RESEARCH ARTICLE

Comparative Economic Analysis of Clonal Tea Yield Response to Nitrogen Fertiliser Rates within Selected Geographical Areas in Kenya

Rosebell A. Owuor[1; *], Alphonce J. Odondo[2], P. Okinda Owuor[3], David M. Kamau[4]

Abstract

Tea sector contributes approximately 30% of export earnings in Kenya. Despite the industry continuing to realize positive gross margins, high costs of production coupled with weak trends in export prices threaten its future contributions. Nitrogen fertiliser is mandatory in tea production and its appropriate use promotes tea growth rate and yields. Previous studies using different tea cultivars established that optimal fertiliser rates varied with clones and geographical area of production. However, economics of nitrogenous fertilisers use on same tea cultivar in different tea growing regions in Kenya remains undefined. This study evaluated response of NPKS 25:5:5:5 fertiliser applied at 0, 75, 150, 225 and 300 kg N/ha/year on clone BBK35 to determine the viable economic rate under uniform management in different locations (Karirana, Timbilil, Changoi, Sotik Highlands and Kipkebe) within Kenya. The study used time series tea yield data and corresponding variable costs from field experiments running from 1997 to 2007. The data were subjected to Partial Budget Analysis (PBA) procedures for economic analysis of on-farm experiments. The economic returns varied with rate of nitrogen and region of production. Maximum marginal rate of return (MRR) were achieved at 75 kg N/ha/year at Kipkebe, Changoi and Timbilil, and 150 at Sotik Highlands and Karirana. However best economic returns were recorded at 300 kg N/ha/year in Kipkebe and Sotik Highlands, 225 kg N/ha/year in Changoi, and at 150 kg N/ha/year in Timbilil and Karirana. These results demonstrate that current uniform fertiliser recommendation rate of 100 to 220 kg N/ha/year may not be suitable for all regions. There is need to develop region specific nitrogen fertiliser requirements for tea growing areas in Kenya.

Keywords: Tea yield, Economic Analysis, Partial Budget Analysis, Nitrogen Application Rates, Geographical Areas, Kenya.

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Introduction

Tea (*Camellia sinensis* (L) Kuntze) is the second leading foreign exchange earner after coffee in Kenya.In 2019, the tea sector contributed approximately 30% of the country's export earnings.[1] While the industry realizes positive gross margins, its future contributions to the economy is threatened by high costs of production coupled with weak trends in export tea prices.[2] In tea production, use of nitrogenous fertiliser is the second most expensive agronomic input after plucking.[3] Appropriate use of nitrogenous fertiliser increases tea yields through enhancement of growth rate and leaf density.[4-8] Nevertheless, leaching, surface run offs, fixation and removal with crop contribute to nutrients losses necessitating the need for continuous nutrients replenishment through fertiliser application to ensure continuous economic production.

NPKS 25:5:5:5 or NPK 20:10:10 are the recommended fertiliser formulation for tea in Kenya,[9] at rates between 100 and 250 kg N/ha/year for maximum yield, the actual rate being dependent on the production level.[10] The recommended rates were based on yield responses of experiments conducted at single sites, mostly on seedling. However, most of tea produced in Kenya are now clonal plants[11] suggesting the recommended rates may not be appropriate. Most trials have demonstrated variations in tea yields,[12-15] black tea quality[8,12,16] and other tea attributes[16-19] responses to nitrogenous fertiliser due to cultivars grown in a single site. Such variations in responses were much larger at the various tea growing environments, even with use of a single cultivar under same management practices.[6,8,18-20]Despite the variations, the same fertiliser use recommendations are embraced throughout the tea growing regions in Kenya and East Africa.[9, 10]

Although several studies have evaluated yield[8,21-23] and quality[7,8,16,19,20] responses to tea in Kenya, few studies evaluated the economic response.[13,24,25] The studies evaluated economic responses of seedling or clonal tea at single sites. These results of economic analysis of nitrogenous fertiliser use in Kenya using data from single site studies demonstrated that the optimum economic rate was much lower than the recommended yield rate at between 110 and 220 kg N/ha/year.[24,26]For this purpose, the optimum economic rate was defined as the point where the marginal cost (MC) of the specific fertiliser rate is equal to the marginal revenue (MR).[26,27]It was not possible to discern if these responses could be replicated in different tea growing locations. Where the economic evaluations were conducted at multiple sites, the cultivars were not uniform,[13,24,25] making it difficult to isolate effects arising from the localities and cultivars. This study compared the response of clone BBK35 to nitrogenous fertiliser application rates in five

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tea-growing locations of Kenya, thereby determining the most economically efficient application rate for single genotype under uniform management.

