LONG TERM FIELD EXPERIMENT

LONG TERM FERTILIZER USE ON HIGH YIELDING CLONE S15/10 TEA: YIELDS

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ABSTRACT

High production of young tender shoots of *Camellia sinensis* L. O. Kuntze to make tea beverages leads to soil nutrients depletion through harvested crop and leaching. The production can be sustained by replenishing the lost nutrients through regular addition of fertilizers and/or organic manures. In Kenya, NPKS 25:5:5:5 or NPK 20:10:10 are the recommended fertilizers for tea. Clone S15/10 is a high yielding tea and has yielded of over 10000 kg made tea (mt) per hectare per year in a year with good cropping weather. Long term (18 years) experimentation on the amounts of fertilizers needed to sustain the yields demonstrated that application of nitrogenous fertilizer resulted in significant ($P \leq 0.05$) yield responses. The application of high rates of fertilizer produced quadratic yield response with a maximum at about 300 kg N ha^{-1} $year^{-1}$. Quantities between 200 and 250 kg N ha^{-1} $year^{-1}$ were considered optimal. There were no significant ($P \leq 0.05$) differences in the yields responses due to use of NPKS 25:5:5:5 and NPK 20:10:10. The NPK formulation to use on tea in Kenya should therefore be decided based on other factors like availability, cost, ease of handling, etc. Despite the control plot not receiving fertilizer for the 18 years, it continued to produce yields higher than most seedling tea receiving adequate nutrition. In a subsequent trial to assess if splitting annual fertilizer application could improve yields, applying fertilizer at half rate annual rate every six months or one third rate at four months intervals did not cause any significant changes in yields at all rates tested for six years. The splitting annual fertilizer applications may therefore be practised for other reasons like uniform distribution of the fertilizer in the tea plantations, cash flow and storage considerations, ease of handling, etc. In a trial to establish the effect of plucking rounds on yields, there were significantly ($P \leq 0.05$) higher yields when harvesting interval was 7 days compared to 14 or 21 days intervals in the eight out of ten years of experimentation. In most years the 14 day plucking interval produced the lowest yields. These results demonstrate that shorter plucking intervals are beneficial to high tea production in the Kenya highlands.

Keywords: Long term nitrogen, high yielding clone, NPK formulations, splitting annual fertilizer application, plucking rounds, yields.

1. INTRODUCTION

Tea is a perennial plant and once planted can last over 100 years of economic production when good agronomic and cultural practices are observed. The first tea plantations in Kenya in 1920's are still in production while tea plantations

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over 100 years old continue to produce economic yields in India and China. To continuously produce economic yields over such long periods, it is necessary that the lost nutrients through harvesting and leaching are replenished into the soil through fertilizer applications. Nitrogen is the main nutrient for the tea plant and fertilizer use on tea is usually based on nitrogenous fertilizers (Ranganathan and Natesan 1985; Othieno 1988; Bonheure & Willson 1992). The fertilizer use on tea varies from country to country (Owuor & Wanyoko, 1996; Bonheure & Willson, 1992). The lowest fertilizer use per hectare per year is in Vietnam at 36 to 40 kg N, while highest is in Japan at 800 kg N (Table 1). Despite these variations, tea yields were generally below 2000 kg made tea (mt) per hectare per year in most of the tea producing countries in the 1980s. In Kenya, during that period, yields of between 2500 and 3000 kg black tea per hectare per year were considered normal. However, in 1983 clone S15/10 yielded over 8,000 kg black tea per hectare in one field in lower Kericho. Such yields, had not been obtained anywhere in the world. In a subsequent year with good cropping weather, the clone yielded a record 10,995 kg made tea per hectare (Oyamo, 1992), arguably the highest yield per unit area recorded in the world under commercial production.

Although potassium (Venkatesan *et al* 2005, Dang 2005) and phosphorus (Dang 2005) are important nutrients for tea (Willson 1972) no significant yield responses have been observed in Kenya due to application of the two nutrients. This is despite the observation that potassium is required during nitrogen metabolism (Mengel and Helal 1968; Marschner 1995; Pfinger and Wideman 1977). After several years of application without response, Rahman and Jain (1985) observed positive yield response in India and in south India potassium application improved yields (Venkatesan *et al* 2003). Consequently potassium application is recommended in tea production in southern India (Venkatesan *et al* 2003; Verma and Palani 1997). Phosphorus is a constituent of phophatides like nucleic acid, phospholipids, and co-enzymes in several metabolic processes in the plant. It is important for cell division and functions as a carrier in high energy transformations. A deficiency of phosphorus results in stunted growth of the plants and the mature tea plants show a characteristic bluish coloration. However, surplus in the soil through fertilizer application which is not used by the plant undergoes transformation process into stable fraction until the soil is saturated, without negative effects for plant growth (Mengel 1991). Although nitrogen used to be applied to tea in the form straight nitrogen compound (Bonheure and Willson 1992), it is now commonly applied in form of compound fertilizers (Othieno 1988). Consequently, in addition to nitrogen, potassium and phosphorus are regularly supplied to tea plantations as fertilizers.

