interactions ($P \leq 0.05$)			NS		
Flavour index	200	1.27	1.13	0.96	1.12
	400	1.10	1.03	0.87	1.00
Mean interval		1.18	1.08	0.92	
CV (%)			18.55		
LSD ($P \leq 0.05$)			0.16		NS
Interactions ($P \leq 0.05$)			NS		
Taster A	200	37	34	28	33
	400	27	23	16	22
Mean interval		32	28	22	
CV (%)			25.78		
LSD ($P \leq 0.05$)			4		NS
Interactions ($P \leq 0.05$)			NS		
Taster B	200	23	21	19	21
	400	20	20	18	19
Mean interval		21	20	19	
CV (%)			7.28		
LSD ($P \leq 0.05$)			1		NS
Interactions ($P \leq 0.05$)			NS		

Table 2. Effects of nitrogenous fertiliser rate and plucking interval on clonal black tea quality

rounds are now being shortened.[4,12] On four different occasions when all the plucking intervals coincided, 3 kg of unselected plucked leaf was obtained from each of the 200 and 400 kg N ha^{-1} year^{-1} plots. The leaf was brought into the factory and separated into two equal parts for each sub-treatment. One part was further subjected to selection so that sections beyond two leaves and a bud were removed, to conform to the recommended plucking practice.[3,8] Both leaves were then subjected to normal wither and miniature manufacture using the crush, tear and curl (CTC) method.[12] Manufactured (black) tea was subjected to chemical analyses and sensory evaluations as reported earlier.[4,11,12] Theaflavins were analysed by the method of Hilton,[27] and thearubigins, brightness and total colour were determined using the method of Roberts and Smith.[28] The volatile flavour compounds (VFCs) from three replicates of the experiment were extracted by the simultaneous steam distillation–extraction method (water–diethyl ether)[29] using cumene as an internal standard. The VFCs were analysed by gas chromatography (GC) using the conditions of Baruah *et al.* [14]

Each manufacture was treated as a replicate and the results were subjected to analysis of variance (ANOVA) using a split–split plot design. Nitrogen rates were

Parameter	Rate of nitrogen (kg N ha^{-1} year^{-1})	Plucking standard			
		Selective		Unselective	Mean N rate
Theaflavins	200	12.32		10.94	11.63
(μmol g^{-1})	400	11.51		9.76	10.64
Mean standard		11.92		10.35	
CV (%)			7.56		
LSD ($P \leq 0.05$)			0.51		NS
Interactions ($P \leq 0.05$)			NS		
Thearubigins	200	136.3		144.6	140.5
(g kg^{-1})	400	140.8		149.8	145.3
Mean standard		138.6		147.2	
CV (%)			9.04		
LSD ($P \leq 0.05$)			7.8		NS
Interactions ($P \leq 0.05$)			NS		
Total colour	200	3.66		3.19	3.43
(%)	400	3.42		2.97	3.19
Mean standard		3.54		3.08	
CV (%)			5.52		
LSD ($P \leq 0.05$)			0.11		0.22
Interactions ($P \leq 0.05$)			NS		
Brightness	200	20.48		18.33	19.40
(%)	400	20.63		17.73	19.18
Mean standard		20.56		18.03	
CV (%)			6.24		
LSD ($P \leq 0.05$)			0.73		NS
Interactions ($P \leq 0.05$)			NS		
Flavour index	200	1.41		0.83	1.12
	400	1.19		0.80	1.00
Mean standard		1.30		0.82	
CV (%)			18.55		
LSD ($P \leq 0.05$)			0.14		NS
Interactions ($P \leq 0.05$)			NS		
Taster A	200	39		26	33
	400	28		15	22
Mean standard		34		21	
CV (%)			25.78		
LSD ($P \leq 0.05$)			4		NS
Interactions ($P \leq 0.05$)			NS		
Taster B	200	22		20	21
	400	20		19	19
Mean standard		21		19	
CV (%)			7.28		
LSD ($P \leq 0.05$)			1		NS
Interactions ($P \leq 0.05$)			NS		

Table 3. Effects of nitrogenous fertiliser rate and plucking standard on clonal black tea quality

split for plucking intervals, which were sub-split for plucking standards (unselective and selective (recommended) plucking standards).