Methodology

Study area and research design

The study used long-term tea yield data obtained from field experiments[20] conducted from the year 1997 – 2007, in five tea-growing regions in Kenya (Karirana, Timbilil, Changoi, Sotik Highlands and Kipkebe) using Clone BBK 35(Table 1).Clone BBK 35 fields, that had been uniformly managed and with known past cultivation histories were selected in each location.

At each site, a randomized complete block design laid out and replicated 3 times, with locations as main treatments and five nitrogen fertiliser application rates (0, 75, 150, 225 and 300 kg N/ha/yearas NPKS 25:5:5:5) as sub-treatments. Before the experiment commenced, all the plots received 150kg N/ha/year. Each plot had 60 tea bushes in a 6 × 10 plants format. During the duration of the experiment, pruning took place every four years and fertiliser treatments were applied in November of each year. Green leaf from each plot was plucked using the recommended standard of two leaves and a bud and commenced in November 1997.

Data collection and analysis.

Young tender shoots comprising mostly of two leaves and a bud were harvested and weighed per experimental plot after every 7 days. Annual average yield data[20] from the plots were converted from made tea (mt) per hectare to green leaf yield using a conversion factor of 0.225[10] then multiplying by 0.9 to adjust the yield to better approximate smallholder yields.[28,29] Downward adjustment of green leaf yield was a necessary precaution against possible overestimation of the returns that smallholder tea growers were likely to get from the treatments. The over estimation could be ascribed to the fact that experimental plots generally have better management levels, smaller plot sizes and higher precision in plucking than smallholder tea farms. Unit costs of agronomic inputs (labour plucking costs, fertiliser application and cess), were obtained from the Tea Research Institute[30] reports and averaged over the ten years of the study period (Table 2). Similarly, average net auction prices of tea were obtained from the International Tea Committee Annual Bulletins.[31,32] Monetary values were converted from the local currency (Kenya Shillings (KSH)) at a rate of 73.43 KSH/USD, which was the average exchange rate based on data from Central Bank of Kenya[33] and the International Tea Committee[31,32] during the study period.

Results from[20] on average yield response of clone BBK 35 showed significantP≤0.05) interaction effects between varying rates of nitrogenous fertiliser and geographical area of production. On this basis, average yield data from each tea growing region were analysed using partial budget and marginal analysis[29] to evaluate and compare the economic returns (net benefits) of tea production under the different nitrogenous fertiliser application rates, using production costs listed in Table 2.

Three economic indicators were computed in the economic analysis of the data: (i) Net Benefits (NB),(ii) Marginal Rate of Return (MRR) and (iii) Residuals.Net benefits were calculated to allow for comparison among different treatments, while the purpose of marginal analysis was to compare variables costs with net benefits. MRR was defined as the change in net benefits (marginal net benefit) divided by the change in costs that vary (marginal cost), expressed as a percentage. The marginal rate of return indicated how much gain was expected on average, in return for investment when a decision was made to change from one practice/treatment (or set of practices) to another.

As part of the partial budgeting procedure,[29] gross benefits (Equation 1) and total variable costs (Equation2) per rate of nitrogen fertiliser application per year were first computed for each location as follows:

$$GB_{it} = Y_{it} \times P_{avg} \qquad \text{Equation 1}$$

Whereby:

GB_{it} = Gross benefits of NPKS 25:5:5:5 treatment *i* in year *t*

Y_{it} = Adjusted yield per hectare of NPKS 25:5:5:5 treatment *i* in year *t*

P_{avg} = Mean net countrywide tea price over the study period

$$TVC_{it} = C_{NPKS_{it}} + C_{App_{it}} + C_{avg\,+} C_{cess} \qquad \text{Equation 2}$$

Table 1: Experimental sites

Site	*Altitude (m a m s l)*	*Latitude*	*Longitude*
Karirana	2260	1˚6'S	36˚ 39'E
Timbilil	2180	0˚22'S	35˚ 21'E
Changoi	1860	0˚29'S	35˚ 14'E
Sotik Highlands	1800	0˚35'S	35˚ 5'E
Kipkebe	1800	0˚41'S	35˚ 5'E

m a m s l:metres above mean sea level

Source: Field experiment[20]

Table 2: Parameters used for economic analysis for the different fertiliser rates

Parameter	*Notation*	*Unit*	*Value*
Mean cost of NPKS 25:5:5:5 or NPK	$NPKS_{avg}$	USD kg^{-1}	0.53
Mean cost of application of fertiliser	APP_{avg}	USD kg^{-1}	0.02
Mean plucking cost (wage) green leaf	$WAGE_{avg}$	USD kg^{-1}	0.13
Mean cess on green leaf earnings	$C_{\%}$	(%)	1
Mean net country wide tea price	P_{avg}	USD kg^{-1}	2.55

