RESEARCH ARTICLE

Nitrogenous Fertilizer Rates and Plucking Intervals Effects on Soil Organic Carbon, pH and Tea Yields and Their Relationships in Eastern Africa Tea Growing Regions

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Abstract

Eastern Africa tea grows in high rainfall areas where nutrients depletion through leaching, and surface run-off can be high, in addition to removal with crop. Nutrients replenishment through fertilizer applications is therefore necessary. But inappropriate fertilizer use can cause nutrients imbalance, change soil pH, and organic carbon contents. Variations in plucking intervals result in differences in tea productivity. Although environmental factors vary within Eastern Africa tea growing regions, recommended fertilizer type and rates and harvesting intervals are largely uniform. Fertilizer use and harvesting policy may influence soil chemical parameters within the region to varying degrees. Effects of NPKS 25:5:5:5 fertilizer rates and plucking intervals on soil organic carbon, pH and the relationship between soil organic carbon, pH and tea yields in Eastern Africa were evaluated. Trials were conducted on clone TRFK 6/8 at Timbilil, Changoi, Arroket (Kenya), Maruku, Katoke (Tanzania), Kitabi and Mulindi (Rwanda). Soil organic carbon contents ranged from 4.16 – 17.61% and were sufficient. Increasing nitrogen rates increased ($p \leq 0.05$) soil organic carbon but lowered ($p \leq 0.05$) soil pH. The pH values ranged between 3.22 and 4.84. The increase in soil acidity due to high rates of nitrogen rates reduce tea productivity in the long run. Periodic monitoring of soil pH is necessary in tea production to invoke mitigation activities when decline below 3.5. Plucking intervals had no influence on SOC and pH at all sites. Soil organic carbon and pH varied significantly ($p \leq 0.05$) from location to location, though the values were within acceptable range. Soil organic carbon directly correlated (r.>0.878; $p \leq 0.05$ for all sites except Mulindi and Maruku) with yields and inversely ($r \leq -0.878$, $p \leq 0.05$ for most sites) with pH. The correlation between SOC and yields suggest that tea production management need to maintain SOC at optimal levels realization of sustained tea yields.

Keywords: Nitrogen rates; plucking intervals; location of production; soil organic carbon; soil pH; Clone TRFK 6/8; Kenya; Rwanda; Tanzania.

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Introduction

Tea is grown in from 45°N (Russia) to 30°S (South Africa), and 150°E (New Guinea) to 60°W (Argentina),[1] at altitudes ranging from sea level[2] to about 2,700 m above mean sea level (amsl).[3] In East Africa, favourable tea growing conditions include suitable temperatures (15-25°C), high humidity (80-90%), medium to high well distributed annual rainfall (1200–2000mm) and acidic soils (pH 4.5–5.6).[4] The crop adapts well to various environmental factors, which usually influence growth, soil quality and nutrients supply.[1,2] The plant can tolerate large deviations in nutrients requirements before first visible signs of deficiency/toxicity begin to appear on the foliage. Periodic soil quality tests to detect nutrients deficiency/toxicity that may affect yields,[4-6] is necessary to facilitate invoking corrective measures.

Clone TRFK 6/8 is widely grown in Eastern Africa, constituting about 80% of tea in Rwanda, 60% of clonal tea in Kenya and 35-40% of tea in Tanzania.[7,8] Agronomic recommendations applied in eastern Africa tea growing regions are largely uniform. The recommendations were mainly adopted from Kenya,[4] normally without re-testing in new growing areas. Nitrogenous fertilizer rates vary between 100 and 250 kg N/ha/year.[4] Despite the uniform applications, yields are not replicated in different locations within Eastern Africa even in the same clone under similar management.[9] Some recommendations may therefore be inappropriate in some regions. The influence of the agronomic inputs on soil nutrients levels may vary with location and it is not documented if soil nutrients levels are related to tea yields within Eastern Africa.