Table 1: Nitrogenous fertilizer use in different countries.

Country	Rates of N (kg N/ha/year)
North India	100-200
South India	120-200
Sri Lanka	120-360
Malawi	180-300
Kenya	100-250
Queensland (Australia)	182
Malaysia	153-270
Indonesia	120-200
Vietnam	36-40
USSR	200-300
Turkey	112
Taiwan	150
Cong (Kivu)	45-150
Japan	800

Source: Bonheure & Willson, 1992; Owuor & Wanyoko, 1996

When clone S15/10 yielded 8,000 kg made tea per heactare, it was speculated that for the high yields to be maintained or sustained, the 100 to 250 kg N ha^{-1} $year^{-1}$ applied annually (Othieno 1980, 1988) could be inadequate, and the plants were expected to succumb to inadequate nutrients supply and thus stop growing altogether. Earlier, some Kenya tea growers had raised concern that use of NPK 20:10:10 as an alternative to NPKS 25:5:5:5 lead to low production. It became necessary to establish appropriate nitrogenous fertilizer rate for such high yielding tea and to compare tea yield responses of the clone to the two recommended (Othieno 1980, 1988) fertilizer formulations. A long-term experiment was set up in 1984, on the same field where the high yields had been obtained, to establish the optimal fertilizer rate for the tea and to compare yield response of the tea to the two NPK formulations. This experiment run from September 1984 to December 2002.

It is recognised that increase in nitrogen use efficiency can be achieved through improvement of agronomic practices (Ranganathan 1980). The current fertilizer regimes for tea are based on the financial year accounts. Fertilizers are applied once a year to coincide with company/ organisation financial year. For high yielding tea like S15/10, when fertilizer was applied as a single dose, the tea plants that received less than 300 kg N ha^{-1} $year^{-1}$ started showing leaf yellowing signs before the next fertilizer application time suggestive of possible lack of adequate nutrients, particularly nitrogen (Anon 2002) and the fertilizer use efficiency appeared low (Ranganathan 1980). This suggested that the tea may require split application of fertilizer. It became necessary to evaluate if the single application was adequate for realisation of maximum yields for the high yielding tea cultivar or if the yields could be improved by splitting the annual fertilizer application.

High yielding tea like cultivar S15/10 could be growing very fast. The fast growth would be translating to a requirement of shortening plucking intervals. Indeed, in 1991 under commercial production, the clone yielded 10,995 kg made tea (mt) ha^{-1} $year^{-1}$ (Oyamo 1992) when the tea was intensively plucked at 10 to 12 days intervals. While that was arguably one of the highest yields recorded in tea production then, this suggested that it was possible to improve the yields of the high yielding cultivar by intensifying plucking. Earlier, it had been demonstrated that even for a moderately yielding tea cultivar, short plucking intervals improved yields (Odhiambo 1989). It became necessary to assess if yields of high yielding clone S15/10 could be improved/optimised through plucking interval and if such interval would change with rates of nitrogen as yields and growth are known to change with nitrogen rates (Odhiambo 1989). The split fertilizer trial was converted after six years to rates of nitrogen and frequency of harvesting trial. Several lessons were learnt from these experiments. This paper reviews yields observations noted from the trials.

EXPERIMENTAL

The trials were set on high yielding clone S15/ 10 planted in 1970 in a 122 cm x 61 cm rectangular spacing with a plant population of 13,448 plants ha^{-1} at the Kaproret Estate 0^{o} 27'S; 35^{o} 15'E) of the African Highlands Produce Company (now James Finlays Company), at an altitude of 1860 m above mean sea level. Before the tea was planted, the field was under natural forest. The soils are well-drained humic nitrosols, very deep, dark reddish-brown to dark brown and the texture consisted of loam near the surface and clay (Kaolinite) in the lower depths. The soil was derived from tertiary basic igneous rocks (basalt, nepheline, and phonolite) which are commonly found in volcanic footbridges. The site has a very dry season from mid – December to 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 1500mm (Ng'etich *et al*, 1995, Stephens *et al*, 1992; Ng'etich and Stephens 2001). Prior to the start of the trials, the tea was receiving uniform agronomic treatments and fertilizer was applied as NPKS 25:5:5:5 at a rate of 200 kg N ha^{-1} $year^{-1}$ all in a single application in the previous four years, for Trial I and six years for Trial II which was later converted to Trail III.

