RESEARCH ARTICLE

Influence of Nitrogenous Fertilizer Rates and Plucking Intervals on Tea in Peatland and Highland Ultisol Soils of Rwanda: 1 Tea Yields

Wilson Dufitumukiza[1,*], P. Okinda Owuor[2], Joseph Bigirimana[1], Ange R. Akingeneye[1], Balthazar Murenzi[1]

Abstract

Tea in Rwanda, is grown in different agro-ecosystems comprising highlands and drained low elevation peatlands. The plantations use uniform agricultural practices imported from Eastern Africa countries, but without re-testing for suitability. The practices include nitrogenous fertilizer use and harvesting, which are most expensive agronomic inputs in tea cultivation. These practices need optimization for tea the growers to realise maximum tea production. Trials were conducted for eight years using clone TRFK 6/8 fields in Kitabi and Mulindi to evaluate influence of nitrogen fertiliser rates and plucking intervals on tea yields. Nitrogen (NPKS 25:5:5:3) rates used were 0, 75, 150, 225 and 300kg N/ha/year and plucking intervals were 7, 14 and 21 days. Tea yields were higher ($p \leq 0.05$) in Kitabi than in Mulindi, implying tea productivity in Rwanda vary with geographical region of production. Although mean site yields demonstrated increase ($p \leq 0.05$) with nitrogenous fertiliser rates, responses varied between the two sites. At Kitabi, annual yields increased ($p \leq 0.05$) with nitrogen rates, peaking at 225 N ha/year. At Mulindi, significant ($p \leq 0.05$) response to nitrogen rates was observed in only one year. Application of fertiliser was therefore necessary in Kitabi, while in Mulindi, little benefit was realised from nitrogen fertiliser use. Yields increased ($p \leq 0.05$) with short plucking intervals at both sites throughout the eight years. Shortening plucking intervals can therefore improve tea production in Rwanda.

Keywords: Region of production, nitrogen fertiliser; tea harvesting; yield response

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Introduction

Rwanda tea is produced in highlands at altitudes ranging from 1550 m.[1] to 2700 m. above mean sea level (a.m.s.l.).[2] The tea soils in this elevation range in East Africa and most of tropical tea growing countries are classified as Acrisols and Ferralsol.[3-4] Such soils are highly weathered, acidic, leached and devoid of nutrients.[5] In Rwanda tea is also grown on well drained marshes including peatlands. In such tropical ecosystem, soils were generally developed from peats of ombrogenous and oligotrophic nature, that are commonly acidic with pH in the range of 3 to 4.5[6] and have low nutrients content.[7] Due to conversion of native lands into agricultural use, the physical and chemical properties of the soils the highlands have changed,[8] as the soils are vulnerable to leaching, surface run-off and erosion while the peat low lands are vulnerable to flooding, soil erosion and have become nutrient-impoverished.[9] Apart these as sources of nutrient losses, soil nutrients are also lost from tea plantations through harvesting, removal of pruning residues, leaching, fixation and uncontrolled weeds.[3,5,10-12] Consequently, tea growing is thought to require high fertilizer inputs to replenish lost nutrients and meet the crop nutrient demand for higher productivity and conservation of agroecosystems.[13] Fertiliser application may therefore be an important approach in balancing nutrient cycling for sustainable tea production. However, the fertilizer requirements for tea in Rwanda to maintain production and long-term soil fertility is not documented.

The most costly agronomic inputs in tea cultivation are harvesting[14] and nitrogenous fertilizer application.[14-15] Both inputs influence yields and quality.[14,16-17] Nitrogen is the most important nutrient element in tea cultivation and it is required in large quantities, accounting for approximately 3–5%[18] of the dry weight of the harvested shoots. Yield responses to nitrogen application have been recorded in many tea growing countries.[10,14,19-20] For production of black tea, fertiliser recommended rates are in the range 80-300 kg/ha/year,[14] but the exact amount also depends on quantity of leaf harvested.[5] In Kenya, practiced fertiliser use range from 100 to 300 kg N/ha/year but the rates from 100 to 150 kg N/ha/year are most economic for most tea cultivars.[21-22] Despite the recommendations, even in a single cultivar receiving uniform fertiliser rates, yields vary with location of production.[16,19,23] Although Rwanda tea growers have adopted the recommended fertilizer rates from Kenya, it is not documented if the rates are appropriate in tea growing environment of Rwanda.