In tea production, soil nutrients can be lost through soil erosion,[10] leaching,[11] surface run-offs[12] and continuous tea cropping.[13,14] Soil organic matter acts as a revolving nutrient fund among other functions.[15] Leaf drop and prunings left *in situ* return organic matter to the soil which improves soil organic carbon (SOC).[16] SOC is simultaneously source and sink for nutrients and plays a vital role in soil fertility maintenance.[17,18] The management practices adopted in tea plantations including soil organic matter (SOM) management plays important roles in improvement of soil quality.[19] Increasing nitrogenous fertilizer application rates increased SOC.[20,21] In the absence of inorganic fertilization, plants absorb nutrients from the mineralized organic matter in the soil[21,22] causing decline in SOC. Climate and soil management practices also influence SOC contents.[23] In highly weathered tea soils of the tropics, high organic matter decomposition rates[24] reduce

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soil fertility, increase nutrients loses[25] and lower productivity.[26] Although SOC have been investigated at single sites,[20-22] it is not documented if SOC varies with nitrogen fertilizer rates in similar patterns at different sites and if the levels of variations are region specific.

Tea grows well in acidic soils,[27] where pH ranges from 3 to 5.6, the optimum pH being between 4 and 5.[28] Soil pH is a critical factor in tea production since it influences availability of plant nutrients and microbial activities.[29] At low soil pH, base cations K, Ca, and Mg are prone to leaching[30-32] and phosphorus fixation by sorption or precipitation with aluminium and iron oxides increase.[33] Long-term tea cultivation acidifies soil with pH declining below 4.0, especially at high nitrogen fertilizers rates.[14,34,35] Indeed, continuous nitrogen fertilizer application is the main cause of tea soils acidification.[21,30,35-37]

Tea plantations soils in Russia that received 50 to 300 kg ammonium sulphate annually for 35 years, showed decreased soil pH.[38] In Acrisols of Vietnam, 10 years of continuous application of nitrogen fertilizers on tea crop increased H^+ concentrations in the soil[39] causing decline in yields. The magnitude of any change in soil pH, however, depended on management practices.[14] Indeed, in Kenya, high rates of application of nitrogenous fertilizers reduced soil pH.[35] Several studies have demonstrated that soil pH varies due to nitrogenous fertilizer application rates[14,37,39] and this affects yield.[21,30] Most of these studies were conducted at single sites. However, the magnitudes of the changes in the soil pH may vary to different extents with variations in rates of nitrogen fertilizer application and plucking intervals in different locations in East Africa. Also the relationship between SOC, pH and yields in different parts of Eastern Africa is not documented. This study evaluated changes in SOC and pH due to different rates of nitrogenous fertilizer and plucking intervals using clone TRFK 6/8 in different locations within Eastern Africa.

Methodology

The study was set up as nitrogenous fertilizer trial on clone TRFK 6/8 in seven locations within the Eastern Africa tea growing regions. The locations including their coordinates are listed in Table 1. The soil physical characteristics at different sites are presented in Table 2.

At each site, the trial was laid out as factorial two (5x3) in randomized complete block design and replicated 3 times. The main treatments were the seven sites with five nitrogen rates (0, 75, 150, 225 and 300 kg N/ ha /year) as NPKS 25:5:5:5 and sub-treatments were three plucking intervals (7, 14 and 21 days). Each plot comprised of 50 bushes of clone TRFK 6/8. Tea at each site was pruned between April and August 2012 so that all plants were in same pruning cycle life. The treatments commenced in September/ October 2012, depending on when there was adequate soil moisture at different sites in the respective countries. In subsequent years, the trials received fertilizers in September/October in single annual dose.

Yields data were obtained from fertilizer trials on clone TRFK 6/8 at the scheduled experimental plucking regime. Soil was sampled in October 2014 before application of fertilizers. The sampling was done from 3 points within a plot using calibrated steel auger then mixed, at depths of 0–10cm, 10–20cm, 20–30cm, 40–60cm from all plots. Part of the freshly sampled soils was used for soil pH determination. The remaining samples were air-dried, ground into fine powder (<2mm) using a ceramic mortar and pestle before processing for chemical analysis. A portion of air-dried soil sample (0.5 grams) was used for analysis of soil organic carbon using the method of Walkley and Black,[40] Soil pH. Data was analysed as 7x5x3 (sites x N rates x plucking intervals), with locations as main factor, nitrogen rates as sub-treatment and plucking intervals as sub-sub treatment.