Trial I

The long term experiment was laid out on a split plot design with rates of nitrogen as main treatments and fertilizer types as the sub-treatments. The fertilizer rates were 0, 100, 150, 300, 450 and 600 kg N ha^{-1} $year^{-1}$ as NPKS 25:5:5:5 and NPK 20:10:10 all put in a single annual application in September every year. The treatments were replicated four times. Tea was plucked from the different treatments on 10 to 14 days plucking intervals depending on leaf availability. The plucking standard conformed to the normal commercial practice of mostly two leaves and a bud. Other agronomic practices like, pruning, weed control, etc, were undertaken according to recommended practices (Anon 2002, Othieno 1988). Fresh green leaf per sub plot was converted to green yields per hectare and converted to made tea per hectare by multiplying by a factor of 0.225. The experiment started in September 1984 and was terminated in December 2002.

Trial II

During the first one year of experimentation, in Trial I the sub plots which had received up to 300 kg N ha^{-1} $year^{-1}$ showed visual yellowing of leaves suggestive of nitrogen deficiency. It was thought that applying all the fertilizer in one dose could be leading to excessive leaching and that high yielding tea like S15/10 could be requiring application of smaller doses of nitrogen spread during the year. In March 1986, a second experiment, replicated four times, was started in the same field to test the effects of splitting annual fertilizer application on yields of tea at different rates of nitrogen. The experiment was laid out as a split plot design in a randomised complete black arrangement. The main treatments were NPKS 25:5:5:5 at 100, 200, 300, 500 and 600 kg N ha^{-1} $year^{-1}$. Each main treatment was split into a single application all done in March, split applications into two applied in March and September, and split application into three applied in March, July and November every year. This experiment was replicated four times and continued from 1985 to December 1991. Harvested green leaf per sub plot was converted to green leaf per hectare, which was translated to made tea per hectare using a factor of 0.225 (Anon 2002.

Trial III

After six years of experimentation in Trial II, there were no economic gains out of splitting the annual fertilizer application. The experiment was converted to a new fertilizer trial. It was speculated that one part of the reason for the high yields being realized from the clone was that it could be very fast growing. The third experiment (Trial III) started from March 1993 was established to measure the effects of rates of nitrogen and intervals of plucking on yields of clone S15/10. The experiment was set up in four replicates in a split plot design in randomised complete block arrangement. The fertilizer (NPKS 25:5:5:5) rates of 100, 200, 300, 400, 500 and 600 kg N ha^{-1} $year^{-1}$ were main treatments split for plucking intervals of 7, 14 and 21 days. Fertilizer applications were carried out in March every year. During plucking, all the available leaf was harvested without sorting. The plucked leaf per sub plot was converted to green leaf per hectare, which was further converted to made tea per hectare using a factor of 0.225 (Anon 2002). This experiment continued from 1993 to 2002.

RESULTS AND DISCUSSION

Yields

The mean annual yield data from the first trial from 1986 to 2001 are presented in Table 2 while the annual yield data are presented in Figure 1. The annual yield trends were similar although there were years with poor or very good yields in all plots. Based on the mean data (Table 2) for the whole experimental period, the highest yield was observed by applying 300 kg N ha^{-1} $year^{-1}$. This was almost double (97.5% or 2992 kg mt ha^{-1} $year^{-1}$ more) the yield of the control plot. The response was higher than the 450 kg mt ha^{-1} $year^{-1}$ observed in cultivar UPASI-9 over nine years of experimentation (Venkatesan *et al* 2004). Beyond the 300 kg N ha^{-1} $year^{-1}$ there was no yield response. Instead yields declined by 114 and 107 kg mt ha^{-1} $year^{-1}$ at 450 and 600 kg N ha^{-1} $year^{-1}$, respectively, compared to yields at 300 kg N ha^{-1} $year^{-1}$. There was therefore no yield benefit of applying higher than 300 kg N ha^{-1} $year^{-1}$. Generally there were quadratic yield responses to both NPKS 25:5:5:5 and NPK 20:10:10 as also reported elsewhere (Owuor *et al* 1990; Owuor & Wanyoko, 1996; Kamau *et al* 2003). For the mean data, the quadratic yields obeyed the equations: $Yield_{(NPKS\ 25:5:5:5)} = 3478.1 + 13.717x - 0.0171x^2$, $r^2 = 0.8664$, maximum at x = 401; $Yield_{(NPK\ 20:10:10)} = 3251.7 + 14.992x - 0.0185x^2$, $r^2 = 0.9006$, maximum at x = 405; $Yield_{(mean)} = 3406.2 + 14.106x - 0.0175x^2$, $r^2 = 0.886$, maximum at x = 403, where x is the rate of nitrogenous fertilizers used. Thus the yields produced models which could realise maximum yields at about 400 kg N ha^{-1} $year^{-1}$ for both fertilizer formulations. However, although mathematically the data showed significant ($P \leq 0.05$) quadratic relationships, a closer examination of the data reveal that there was actually yield stagnation after 300 kg N ha^{-1} $year^{-1}$, indeed forming a sort of a plateau. Careful examination of the mean data (Table 2) shows that maximum yields were realised at the 300 kg N ha^{-1} $year^{-1}$ for both formulations. Fertilizer rates above this rate resulted in lower yields demonstrating that even for a high yielding tea like clone S15/10, there may be no yield benefits of using higher fertilizer rates than 300 kg N ha^{-1} $year^{-1}$.