1 USD = 73.43

Sources: Tea Research Institute,[30] International Tea Committee Annual Bulletins[31, 32] and Central Bank of Kenya.[33]

Whereby:

TVC_{it} = Total variable costs of NPKS 25:5:5:5 treatment i in year t

$C_{NPKS_{it}}$ = Cost of NPKS 25:5:5:5 computed as

$$\frac{NPKS_{avg} \times treatment_{rate}}{12.5}$$

$C_{App_{it}}$ = Cost of application of fertiliser as

$$\frac{APP_{avg} \times treatment_{rate}}{12.5}$$

C_p = Plucking cost (wage) of green leaf computed as $Wage_{avg} \times Y_{it}$

C_{cess} = Cess on green leaf earnings computed as $C_{\%} \times GB_{it}$

The net benefits (Equation 3) for each NPKS 25:5:5:5 treatment per year in each location were then derived from Equation 1 and Equation 2 as follows:

$$NB_{it} = GB_{it} \times TVC_{it} \quad \text{Equation 3}$$

Whereby:

NB_{it} =Net benefit of treatment i in year t

For economic analysis, the average net benefits (Equation 4) and average total variable costs (Equation 5) for each treatment over the years of the study were computed for each location as:

$$ANB_i = \frac{\sum_{t=1998}^{2007} NB_{it}}{n} \quad \text{Equation 4}$$

$$ATVC_i = \frac{\sum_{t=1998}^{2007} TVC_{it}}{n} \quad \text{Equation 5}$$

Whereby:

ANB_i = Average net benefits of treatment i over the study period

$ATVC_i$ = Total Variable Costs of treatment i over the study period

n = total number of years

The Marginal Rate of Return (MRR) was expressed as a percentage (Equation 6), and recommendations made based on the comparison between the treatments' MRR to the minimum rate of return acceptable to farmers.

$$MRR = \frac{\triangle ANB}{\triangle ATVC} \times 100 \quad \text{Equation 6}$$

Prior to MRR analysis, the treatments were subjected to dominance analysis by arranging the treatments in order of ascending variable total costs with corresponding net benefits. Subsequently, dominated treatments were eliminated from further analysis i.e., any treatment that had net benefits less than or equal to those of a treatment with lower total variable costs was considered dominated.[34] MRRs were only computed for dominant treatments and subsequently compared to a minimum acceptable rate of return to justify the selection of the optimum economic treatment. Studies and experience have shown that in most situations, the minimum rate of return acceptable to farmers range between 50% and 100%.[29] In this study, a 100% minimum rate of return was considered reasonable.

Residuals were also computed to corroborate findings from the marginal analysis prior to policy recommendations. The first step in the computation of residuals was to multiply the tea growers' total variable costs of each dominant treatment by the minimum acceptable MRR for each nitrogenous fertiliser treatment to obtain the returns required for each treatment. Subsequently, residuals were computed by deducting the return required from the net benefits.[29] Microsoft Excel software was used to compute all the economic indicators in the analysis.

Results and Discussion

Net benefits

Net benefits generated from partial budget analysis of clone BBK 35 yields' response to varying rates of NPKS 25:5:5:5 for the 10 years of study in different tea growing locations are in Table 3. In all the tea-growing regions, annual net benefits per hectare for all fertiliser rates, including the control, were positive. The results demonstrate that tea growing is an economically viable investment. The observation demonstrates why there are several tea expansion programmes.[35,36]However, the net benefits generated at control (0 kg N/ha/year) every year in most of the locations were the lowest compared to other treatments, demonstrating the benefits of nitrogen fertiliser use in tea production as have previously been observed using tea yields.[6-8,20]Over time, the net benefits of applied nitrogen varied across the different geographical locations. This justifies the use of nitrogenous fertiliser, similar to earlier observations from single site trials.[13,24,25]

Tea is a perennial crop with a long life span.[37] As such, variations in annual net benefits of tea suggest that recommendations based on single year could be misleading. For this reason, the long-term average of the 10-year study period was used for further economic analyses. The average net benefits data for 10 years of study are presented in Table 4. At every rate of fertiliser application, the net benefit varied with site. Similar variations had been observed in other tea parameters including yields,[6,8] yield components,[18,21] tea quality[19,20] and tea quality precursors.[17,19,38] Benefits of applying same rate of nitrogenous fertiliser therefore vary with location of production. The average net benefit varied with sites in the order; Sotik Highlands >Changoi>Karirana>Kipkebe>Timbilil (Table 4). It had been expected that the order of changes in net benefit would vary inverse to altitude since tea yields, hence growth declines as altitude increases.[39-42] However, the net benefits did not follow the same pattern. Despite the observed differences in net benefits ascribed to nitrogenous fertilisers in different regions, even in one cultivar,[5,6,20] the recommended rates of nitrogenous fertiliser is between 100 and 220 kg N/ha/year.[9,10]These results demonstrated need for development of region/location specific fertiliser use recommendations to realise maximum benefits from tea growing.