Harvesting (plucking) the young tender shoots of tea plant to make tea beverages is labour intensive and costly. In India, harvesting requires 71% of tea plantation work force[24] and constitutes 70% of the total costs of field operations.[25] Despite the high costs, the undertaking is indispensable and its incorrect operations leads to farming losses as it affects yield[16,26-27] and/or quality.[17,21,28] In Kenya, the recommended plucking interval varies from 7 to 14 days,[29] while in Malawi, 10/11 days plucking intervals are practiced during peak period and 14 days in the off season.[30] A plucking interval of 10 to 14 days is generally used in Rwanda

[1]Rwanda Agriculture and Animal Resources Development Board (RAB), Rwanda, P. O Box 5016, Kigali, Rwanda

[2]Department of Chemistry, School of Physical and Biological Sciences, Maseno University, P.O. Box 333 - 40105, Maseno, Kenya

Corresponding Author: Wilson Dufitumukiza, Rwanda Agriculture and Animal Resources Development Board (RAB), Rwanda, P. O Box 5016, Kigali, Rwanda, e-mail: wdufitumukiza@yahoo.fr

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commercial tea production. While the effects of harvesting intervals on tea yields have been established in some tea growing countries [17, 23, 30-32] this has not yet been documented for Rwanda. Similarly, it is not documented if such yield responses may change at different rates of nitrogen fertiliser application and geographical area of production in Rwanda. The objective of this study was to determine the influence of nitrogenous fertilizer rates and harvesting intervals on tea yields in lowland peat soil and highland Ultisol of Rwanda.

Materials and Methods

Trials were established in 2009 in existing fields of mature tea plantations of Kitabi, in Nyamagabe District (latitude: 2°32'S, longitude: 29°26'E, altitude 2231 m a.m.s.l.) and Mulindi, Gicumbi District (latitude: 1° 27'S, longitude: 30°1'E; altitude 1800 m. a.m.s.l.). The site of Kitabi was located on top of hill locally named Nyarusozi, while the site of Mulindi, locally named Nyamulindi II was situated in marshland. The sites represent major characteristics of the plantations in the two respective areas. At each site, a 5 x 3 factorial experiment was laid out in a randomized complete block design and replicated 3 times. Treatments consisted of nitrogen rates at 0, 75, 150, 225 and 300kg N/ha/year, applied as NPKS 25:5:5:3 in October/November every year in single annual dose and plucking at 7, 14 and 21 days intervals. Each plot comprised 48 plants of clone TRFK 6/8, surrounded by a row of guard rows. Tea was planted in 1982 at Kitabi and 2003 at Mulindi, at spacing of 1.20 m x 0.6 m and 1 m x 0.60 m corresponding to plant populations of 13889 and 16667 plants per hectare, respectively. Plucking was done as per the experimental schedules. Yield data comprising two leaves and a bud harvested at respective intervals was transformed to made black tea from green leaf using a conversion factor 0.225.[29] Recorded data were subjected to analysis of variance (ANOVA) using the Genestat (13th Edition) and means separated by Least Significant Differences (LSD)

Results

There were differences in annual yields with geographical area of production (Figure 1). In the eight years of the study, the differences were significant ($p \leq 0.05$) in five years, with higher yields in Kitabi than in Mulindi. There were no any two years when the annual yields were equal. For the mean yields in 8 years, Kitabi produced yields which were higher ($p \leq 0.05$) than Mulindi.

The yield responses to rates of nitrogenous fertiliser at Kitabi and Mulindi during the eight years of experimentation are presented in Figures 2a and 2b. There were significant ($p \leq 0.05$) increase in yields every year in Kitabi. However, the yields in Mulindi increased ($p \leq 0.05$) with rates of nitrogen in 2012 and 2013 (Figure 2a). In the other years there were no responses to nitrogen. Due to the effects in Kitabi, mean annual yields should increase ($p \leq 0.05$) in yields due to rates of application of nitrogenous fertilisers.

For the eight year mean, yields increased ($p \leq 0.05$) with increase on nitrogenous fertiliser rate up to 225 kg N/ha/year in Kitabi. Whereas, the eight year annual yield also showed a significant ($p \leq 0.05$) response, the pattern of the responses was not systematic. The mean of all the data showed yield increase ($p \leq 0.05$) with nitrogen fertiliser even up to 300 kg N/ha/year (Figure 2b).