Table 2: Effect of rates and types of NPK(S) fertilizers on tea yields (kg mt ha^{-1})

	N-rates (kg N ha^{-1} $year^{-1}$)						N type mean
N type	0	100	150	300	450	600	
25:5:5:5	3046	5174	5467	5885	5763	5818	5192
20:10:10	2948	5065	5287	5952	5846	5808	5151
Rates mean	2997	5119	5377	5919	5805	5812	
C.V. (%)			4.80				2.26
LSD, (P≤0.05)			187				NS

Despite the control plot not receiving fertilizer for over 18 years, the mean yields were still high, being above 3000 kg mt ha^{-1} $year^{-1}$. Such yields were actually higher than the national mean yields realised in most tea producing countries (Anon 2007). This suggests that provided other agronomic practices are optimal, one way of increasing tea production to meet the world tea demand is cultivating high yielding varieties. Such improvement can lead to reduction of the current large land areas committed to tea production without meeting world tea demand (Anon 2007). With high yielding varieties as S15/10 even poor tea producing countries that can not afford adequate fertilizer input would improve their productivity or production without committing more land to tea. It had been anticipated that with long term of control going without fertilizer application, the yields would linearly go down with time as nutrients get depleted. But annual yield of the control (0 kg ha^{-1} $year^{-1}$) varied in a similar trend to where fertilizer had been applied (Figure 1). These results demonstrate that the tea field had very high nutrients reserve that can sustain the plants for a very long time. Sustained high yields relative to seedling tea, in the control plot