Apart from Karirana and Timbilil, all the locations recorded highest net benefits at nitrogen fertiliser application rates higher than 150 kg N/ha/year, i.e. the net benefits declined beyond 150 kg N/ha/year in the aforementioned locations. This suggested that the recommended rates of nitrogen were only appropriate at these two sites. The maximum rates applied in these trials was 300 kg N/ha/year. In Kipkebe and Sotik Highlands, it was overt that there was potential of generating more returns by adopting higher rates than the 300 kg N/ha/year. Low altitude areas with adequate rainfall, optimum growing temperature and relative humidity may require higher rates of nitrogen for realisation of maximum benefits from tea growing.[18,20] These results point to the need for revising the current nitrogenous fertiliser use recommendations to site-specific recommendations.

Dominance analysis and net benefits curves

Dominance analysis[29] was used to select nitrogenous fertiliser application rates with high potential positive net benefits. In this study, the selected and ignored treatments were referred to as dominant and dominated treatments, respectively. Total variable costs and associated net benefits used in dominance analysis of tea yield as influenced by different rates of nitrogenous fertiliser applications in the different sites are presented in Table 5. The results from dominance analysis were used to generate net benefit curves (Figure 1 to 5) for all the geographical regions. All the nitrogen fertiliser treatments in Kipkebe and Sotik highlands were dominant (Figure 1 and Figure 2respectively). On the other hand, the nitrogen fertiliser treatments of 225 kg N/ha/year and 300 kg N/ha/year were

Table 3: Annual Net Benefits Values (USD/ha/year) of clone BBK 35 from 1998 to 2007 under different nitrogenous fertliser rates

Location	*N- rate*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*
Kipkebe	0	41,404	24,128	12,117	19,640	15,773	14,155	12,949	17,094	13,667	15,553
	75	49,495	32,143	15,709	32,621	25,826	23,194	24,266	26,620	25,969	26,907
	150	51,288	36,415	17,091	42,492	34,903	28,404	23,351	36,099	32,098	32,778
	225	51,780	35,701	18,750	42,611	35,547	30,743	25,115	35,461	35,940	33,317
	300	53,362	40,327	19,912	48,089	38,240	33,866	25,722	38,614	31,694	32,775
Sotik Highlands	0	45,893	17,783	28,809	32,053	23,956	20,137	40,179	33,374	30,522	28,904
	75	49,629	23,031	34,516	42,317	34,200	26,324	51,122	44,106	40,460	41,876
	150	54,035	26,729	48,350	61,012	44,426	30,500	63,548	57,605	52,063	47,622
	225	56,919	28,494	54,871	65,648	49,310	36,026	76,320	63,035	60,547	51,205
	300	58,933	30,124	62,244	70,313	48,874	34,096	76,821	65,728	64,101	50,711
Karirana	0	41,433	31,048	22,942	20,731	35,987	33,852	34,924	48,592	17,984	35,901
	75	37,081	29,520	24,046	18,236	36,392	36,497	36,076	47,504	18,638	39,053
	150	41,497	33,266	24,681	19,197	37,707	37,717	41,028	48,312	21,417	45,211
	225	41,137	31,173	25,067	18,626	36,323	36,131	40,007	48,564	21,248	45,731
	300	42,011	34,546	26,392	19,721	41,322	31,512	38,240	41,399	20,888	45,045
Changoi	0	40,772	49,070	56,459	43,299	36,360	34,120	33,230	33,192	22,607	32,005
	75	40,201	49,141	56,884	53,007	41,283	42,077	47,408	40,489	25,883	41,723
	150	42,425	48,024	56,878	50,838	42,253	45,536	50,513	42,358	29,227	43,842
	225	40,237	51,828	61,733	50,354	41,414	48,612	59,006	45,463	26,522	41,194
	300	40,671	46,347	58,531	54,080	41,399	48,012	55,056	45,773	30,593	44,471
Timbilil	0	38,542	30,847	21,803	18,893	19,908	17,821	15,888	23,411	17,620	20,999
	75	42,996	35,722	23,165	24,036	25,606	21,787	25,376	29,224	27,233	28,601
	150	45,613	41,143	25,552	27,677	32,567	28,280	25,284	40,253	24,126	31,371
	225	46,085	40,218	21,861	25,287	32,332	23,402	22,655	41,702	24,914	33,174
	300	43,964	40,690	22,601	27,827	34,412	25,300	23,530	40,863	26,248	34,938