Results and Discussions

Variations in Soil pH with Location of Production, Nitrogenous Fertilizer Rates and Plucking Frequencies

The soil pH data are presented in Tables 3 to 6. The acidity decreased down the soil profiles except at Arroket, Kitabi and Katoke where there were slight increase at the lower depths. Nitrogen fertilizer application reduced soil pH.[22,35] The upper soil profiles had high clay (Table 2) and SOC (Tables 7 to 10) contents. Hydrogen (H^+) and aluminium (Al^{+3}) ions in the cation exchange sites of negatively charged clay and organic matter fractions of the soil contributed to increased soil acidity.[27] Similarly more feeder tea roots at the top soil depths,[41] enhanced absorption of nutrients cations over anions from soil solution and resulted in the efflux of H_3O^+ ions from plant roots into the rhizospheres. A combination of these factors contributed to lower soil pH at the top soil level than at the lower depths. The reduction in soil pH at the top depths may influence leaching of base ions[30, 32] and fixation of phosphorus.[33,35] The high concentration of H^+ ions in the soil enhanced were more strongly bound to soil colloids than base ions (Ca^{+2}, Mg^{+2}, and K^+). Therefore, the low soil pH encouraged leaching of the base cations. Soil pH should therefore be monitored periodically to invoke mitigation activities if the pH decreases below the optimal values.[4,27] Soil pH varied significantly ($p \leq 0.05$) with the sites, as observed in a previously study.[42] At some sites, the soil pH was less than 3.5, which is considered below acceptable range for optimal tea growing in East Africa.[4,27] Due to variations in environmental factors and soil characteristics (Table 2) at the study sites, even with application of same agronomic inputs, the soil pH differed.

Increasing nitrogen fertilizer application rates increased soil acidity, although not reaching significant level at some sites. The trend was similar to previous studies.[8,35,43] The decrease in soil

Table 1: The study sites and coordinates

Country	*Site*	*Latitude*	*Longitude*	*Altitude (amsl)*	*Rainfall*	*Temperature*
Kenya	Timbilil Estate (TRI)	0° 22’S	35° 21’E	2180m	2175mm[a]	19.5°C[a]
	Changoi Estate	0°30’S	35°13’E	1860m	2130mm[a]	19.0°C[a]
	Arroket Estate (Sotik)	0° 36’S	35° 04’E	1800m	2000mm[a]	20.5°C[a]
Tanzania	Maruku Tea Estate	1°23’ S	31° 45’E	1488m	21000mm[b]	19.5°C[b]
	Katoke Tea Estate	1°36’S	31° 41’E	1217m	1950mm[b]	21.5°C[b]
Rwanda	Kitabi Estate	2°32’S	29°26’E	2231m	1500mm[c]	23.5°C[c]
	Mulindi Estate	1°27’S	30°01’E	1800m	1400mm[c]	18.5°C[c]