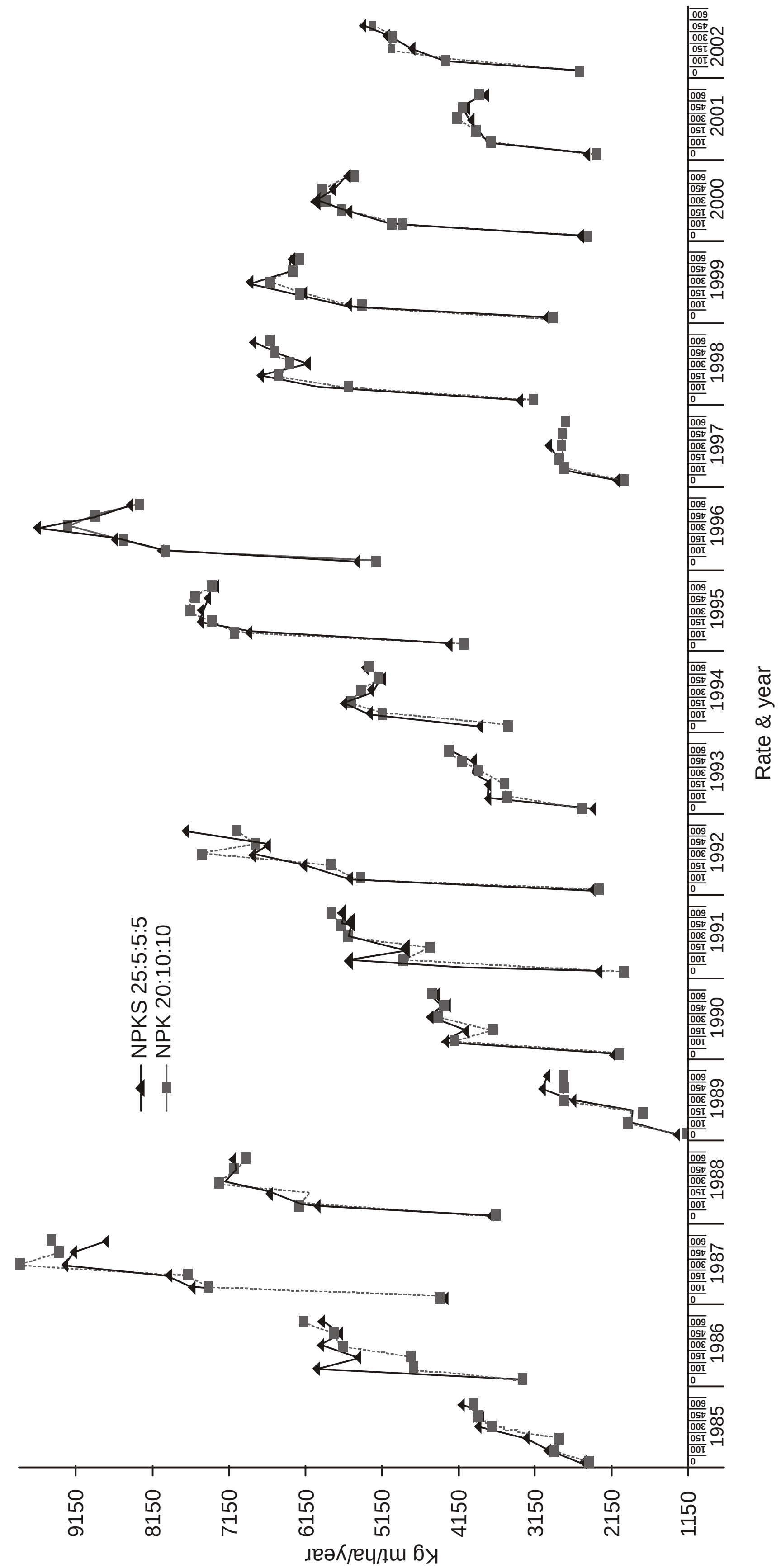

Figure 1: Yields responses to formulations and rates of NPK fertilizers from 1985 to 2002

after 18 years of experimentation is surprising (Table 2). However tea plantations are characterised by intensive nutrient recycling from litter fall and decomposition (Wang *et al* 1997). Part of the nutrients supply came from recycling of leaf fall and prunings which were left *in situ*.

The annual yields are summarised in Figure 1. The actual point of maxima varied slightly from year to year as expected of a biological system. However, the most economical rate of application was about 250 kg N ha^{-1} year^{-1}. Thus, despite the high yields, there is no need to apply excessively high rates of nitrogen. Indeed, the tea produced negative yield returns with very high nitrogenous fertilizer rates above 300 kg N/ha/year (Table 2). Again there was no difference in response between applying NPKS 25:5:5:5 and NPK 20:10:10. The actual yield responses varied from year to year although the response curves remained more or less similar. These results show that the actual yields are to a large extent controlled by environmental factors controlling growth even for the high yielding varieties. In years with good tea growing conditions, the yields were higher and responses to nitrogen between 0 and 300 kg N ha^{-1} year^{-1} were better. Good growing environment include adequate soil moisture level (Carr *et al* 1992, Squire & Callander 1981, Kigalu 2007, Stephens and Carr 1990), suitable temperatures (Carr *et al* 1992, Waheed *et al* 2002, Joshi and Palni 1988), lack of hail storm (Othieno *et al* 1992, Stephens *et al* 1992), and absence of pests and diseases. Yields were low in the years of pruning due to short plucking periods.

These results demonstrate that either of the fertilizers can be used on tea without loss of yields. Thus between the two fertilizers, farmers should be encouraged to use whatever is available in the market at the correct price and consider any additional convenience which maybe obtained by using either of the two fertilizers. For example NPKS 25:5:5:5 would be easier to handle because farmers need fewer bags per hectare than NPK 20:10:10. Although this may look insignificant for an individual smallholder tea farmer whose mean area under tea is only with 0.22 ha (Ogola and Kibiku 2004), the figure becomes significant for a distributor ferrying large quantities of fertilizer to the farms, as Kenya Tea Development Agency Ltd (KTDA) does.

In 1990, a cost benefit analysis was done on the 1986 to 1989 data (one pruning cycle data) to establish the returns farmers get as a result of the fertilizer applications (Owuor *et al* 1990). The data is presented in Table 3. The application of lower rates of nitrogen resulted in higher returns from 1 kg N applied than higher nitrogen rates. These results further demonstrate that gains from fertilizer applications are not linear. The benefits diminish the higher the rates of nitrogen fertilizer used (Owuor *et al* 1987, 1990; Owuor & Othieno, 1996).