Source: Author's computation from filed experiment data[20]

Table 4: Mean (1998-2007) net benefits (USD/hectare/year) of clone BBK 35 for different nitrogenous fertiliser application rates at different geographical locations

	Rate of nitrogen (kg N/ha/year					
Location	*0*	*75*	*150*	*225*	*300*	*Mean location*
Kipkebe	18,648	28,275	33,492	34,497	36,260	30,234
Sotik Highlands	30,161	38,758	48,589	54,238	56,194	45,588
Karirana	32,339	32,304	35,003	34,401	34,108	33,631
Changoi	38,111	43,810	45,189	46,636	46,493	44,048
Timbilil	22,573	28,375	32,186	31,163	32,037	29,267
Mean rate	28,367	34,304	38,892	40,187	41,019	

Source: Authors computation from field experiment data[20]

dominated in Karirana (Figure 3) and Timbilil (Figure 5).A previous study[25] done in Timbilil using a blended nitrogenous fertiliser on a different cultivar recorded dominant rate of 225 kg N/ha/year. This indicated that economic nitrogen application rates vary among different cultivar for even in the same location. Most of the nitrogenous fertiliser application rates in Changoi were dominant except, at 300kg N/ha/year (Figure 4). The net benefits decreased as the total variable costs increased beyond the dominant nitrogenous fertiliser application rates. This indicated that it was unlikely for any tea grower to choose a dominated treatment in comparison with other dominant treatments. As a result, the dominated treatments were omitted from the estimation of marginal rates of return since they did not merit the extra cost.[29] These results compare favourably with previous studies on perennial crops[43-45] that reflected lower net benefits at higher nitrogen application rates in a single location. In the studies, the application of nitrogen

Table 5: Net benefits, total variable costs and marginal rate of return as influenced by different nitrogenous fertiliser application rates at different geographical locations

Location	*Treatment*	*Net Benefits (USD/ha/year)*	*TVC (USD/ha/year)*	*DA*	*MRR%*
	0	18648	1226		
	75	28275	2038	*	1185
Kipkebe	150	33492	2561	*	998
	225	34497	2807	*	409
	300	36260	3103	*	596
	0	30161	1982		
	75	38758	2727	*	1154
Sotik Highlands	150	48589	3553	*	1190
	225	54238	4104	*	1025
	300	56194	4413	*	634
	0	32339	2126		
	75	32304	2303	D	
Karirana	150	35003	2660	*	498
	225	34401	2801	D	
	300	34108	2961	D	
	0	38111	2505		
	75	43810	3059	*	1028
Changoi	150	45189	3330	*	510
	225	46636	3605	*	526
	300	46493	3775	D	
	0	22573	1484		
	75	28375	2045	*	1034
Timbilil	150	32186	2475	*	886
	225	31163	2588	D	
	300	32037	2825	D	

DA= Dominance Analysis, *= Dominant treatment, D= Dominated treatment ,MRR- Marginal Rate of Return

Source: Authors computation from field experiment data[20]