RESULTS AND DISCUSSION

For high-yielding clone S15/10[9] the most profitable production had been achieved under an unselective plucking system by applying 200 kg N ha^{-1} year^{-1}.[4] Despite this, there are farmers who regularly use higher than recommended fertiliser rates in the belief that yield and/or profit response to nitrogen fertiliser application is linear. In this study, therefore, the most economic rate of nitrogen fertiliser application[4] was compared with the higher application rate of 400 kg N ha^{-1} year^{-1} which was previously being used by tea farmers in Kenya. In the previous study,[4] under 7, 14 and 21 day plucking intervals, the quality of black tea from unselective plucking was observed to reduce with longer plucking intervals.

Black tea quality is assessed by look (colour), taste (tongue) and smell (nose). The chemical black tea quality parameters responsible for taste and look are referred to as the plain black tea quality parameters and are due to the polyphenolic components of black tea, mainly theaflavins and thearubigins.[28,30] The

Table 4. Effects of plucking standard and plucking interval on clonal black tea quality

Parameter	Plucking standard	Plucking interval (days) 7	14	21	Mean plucking standard
Theaflavins	Selective	12.14	11.90	11.71	11.92
(μmol g^{-1})	Unselective	10.96	10.22	9.88	10.35
Mean interval		11.55	11.06	10.80	
CV (%)			7.56		
LSD ($P \leq 0.05$)			0.50		0.51
Interactions ($P \leq 0.05$)			NS		
Thearubigins	Selective	133.8	141.3	140.6	138.6
(g kg^{-1})	Unselective	145.8	153.3	142.5	147.2
Mean interval		139.8	147.3	141.6	
CV (%)			9.04		
LSD ($P \leq 0.05$)			NS		7.8
Interactions ($P \leq 0.05$)			NS		
Total colour	Selective	3.70	3.51	3.40	3.54
(%)	Unselective	3.16	3.15	2.93	3.08
Mean interval		3.43	3.33	3.17	
CV (%)			5.52		
LSD ($P \leq 0.05$)			0.11		0.16
Interactions ($P \leq 0.05$)			NS		
Brightness	Selective	21.61	20.32	19.74	20.56
(%)	Unselective	19.09	18.36	16.65	18.03
Mean interval		20.35	19.34	18.19	
CV (%)			6.24		
LSD ($P \leq 0.05$)			0.85		0.73
Interactions ($P \leq 0.05$)			NS		
Flavour index	Selective	1.50	1.31	1.09	1.30
	Unselective	0.87	0.85	0.74	0.82
Mean interval		1.18	1.08	0.92	
CV (%)			18.55		
LSD ($P \leq 0.05$)			0.16		0.14
Interactions ($P \leq 0.05$)			NS		
Taster A	Selective	40	33	28	34
	Unselective	24	23	15	21
Mean interval		32	28	22	
CV (%)			25.78		
LSD ($P \leq 0.05$)			4		4
Interactions ($P \leq 0.05$)			NS		
Taster B	Selective	23	21	19	21
	Unselective	20	20	18	19
Mean interval		21	20	19	
CV (%)			7.28		
LSD ($P \leq 0.05$)			1		1
Interactions ($P \leq 0.05$)			NS		

black tea parameters assessed by smell are the volatile flavour compounds (VFCs). Many of these compounds which have been identified in black tea[23] can be classified into two groups. There are those which impart a green, grassy, undesirable aroma to black tea (group I VFCs) and those which confer a sweet, floral, aromatic smell (group II VFCs). For Kenyan black teas it had been demonstrated that the ratio of group II to group I, the flavour index, is a reasonable measure of aroma quality of black teas.[31]

All the data generated from the experiment are presented in Table 1, while the changes in black tea quality parameters and sensory evaluations due to varying nitrogen rates, plucking standards and plucking intervals are presented in Tables 2–4. As in previous studies, there was a quality decline with longer plucking intervals.[4,10–12,14] Although there was a decline in quality parameters with higher rates of nitrogen, only the total colour of the black teas was significantly ($P \leq 0.05$) superior as a result of applying 200 rather than 400 kg N ha^{-1} year^{-1} (Tables 2 and 3). The changes in quality as assessed by theaflavins, thearubigins, brightness and flavour index did not reach significant levels. Similarly, black teas from