Crop Distribution

As part of planning field and processing operations it is important to understand how the application of high rates of nitrogen affects the crop distribution. The effects were monitored at zero and the fertilizer rate where maximum yield was being observed, i.e. 300 kg N ha^{-1} year^{-1} (Kamau *et al* 2004, Owuor *et al* 1990, Owuor & Othieno, 1996, Owuor & Wanyoko 1996). Although it had been anticipated that use of high rates of nitrogen would lead to steady production of tea and even out the monthly tea leaf production thus helping in planning intake of the leaf into the factory, there were large variations (Table 4) in the monthly leaf intake by 42 and 40% for NPKS 25:5:5:5 and NPK 20:10:10, respectively (Owuor *et al* 1991). The production was more controlled by weather and environmental factors particularly temperature and rainfall patterns [Owuor *et al* 1991; Owuor 1990, 1992a, 1994a] than fertilizer. Thus steady leaf in flow into the factory cannot be controlled by fertilizer application and it is not possible to have regular intake of tea throughout the year as long as there are monthly variations in growth factors, particularly weather.

Table 3: Effect of different rates of nitrogenous fertilizer on yield in a pruning cycle (1986-1989).

Rates fertilizer (kg N ha-1 year-1)	Yield (kg mt ha-1 pruning cycle-1)	Mean annual yield (kg mt ha-1 year-1)	Yield (kg mt ha-1 year-1 benefit of applying 1 kg N)	Yield (kg ha-1 year-1) benefit of applying 1 kg N above previous rate
0	12,716	3,179	-	-
100	20,621	5,155	19.76	19.76
250	20,918	5,230	13.67	1.5
300	25,359	6,340	10.54	7.4
450	25,318	6,330	7.00	0.1
600	25,589	6,392	5.36	0.4

Table 4: Mean and extent of monthly variations of the yields (Kg wt)

Item	*Mean*			*CV (%)*		
	0	NPKS 25:5:5:5 at 300 kg N ha^{-1}	NPKS 20:10:10 at 300 kg N ha^{-1}	0	NPKS 25:5:5:5 at 300 kg N ha^{-1}	NPKS 20:10:10 at 300 kg N ha^{-1}
Monthly yield (kg mt ha^{-1})	278	549	561	40.3	42.3	40.1

Effects of splitting fertilizer

During the first year of comparing different rates of NPKS 25:5:5:5 and NPK 20:10:10, it was observed that at low rates of nitrogen, the tea was yellowing after few months, reminiscent of nitrogen deficiency. An experiment was initiated to find out if the yields could be improved by splitting fertilizer application. NPKS 25:5:5:5 was applied at 100, 200, 300, 400, 500 and 600 kg N ha^{-1} $year^{-1}$ applied as single, split into three at four months intervals. As in the previous trial, there was yield response to different rates of NPKS 25:5:5:5 (Table 5). The rates applied produced significantly ($P \leq 0.05$) higher yields than 100 kg N ha^{-1} $year^{-1}$ which was the lowest rate used in the trial. Mean data generated in one pruning cycle or mean data for the six years (Table 6) showed the same trend as the annual yield data. In the six years of experimentation, all rates above 200 kg N ha^{-1} $year^{-1}$ did not produce yields significantly ($P \leq 0.05$) higher that those realised at 200 kg N ha^{-1} $year^{-1}$. This is significant as it demonstrates that applying fertilizers beyond this rate may not be economical in Kenya even for the high yielding cultivars like S15/10.

Splitting the annual fertilizer application did not cause annual yield differences (Tables 5 and 6). Yields of tea in Kenya may not be improved by splitting the annual fertilizer application. Throughout the trial there were no significant interactions between fertilizer rates and mode of application, showing that the response to fertilizer was not affected by splitting the nitrogen fertilizer rates. The lack of significant yield response to splitting annual fertilizer application has other implications. The annual fertilizer regimes as practised now are designed to concur with the financial years of the companies or tea organisations. It is not established if this is the most economical way of applying fertilizers to tea. Indeed, it is not known if tea plants can maintain the yields if the intervals of fertilizer applications are lengthened to more than 12 months. There is need for studies to establish the optimal fertilizer application interval for high tea production. This may save tea farmers revenue and conserve the environment as application of nitrogenous fertilizers are known to reduce soil pH and cause other soil nutrients imbalances (Venkatesan *et al* 2004, Bonheure and Willson 1992), leading to soil quality degradation. Yields recorded showed that spitting fertilizers also had no effect on monthly yield distribution (Owuor, 19912b). At low rates (100 and 200 kg N ha^{-1} $year^{-1}$) of fertilizer application the splitting fertilizer produced slightly less yields, but this did not reach significant levels. Overall there was no yield benefit in splitting the fertilizer application (Owuor, *et al* 1992). Even the distribution of crop did not change due to splitting fertilizer application (Owuor, *et al* 1990a, 1991; 1992). The experiment demonstrated that even for high yielding tea, splitting annual fertilizer application should be done for other reasons like cash flow management, storage, adequate availability of fertilizers, and more uniform distribution of fertilizer on the ground, etc. This experiment was therefore transformed to measure the effect of plucking frequency while the plots continued to receive same fertilizer rates at single annual application.