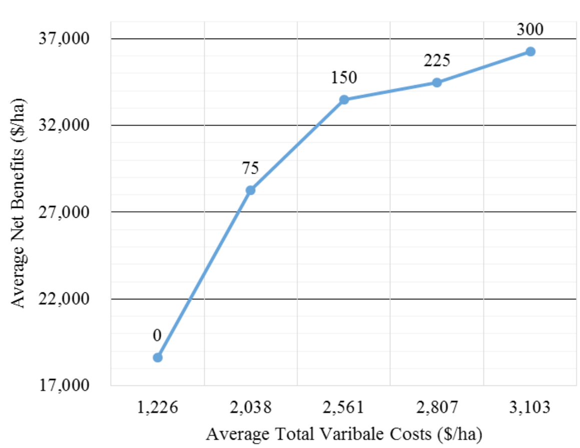

Figure 1: Kipkebe Net Benefit Curve

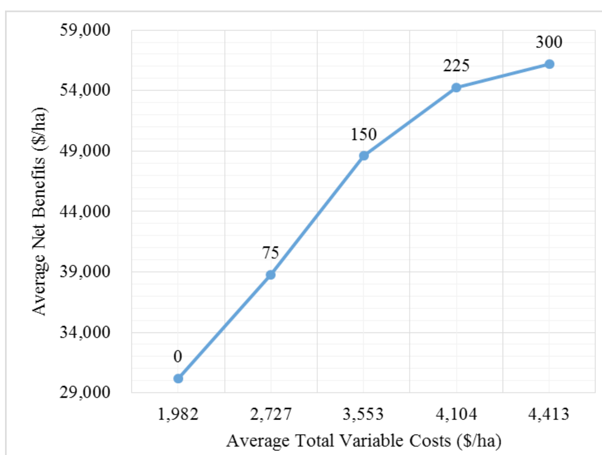

Figure 2: Sotik Highlands Net Benefit Curve

represents dominated treatments

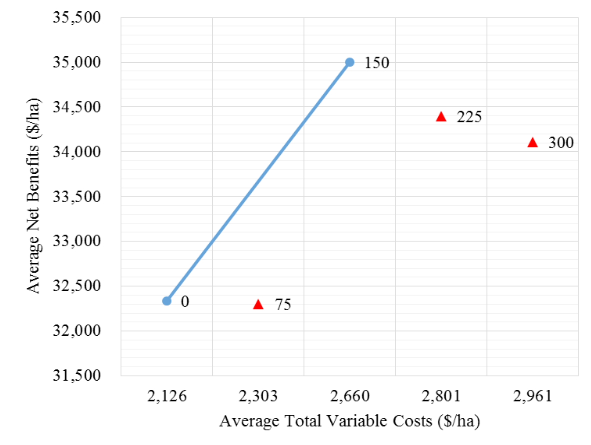

Figure 3: Karirana Net Benefit Curve

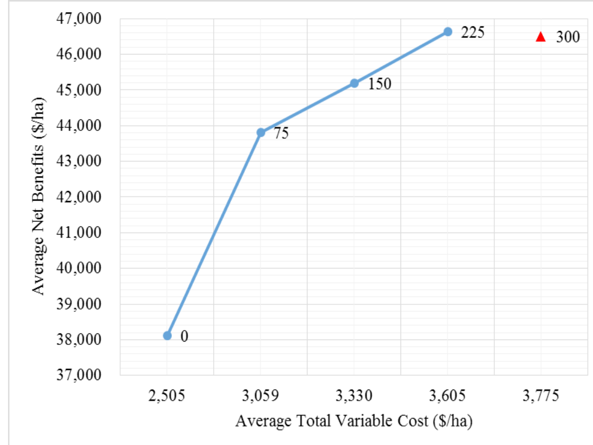

Figure 4: Changoi Net Benefit Curve

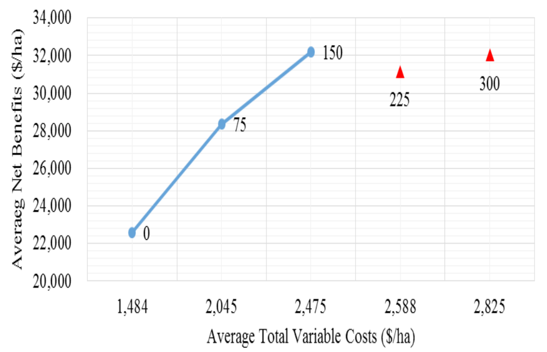

Figure 5: Timbilil Net Benefit Curve
represents dominated treatments

fertiliser rates within the dominated treatments were not financially viable therefore were not economically beneficial. Spending on variable inputs did not necessarily increase net benefits in spite of an improvement in yield.[46,47]

The results of the present study demonstrated that returns of nitrogenfertiliserapplication rates to clone BBK35 are unstable under environmental conditions. Net benefits obtained at one location may not be replicated at another location under the same treatment, despite uniform management. In other words, the same rate of fertiliser may not be applicable in one location since it leads to a reduction in net benefits when adjusting to a higher fertiliser rate. For instance, while tea growers in Kipkebe, Sotik Highlands and Changoi may benefit by increasing application rates from 150 kg N/ha/year to 225 kg N/ha/year, Timbilil farmers would incur a reduction in net benefits in the same scenario. These results agreed with other studies on perennial crops that showed best returns at different rates of fertiliser for different agro-ecological zones.[48,49]

The net benefit curves (Figure 1 to 5) also clarified the reasoning behind the calculation of marginal rates of return, which compared the increments in costs and benefits between such pairs of treatments. The net benefit curves for all the locations indicated that as the cost increased, the net benefit also increased, attaining a peak at 150kg N/ha/year in Karirana and Timbilil and 225kg N/ha/yearin Changoi. Thereafter, the net benefits reduced as the application rate of nitrogenous fertiliser increased. Similar responses were observed on other crops for studies done at single sites,[50,51] showing nitrogen fertiliser application increased net benefits up to a certain level, beyond which the net benefits declined.