The responses to plucking intervals was more systematic. In all years, yields increased with shortening of plucking intervals (Figure 3). The increase was significant ($p \leq 0.05$) in Kitabi in all years, and in Mulindi, in all years, except 2012, which was a pruning year.

The mean yield data for eight years were used to generate a production function using a quadratic model. The results are summarized in Table 1. The regression coefficients were higher for Kitabi than Mulindi. Indeed, in Mulindi, the 14 days plucking interval produced very relationship between yields and rates of nitrogen. From the results were used to generate predicted returns of tea when applying various rates of nitrogen. Returns from applying nitrogenous fertilizer were higher in Kitabi than in Mulindi. Better returns were obtained by harvesting at short plucking intervals. In Kitabi, at 7 days plucking intervals, increasing rate of application increased returns per kilogram nitrogen applied even up to 300 kg N/ha/year. However, after the initial rate of 25 kg N/ha/year, the returns form applied nitrogen declined with rates on nitrogen,

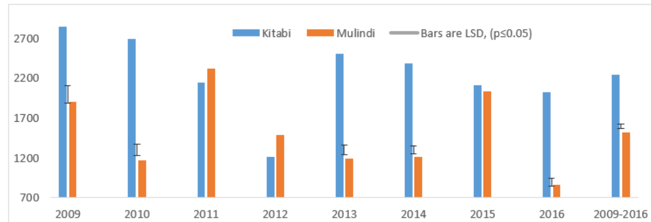

Figure 1: Influence of geographical area of production on tea yields (kg mt/ha/year) in different years.

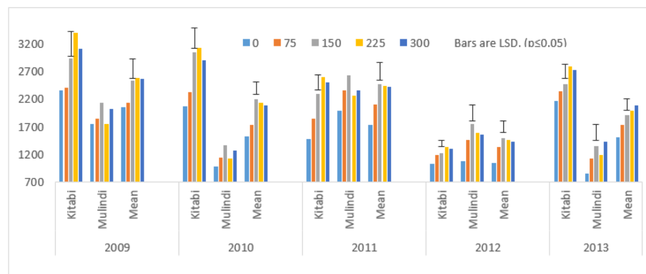

Figure 2a: Influence of rates of nitrogen (kg N/ha/year) on tea yields (kg mt/ha/year) between 2009 and 2013

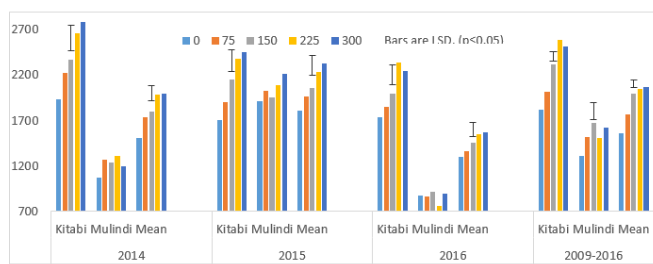

Figure 2b: Influence of rates of nitrogen (kg N/ha/year) on tea yields (kg mt/ha/year) from 2014 to 2016 and 2009 to 2016 Mean

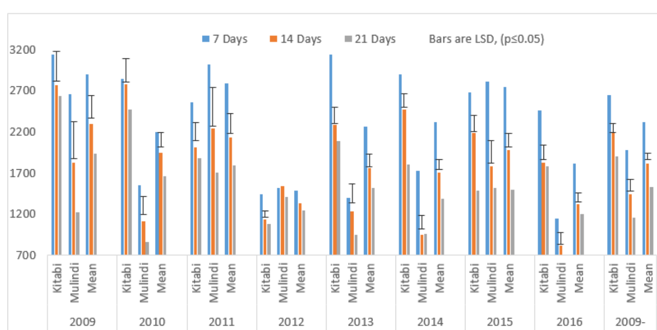

Figure 3: Changes in annual tea yields (kg mt/ha/year) due to plucking intervals in Kitabi and Mulindi for eight years

Table 1: Predicted return of tea (kg made tea/kg N/ha/year) by applying various rates of nitrogen at various harvesting intervals (Kitabi)