Table 5: Yield response of clone S15/10 to rates on NPKS 25:5:5:5 fertilizer in different years

Year	Split	Nitrogen rates (kg N/ha/Year)						Mean split
		100	200	300	400	500	600	
1986	Once	4690	5527	5253	5626	6312	6042	5575
	Split/2	4671	5654	5063	5858	5957	5867	5512
	Splt/3	4548	5196	4969	5243	5649	5919	5254
	Mean N rates	4636	5459	5095	5576	5973	5943	
	Cv (%)			7.43				
	LSD, P≤ 0.05			761				503?
	Interactions			NS				
1987	Once	7290	8737	8463	8534	9453	9219	8616
	Split/2	7163	8808	8581	8836	9022	9063	8577
	Splt/3	6898	8416	8614	8860	9489	9668	8657
	Mean N rates	7117	8653	8553	8743	9318	9317	
	Cv (%)			6.09				
	LSD, P≤ 0.05			997				NS
	Interactions			NS				
1988	Once	5555	7087	6822	6799	7361	7002	6771
	Split/2	5834	7087	6945	6803	7262	7044	6829
	Splt/3	5697	6737	6980	6902	7413	7087	6802
	Mean N rates	5695	6970	6916	6835	7345	7044	
	Cv (%)			6.66				
	LSD, P≤ 0.05			807				NS
	Interactions			NS				
1989	Once	2014	2671	2747	2359	2945	2605	2557
	Split/2	2108	2690	2756	2482	2841	2732	2602
	Splt/3	2032	2525	2860	2293	2912	2789	2569
	Mean N rates	2052	2629	2788	2378	2900	2709	
	Cv (%)			7.94				
	LSD, P≤ 0.05			NS				NS
	Interactions			NS				
1990	Once	3719	5083	4516	4361	4919	5078	4613
	Split/2	3546	5115	4428	4715	4628	4926	4560
	Splt/3	3549	4840	4521	4637	4864	4842	4542
	Mean N rates	3605	5013	4488	4571	4804	4948	
	Cv (%)			7.85				
	LSD, P≤ 0.05			948				NS
	Interactions			NS				
1991	Once	4174	5677	5590	5079	6221	6062	5467
	Split/2	4347	5776	5377	5087	6083	5941	5435
	Splt/3	4036	5604	5567	5101	6141	6263	5452
	Mean N rates	4185	5686	5511	5089	6148	6089	
	Cv (%)			8.25				
	LSD, P≤ 0.05			858				NS
	Interactions			NS				

Table 6: Long term mean yield response of clone S15/10 to rates on NPKS 25:5:5:5 fertilizer in different years

Year	Split	Nitrogen rates (kg N/ha/Year)						Mean Split
		100	200	300	400	500	600	
Pruning	Once	4887	6006	5821	5829	6518	6217	5880
cycle	Split/2	4944	6060	5837	5995	6268	6177	5880
(1986-	Splt/3	4794	5718	5850	5825	6366	6366	5820
1989)	Mean N rates	4875	5928	5836	5883	6384	6253	
mean	Cv (%)			5.96				
	LSD, P≤ 0.05			657				NS
	Interactions			NS				
1986 –	Once	4574	5797	5565	5460	6202	6001	5560
1991 mean	Split/2	4612	5855	5525	5630	5964	5929	5586
	Splt/3	4460	5553	5581	5506	6078	6095	5545
	Mean N rates	4548	5735	5557	5532	6081	6008	
	Cv (%)			5.95				
	LSD, P≤ 0.05			477				NS
	Interactions			NS				