Marginal and Residual Analyses

To enable comparison between the fertiliser application rates, marginal analysis was done based on the dominant treatments. The study set a minimum marginal rate of return (MRR) of 100% as the criterion for acceptability since the treatments did not require acquisition of new skills or complex equipment by tea growers.[29] Hence, any treatment that returned MRR above 100% was economically feasible. All the dominant treatments in different locations returned an MRR above 100%.This showed that the returns from the application of any of the dominant treatments in any of the locations would offset the cost of variable inputs while still giving an attractive positive net benefit to serve as an incentive for investment by tea growers. Therefore, even tea growers with low financial resources should be encouraged to apply fertiliser, as observed in studies on other perennial crops.[52,53] This is corroborated a study which showed that farmers were able to tentatively choose any of the dominant nitrogen application rates based on their resources since such treatments guaranteed at least 100% MRR.[51]
The MRRs ranged from 1190% for 150kg N/ha/year application

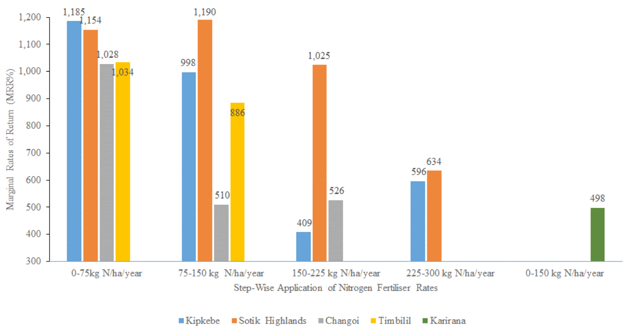

Figure 6: Marginal rate of return analysis for nitrogenous fertiliser rates application to clone BBK 35 in different locations

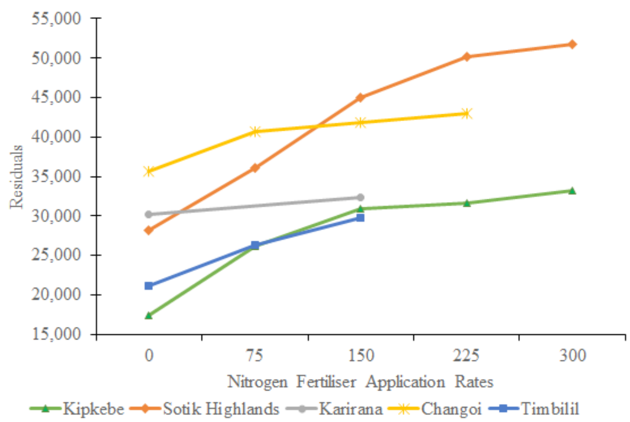

Figure 7: Residuals among dominant treatments by geographical location

rate in Sotik Highlands to 409% for 225kg N/ha/year application in Kipkebe (Figure 6). This implied that it was possible to recover an extra income of 11.90 USD/ha/year on spending an additional USD as the nitrogenous fertiliser rate changed from 75 kg N/ha/year to 150kg N/ha/year in Sotik Highlands. On the other hand, it was possible to recover an extra income of 4.09 USD/ha/year on spending an additional dollar as the nitrogenous fertiliser rate changed from 150 kg N/ha/year to 225 kg N/ha/year in Kipkebe.

MRR for the different application rates varied with all geographical location (Figure 6). For instance, the MRR for application of 75kg N/ha/year varied with sites in the order of Kipkebe>Sotik Highlands >Timbilil > Changoi. This suggests that at the rate of 75 kg N/ha/year, tea growers in Kipkebe were in a better position to realise more net benefits from tea production than farmers in the other locations. Specifically, if a tea-grower spent a dollar on changing fertiliser application rate from 0 kg N/ha/year to 75 kg N/ha/year it was possible to recover the dollar plus an extra 11.85, 11.54, 10.28 and 10.34 USD in Kipkebe, Sotik Highlands, Changoi and Timbilil respectively.

The MRR for application of 150kg N/ha/year varied with sites in the order of Sotik Highlands > Kipkebe > Timbilil > Changoi > Karirana (Figure 6). This demonstrated that tea growers from Sotik Highlands who invested in 150 kg N/ha/year application rate were generally able to recoup more per USD than their counterparts in other regions.