	Kitabi						*Mulindi*					
	7 day interval		*14 day interval*		*21 day interval*		*7 day interval*		*14 day interval*		*21 day interval*	
Rate (Kg N/ Ha/year)	*Expected Yield*	*Response (kg yield/ kg N)*	*Expected Yield*	*Response (kg yield/ kg N)*	*Expected Yield*	*Response (kg yield/ kg N)*	*Expected Yield*	*Response (kg yield/ kg N)*	*Expected Yield*	*Response (kg yield/kg N)*	*Expected Yield*	*Response (kg yield/ kg N)*
0	2272		1669		1368		1649		1384		957	
25	2323	2.0	1801	5.3	1531	6.5	1782	5.3	1405	0.9	995	1.5
50	2377	2.2	1922	4.8	1675	5.8	1896	4.5	1424	0.7	1031	1.5
75	2433	2.3	2030	4.4	1801	5.0	1990	3.8	1439	0.6	1067	1.4
100	2493	2.4	2128	3.9	1909	4.3	2064	3.0	1450	0.5	1101	1.4
125	2555	2.5	2213	3.4	1998	3.6	2119	2.2	1459	0.3	1134	1.3
150	2621	2.6	2287	3.0	2068	2.8	2154	1.4	1464	0.2	1166	1.3
175	2689	2.7	2349	2.5	2120	2.1	2170	0.6	1466	0.1	1197	1.2
200	2760	2.8	2400	2.0	2154	1.3	2166	-0.2	1465	-0.1	1227	1.2
225	2834	3.0	2439	1.6	2169	0.6	2142	-0.9	1460	-0.2	1255	1.1
250	2910	3.1	2467	1.1	2165	-0.1	2099	-1.7	1453	-0.3	1283	1.1
275	2990	3.2	2483	0.6	2143	-0.9	2036	-2.5	1441	-0.4	1309	1.1
300	3073	3.3	2487	0.2	2100	-1.7	1953	-3.3	1427	-0.6	1334	1.0

Kitabi:

$Y_{(7\ day\ interval)} = 0.0023x^2 + 1.9785x + 2272.3, (R^2 = 0.8823)$
$Y_{(14\text{-}day\ interval)} = -0.0093x^2 + 5.516x + 1669, (R^2 = 0.8776)$
$Y_{(21\text{-}day\ interval)} = -0.0148x^2 + 6.8893x + 1368, (R^2 = 0.7213)$
Y= yield (kg mt/ha/year), x = rate of nitrogen (Kg N/Ha/year)

Mulindi:

$Y_{(7\text{-}day\ interval)} = -0.0157x^2 + 5.7246x + 1649.4, (R^2 = 0.6867)$
$Y_{(14\text{-}day\ interval)} = -0.0026x^2 + 0.924x + 1383.8, (R^2 = 0.0975)$
$Y_{(21\text{-}day\ interval)} = -0.0009x^2 + 1.5278x + 956.46, (R^2 = 0.5435)$
Y= yield (kg mt/ha/year), x = rate of nitrogen (Kg N/Ha/year)

Figure: Production function for annual mean (eight years) response of clone TRFK 6/8 to rates of nitrogenous fertilizers at different harvesting intervals (Mulindi site) becoming negative at 250 kg N/ha/year at 21 days plucking interval. The return from applied nitrogen declined with increase in rates on nitrogen application at all plucking intervals. At 7 days and 14 days plucking intervals, the returns became negative at 225 kg N/ha/year.

Discussion

Although tea plants respond to growing environments differently,[33-36] agronomic input recommendations are fairly uniform over wide areas.[29] In previous studies, yields of most tea cultivars decreased with rise in altitude,[37-40] although some cultivars were stable in yield responses to altitudes.[35,40-41] The pattern of yield response to altitude of production in this study was at variance with the previous studies. Yields were higher in higher altitude (Kitabi) than low altitude (Mulindi) (Figure 1). The differences in yields were partly attributed to the types of soil in the two areas. The soil at Kitabi free flowing ultisol on top of a hill while the Mulindi site peat soil was situated in marshland. The Mulindi site had high water table and was susceptible to frequent flooding and water logging. Tea growth on such soils are problematic,[42] and it is necessary to drain the soils to enable the tea plants to grow. These results demonstrated that returns from growing tea in these two sites cannot be equal even with equivalent inputs.