Table 7: Effects of rates and frequency of plucking on yields of clone S15/10

Year	Plucking frequency (days)	Nitrogen rates (kg N/ha/year) 100	200	300	400	500	600	Mean frequency
1993	7	3236	4756	4393	4841	4981	4773	4497
	14	3152	4352	5250	4305	4903	4542	4251
	21	3466	5265	5095	5026	4899	5303	4842
	Mean	3285	4791	4579	4724	4982	4873	
	Cv (%)			10.66				
	LSD, (P ≤0.05)			279				394
1994	7	6060	6372	6184	6254	6352	6460	6280
	14	5950	6134	5408	5484	6281	5867	5854
	21	5938	6465	5950	5721	6294	6218	6097
	Mean	5983	6324	5847	5820	6309	6182	
	Cv (%)			9.60				
	LSD, (P ≤0.05)			338				NS
1995	7	6621	7512	7479	7365	7316	7217	7252
	14	5893	6512	6306	6723	6931	6805	6528
	21	6254	7110	6874	6971	7439	6940	6931
	Mean	6256	7045	6887	7019	7228	6988	
	Cv (%)			7.9				
	LSD, (P ≤0.05)			316				447
1996	7	7805	9071	8747	9514	8843	9200	8487
	14	6602	7616	7072	7893	7396	7893	7412
	21	6257	7186	6791	7604	7198	7699	7122
	Mean	6888	7958	7537	8337	7812	8264	
	Cv (%)			8.4				
	LSD, (P ≤0.05)			379				536
1997	7	3699	4370	4323	4523	4416	4332	4277
	14	2927	3644	3260	3635	3711	3494	3448
	21	2579	2992	2809	2834	2961	2938	2852
	Mean	3068	3675	3464	3664	3696	3588	
	Cv (%)			7.4				
	LSD, (P ≤0.05)			213				151
1998	7	6136	8110	8060	8445	8226	8439	7903
	14	5349	7694	6850	7476	7874	7697	7155
	21	5682	7514	7406	7384	7569	8226	7297
	Mean	5723	7773	7439	7767	7889	8120	
	Cv (%)			7.1				
	LSD, (P ≤0.05)			559				343
1999	7	5816	7954	7923	8441	8261	8228	7771
	14	4931	7049	7049	7460	7680	7401	6928
	21	5567	7496	7876	8188	7812	8446	7564
	Mean	5438	7499	7616	8030	7918	8025	
	Cv (%)			9.9				
	LSD, (P ≤0.05)			425				601
2000	7	5007	6828	7049	7081	7193	6837	6666
	14	4556	6343	6454	6201	6910	6700	6194
	21	4718	6651	6436	6702	7205	6750	6410
	Mean	4760	6607	6646	6661	7102	6762	
	Cv (%)			9.7				
	LSD, (P ≤0.05)			365				NS
2001	7	4737	5786	5068	5626	5550	5541	5385
	14	4264	5351	4406	4973	5011	4822	4805
	21	3933	5172	4245	4794	4822	4870	4639
	Mean	4312	5436	4573	5131	5128	5078	
	Cv (%)			8.21				
	LSD, (P ≤0.05)			946				426
2002	7	6677	9401	8704	8730	8706	8361	8430
	14	6080	8184	7947	8557	8155	7902	7798
	21	6427	8372	8283	7666	8306	8176	7872
	Mean	6395	8640	8311	8318	8389	8146	
	Cv (%)			7.21				
	LSD, (P ≤0.05)			608				NS

Effect of plucking rounds

As with the other two trials, there were significant ($P \leq 0.05$) yield responses to rates of nitrogen (Table 7). But like Trail II, the difference was between the lowest rate (100 kg N ha^{-1} year^{-1}) and 200 kg N ha^{-1} year^{-1}. There were no significant differences between 200 kg N ha^{-1} year^{-1} and higher rates used in the trial. These results reaffirm the earlier observation that applying over 200 kg N ha^{-1} year^{-1}may not be economical. At the different rates of nitrogen application, plucking rounds were 7, 14 and 21 days. All leaf on offer was harvested to conform to commercial estates practice. The effects of the rates and varying plucking frequency on yields are presented in Table 7. As in other trials in the series (Kamau *et al* 2004; Owuor *et al* 1990, 1992; Owuor & Othieno, 1996) there was quadratic yield response to fertilizer rates (Owuor *et al* 1997). The pattern was the same irrespective of the frequency of harvesting. In all the years, except 1994 and 2000, there were significant yield responses to varying harvesting intervals. The 7 day plucking interval produced the highest yields. These results are similar to other observations on lower yielding tea cultivars (Balasuriya 1996, 1999, Odhiambo 1989). The results demonstrate that shortening plucking rounds from the recommended 10 to 12 days (Carr *et al* 1992, Anon 2002) to 7 days produces higher yields than longer harvesting intervals on the high yielding cultivar S15/10.

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