In Karirana, for each dollar spent on using nitrogenous fertiliser at the rate of 150kg N/ha/year it was possible to recover an extra income of 4.98 USD/ha/year as the fertiliser application changed from 0kg N/ha/year to 150kg N/ha/year. However, in Sotik Highlands, it was possible to recover an extra income of 11.90 USD/ha/year on spending an additional dollar as the fertiliser application changed from 75kg N/ha/year to 150kg N/ha/year. Application of 225kg N/ha/year had an MRR of 1,025%, 510% and 409% in Sotik Highlands, Changoi and Kipkebe respectively (Figure 6). Correspondingly, this demonstrated that tea growers in Sotik Highlands were generally able to regain more for each US dollar spent on changing the application rate from 150kg N/ha/year to 225kg N/ha/year, than the other locations. This was an additional 5.15 USD/ha/year and 6.16 USD/ha/year more than the tea growers in Changoi and Kipkebe, respectively. Changing the application rate from 225 kg N/ha/year to 300 kg N/ha/year was only possible in Kipkebe and Sotik Highlands at MRR of 596% and 634% respectively. This indicated that for each dollar spent on using nitrogenous fertiliser at the rate of 225kg N/ha/year it was possible to recover an extra income of 5.96 USD/ha/year and 6.34 USD/ha/year in Kipkebe and Sotik Highlands respectively. As a result, tea growers in Sotik Highlands were, in comparison to Kipkebe tea growers, able to recoup 0.38 USD/ha/year more for each US dollar spent on changing the application rate from 225kg N/ha/year to 300kg N/ha/year.

Location analysis indicated it was economical to apply nitrogenous fertilisers in a stepwise fashion from 0kg N/ha/year up to 300kg N/ha/year in Sotik Highlands and Kipkebe, 0kg N/ha/yearup to 225kg N/ha/year in Changoi, and 0kg N/ha/year up to 150kg N/ha/year in Timbilil. The results from Karirana showed it was only economical to increase nitrogenous fertiliser rate from 0 kg N/ha/year up to 150kg N/ha/year. A previous study[44] also found one nitrogen fertiliser application rate among other treatments as the only economical treatment. Although the highest MRR was obtained from tea plots supplied with 75 kg N/ha/year in Kipkebe, Changoi and Timbilil, the recommended economic optimum was 300 kg N/ha/year in Kipkebe, 225 kg N/ha/year in Changoi and 150 kg N/ha/year in Timbilil. This was because these rates recorded the highest net benefits in these areas with acceptable MRR. Similarly, 300 kg N/ha/year was the recommended economic optimum for Sotik highlands, despite the fact that the highest MRR at this location was recorded at 150 kg N/ha/year in Sotik Highlands. Residuals analysis[29] also confirmed the inferences of marginal analysis (Figure 7). The treatment with the highest residual among the dominant treatments was considered the optimum economic treatment,[29] even in the event of having lower MRR than other treatments. As a result, while lower application rates would still give good returns, the tea growers should endeavour to increase the application rates until the optimum economic rate was realized per hectare. This should apply in the case of Kipkebe and Sotik highlands where there were still possibilities of getting more returns at higher fertiliser application rates. These results agree with findings of[54] that showed highest net benefits with lower but acceptable MRR for higher fertiliser rates. However, for Karirana, Changoi and Timbilil this was not the case since applications beyond most application rates 150kg N/ha/year (for Karirana and Timbilil) and 225kg N/ha/year (for Changoi) were dominated, implying their maximum dominant treatments were the optimum economic rate. Moving to higher fertiliser application rates in these locations would be uneconomical for Karirana, Changoi and Timbilil. In addition it was only in the aforementioned locations whereby the optimal economic rates of nitrogenous fertiliser application fell within the uniform recommendation rate of 100–220kg per hectare per year.[9, 26]This suggested that even the same clone of tea will require different rates of nitrogenous fertiliser application rates in different locations in Kenya. Therefore, to get best net returns from a specific clone, it is necessary for policy recommendations to establish specific optimal fertiliser requirements for dominant cultivars in areas they are extensively cultivated. The current uniform recommendations applied countrywide may not be optimal for all locations.

Conclusion

The analysis has provided evidence that the current uniform recommendations of nitrogenous fertiliser applied countrywide to maximise economic benefits may not be optimal for all locations. Net benefits, marginal rate of returns and residuals of applied nitrogen varied across the different geographical locations. Maximum marginal rate of returns (MRR) were achieved at 75 kg N/ha/year in Kipkebe, Changoi and Timbilil, and 150 kg N/ha/year at Sotik Highlands and Karirana. However best economic returns were recorded at 300 kg N/ha/year in Kipkebe and Sotik Highlands, 225 kg N/ha/year in Changoi, and at 150 kg N/ha/year in Timbilil and Karirana. These results demonstrated that *ceteris paribus* current uniform fertiliser recommendation rate of 100 to 220 kg N/ha/year may not be suitable for all regions. There is need to develop region specific nitrogen fertiliser requirements for tea growing areas in Kenya.

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