Tea yield responses to nitrogenous fertiliser is widely reported.[2,17,43]. Such responses vary with geographical area of production.[2,19] In the previous study, better response to nitrogenous fertiliser was reported at lower altitude than higher altitude.[2] Yield response to N rates varied differently at the two sites. Unlike the previous studies,[2,19] response to nitrogenous fertiliser rates were obtained at higher altitude. In the lower altitude are response ($p \leq 0.05$) to nitrogen fertiliser rate as observed only in two years out of the eight years of experimentation (Figure 2). On the other hand, yield response to nitrogen rates was significant ($p \leq 0.05$) in Kitabi in all years. The response was up to 300 kg N/ha/year in most year. The favourable response to nitrogen fertiliser rates in Kitabi caused significant ($p \leq 0.05$) in all years. These results suggest that whereas it may be economic to apply nitrogen fertiliser in Kitabi, in Mulindi such applications may not be giving economic returns. Earlier, the lower yields at Mulindi compared to Kitabi were attributed to the nature of the soil. The peat soils in Mulindi with high water table leading to frequent flooding and leaching was possible responsible for the lack of response to nitrogen fertilisers rates in Mulindi. It is likely that most of the applied fertiliser were being leached and/or washed as surface run off from such soils.[42]

Yields varied ($p \leq 0.05$)) with plucking intervals, similar to previous studies.[17,32,44-45] at both sites, highest yields were obtained at 7 days plucking interval, and yields declined with long plucking intervals. In previous studies ,the number of harvested shoots per surface unit area and mean harvestable shoot weights were lower for shorter harvesting interval than longer harvesting intervals at each plucking round. However, the total (cumulative) leaf weight per annum from shorter harvesting interval far outweighed yield from longer harvesting interval due to more harvestings.[17,32,44-45] These results suggest that tea production Rwanda can derive more benefits from shorter plucking intervals than longer ones.

Similar studies on the response of tea quality to harvesting intervals, related studies showed that shorter harvesting intervals produce better black tea quality[17, 31,45-46] and gross and net income per hectare[47] as compared to longer intervals. The results presented here demonstrate the benefits of shortening the present plucking intervals in Rwanda to shorter than the 10 – 14 days currently practised.

There were no significant interactions effects on yields between nitrogenous fertilizer rates and plucking intervals throughout all the experimental period. A similar finding was observed in a study conducted at eight sites within East African countries.[48] The results suggest that a best plucking interval should be used in tea plantations in Rwanda irrespective of applied fertilizer rate.

Agronomic input is only worth applying if it yields a positive return. The magnitude of responses to fertiliser rates varied with sites and plucking intervals. The eight year mean data from the different plucking intervals were used to estimate returns from applying fertiliser (Table 1). At different plucking intervals the return of applying an extra 1 kg N/ha/year were low. In some tea growing region, a minimum satisfactory profit margin from applying nitrogen fertilizers to tea is 5-10 kg made tea per kg N applied.[2,49] The responses in this study were below 5 kg mt/kg N applied. The results implied that tea growers of Rwanda were not benefiting adequately from applying nitrogenous fertilizers. Despite the significant responses observed in Kitabi, the responses did not reach a point where the present fertiliser application rates could be justified. Although margin profit margin will vary from year to year depending on costs of production and world tea prices [2], present results imply that tea growers of Kitabi should not apply beyond 100 kg N/ha/year. Tea yields at Mulindi were not responding to nitrogenous fertilizers. This suggests that that fertilizers applied to tea in Mulindi are only sustaining the plants without economic benefits in Mulindi. Fertiliser application in Mulindi should therefore not exceed 50 kg N/ha/year.

Conclusion

Tea yields are higher in Kitabi than Mulindi even when agronomic inputs are similar. Production of tea in the highlands sites similar to Kitabi are therefore likely to give farmers economic power compared to growing tea in marshland similar to Mulindi. Although farmers use nitrogen fertiliser at rates beyond 100 kg N/ha/year, such rates are too high. Farmers need to applying only up to 100 kg N/ha/year in areas like Kitabi and rates up to 50 kg N/ha/year in Mulindi. Indeed, in Mulindi there is no response to applied nitrogenous fertiliser. The short plucking intervals (7 days) produced highest yields at both sites. Adoption of shorter than 10/12 days currently in use in Rwanda is recommended and will increase production. It is necessary that studies are undertaken to understand factors that contribute to low response to nitrogenous fertilisers in Rwanda despite using recommended agronomic inputs from Kenya (Anon 2002). It may be the inputs, including the tea cultivars are not appropriate for Rwanda.

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