200 kg N ha^{-1} year^{-1} had higher sensory evaluation than those from 400 kg N ha^{-1} year^{-1}, but the difference was not significant. Earlier in the same trial, when rates of nitrogen application varying from 100 to 600 kg N ha^{-1} year^{-1} were assessed, all the quality parameters changed significantly with nitrogen rate.[4] These results further demonstrate that the application of low rates of nitrogen and short plucking intervals is beneficial to black tea quality.

In all the black tea quality parameters monitored and sensory evaluations, there were no interactions between nitrogen fertiliser rate and plucking interval (Table 2). These results demonstrate that the pattern of quality decline with longer plucking intervals does not vary with changes in nitrogen fertiliser rate and *vice versa*. At any nitrogen fertiliser application rate, finer plucking standards produce better-quality teas. Similarly, at every plucking interval, lower rates of nitrogenous fertiliser application lead to better-quality black teas. Low-quality black teas due to high rates of nitrogen cannot therefore be completely improved by shortening plucking intervals and *vice versa*, although with short plucking intervals the resultant black teas are of better quality than those from long plucking intervals at the same rate of nitrogen fertiliser application.

Although plucking standards had been demonstrated to affect black tea quality, such that coarse plucking reduced quality,[15–17,32] in those previous studies the plucking standard was varied at the same nitrogen fertiliser rate and same plucking interval. Indeed, where the plucking interval was being varied, it was assumed that the decline in quality with longer plucking intervals was due to the variations in plucking standard.[4,11,12] However, the pattern of shoot development varies with time, such that growth is slower in a newly developing shoot compared with a shoot that has been growing for some time.[33,34] This variation in shoot growth pattern with time may cause changes in black tea quality when the plucking interval is varied at the same plucking standard. Yield response to nitrogen fertiliser rate was also recently demonstrated to be partly due to an increase in shoot extension rate.[4]

The changes in black tea quality due to varying plucking standards at different nitrogen fertiliser rates are presented in Table 3. There was a decline in quality with unselective (coarse) plucking at both nitrogen fertiliser rates studied. These results demonstrate that coarse plucking lead to a quality decline irrespective of the nitrogen fertiliser rate being applied. The interactions between nitrogen fertiliser rate and plucking standard were insignificant ($P \leqslant 0.05$), further demonstrating that the patterns of quality decline with plucking standard did not change much between the two nitrogen fertiliser rates. Poor black tea quality due to coarse plucking standards cannot therefore be corrected by reducing the nitrogen fertiliser rate. Thus, at a given fertiliser application rate, high-quality black tea is obtained by fine plucking.

The changes in black tea quality parameters due to varying plucking standards and plucking intervals are presented in Table 4. At all the plucking intervals studied, there was a decline in black tea quality with coarse plucking. Thus, for situations where plucking standards are already set, it is desirable to pluck at short intervals, as this leads to lower amounts of coarse leaf[4] and produces good-quality black teas.

With unselective plucking, the decline in quality with longer harvesting intervals observed here (Table 4) and earlier[4,11,12] was partly attributed to the coarse plucking standard. However, it is observed that although the plucking standard in the selective system was the same (Table 4), longer plucking intervals still produced inferior black tea quality. These results demonstrate for the first time that even when the plucking standard is already set, as in the recommended harvesting policy,[3,8] selecting two leaves and a bud from shoots which have been growing for a long time reduces black tea quality. Thus the quality of black tea from two leaves and a bud harvested every 7 days is superior to that from two leaves and a bud harvested every 21 days. Together with the previously observed yield[4,10,11] and quality[4,11,12,14] benefits from short plucking intervals when harvesting was unselective, further black tea quality improvement is obtained by fine plucking at short plucking intervals.

ACKNOWLEDGEMENTS

Field and laboratory data collected by staff of the Crop Environment and Chemistry Departments of the Tea Research Foundation of Kenya (TRFK) are acknowledged. This paper is presented with the permission of the Director, TRFK.

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