Table 2: Soil characteristics at the study sites

Location	*Depth (cm)*	*CEC (Cmols/kg)*	*Sand (%)*	*Clay (%)*	*Silt (%)*	*Porosity (%)*	*Textural class*	*Soil description*
Timbilil	0–10		41.37	49.75	10.96	37.56	C	Volcanic dark red, deep, friable clays, a dusky red, top soil, with kaolinite classified humic nitosols
	10–20	25.64	41.37	49.75	10.96	37.56	C	
	20–30		42.15	44.13	13.28	45.22	C	
	40–60	16.27	38.08	48.36	15.57	47.00	C	
Changoi	0–10		23.75	70.79	11.52	43.33	C	Volcanic derived, deep, free draining, dark red with dark reddish top soil, classified as nitosols
	10–20	25.42	23.75	70.79	11.52	43.33	C	
	20–30		22.28	72.08	11.67	31.67	C	
	40–60	17.34	23.07	70.32	12.86	31.67	C	
Arroket	0–10		29.84	48.59	21.57	51.33	C	Dark reddish brown, moderately deep, firm clay, moderately deep, firm clay, loam humic top soil classified as chromoluvic phaeozems
	10–20	25.75	29.84	48.59	21.57	51.33	C	
	20–30		27.84	49.59	22.57	42.00	C	
	40–60	18.13	28.20	50.23	21.57	44.00	C	
Kitabi	0–10		35.93	31.22	17.47	59.86	SC	Dark brown, reddish- brown top soil, clay- rich, classified as nitosols
	10–20	36.09	35.93	31.22	17.47	59.86	SC	
	20–30		41.77	44.54	13.16	44.81	SC	
	40–60	17.96	42.03	43.82	17.18	51.87	SC	
Mulindi	0–10		35.13	51.75	46.40	58.97	C	Dark, metasedimentary, deep dark clay- rich top soil, with loam feel classified as peat
	10–20	22.85	35.13	51.75	46.41	59.04	C	
	20–30		39.53	33.66	32.26	51.12	C	
	40–60	18.24	42.44	29.57	28.68	37.52	SC	
Katoke	0–10		47.44	43.39	12.57	43.07	SC	Volcanic dark red, friable clay with dusk top soil, classified as nitosols
	10–20	25.96	47.45	43.31	12.31	42.17	SC	
	20–30		40.10	36.39	12.63	43.02	SC	
	40–60	16.93	39.61	34.49	16.19	48.89	SC	
Maruku	0–10		45.61	19.49	27.98	49.88	SCL	Volcanic dark red, moderately deep clay loam humic top soil classified as nitosols
	10–20	34.80	45.92	19.43	28.06	56.15	SCL	
	20–30		60.44	18.51	31.65	52.76	SC	
	40–60	25.85	60.49	18.44	24.73	47.67	SC	

CEC =Cation Exchange Capacity, C = Clay, SC = Sandy Clay, SCL = Sandy Clay Loam

pH was more conspicuous above 150 kg N/ha rate especially at the 0–10 cm soil depth. Overall, there was significant ($p \leq 0.05$) decrease in soil pH with increased nitrogen application rates. The pH decline in some locations reached lower than optimal limit for tea cultivation.[4,27] The decrease suggest that long term application of high nitrogenous fertilizers rates could increase soil acidity to levels unsuitable for tea or crop production. Continuously monitoring of soil pH is necessary to enable invoking mitigation remedial activities if levels decrease below 3.5. The magnitude of the changes in soil pH varied to different extents with nitrogen fertiliser rates in East Africa tea growing regions. This caused significant nitrogen rates and sites interactions effects (Tables 3 to 6). The significant interactions effects demonstrated that it may not be possible to predict the magnitude of pH changes at different sites based on data from a single site. Previous studies assumed that changes of soil pH at different sites could be predicted from data generated at one site.[21,35]

Plucking frequencies did not influence soil pH at all sites (Tables 3 to 6). Similar to observation had been made in previous studies.[14,30] Results of leaf analysis from this trial had demonstrated that plucking intervals had insignificant effects on mature tea leaf nutrients.[44] These results, together with earlier observation on leaf nutrients[44] implied that plucking intervals is not a contributing factor to decrease in soil pH in tea cultivation.

Variations in Soil Organic Carbon (SOC) Contents with Location of Production, Nitrogenous Fertilizer Rates and Plucking Frequencies

Changes in soil organic carbon contents with locations of tea production, nitrogenous fertilizer rates and plucking frequencies on are presented in Tables 7, 8, 9, and 10 for 0–10, 10–20, 20–30 and 40–60 cm soil depths, respectively. SOC levels ranged from 4.16 to 17.61%, 3.50 – 14.82%, 3.26 to 12.45% and 2.99 to 15.11% for 0–10, 10–20, 20–30 and 40–60 cm soil depths, respectively. There was decrease in SOC with increase in soil depths. Previous studies conducted at single sites had reported similar trends.[30,45,46] The levels were relatively high. These high levels were attributed to high organic matter returns through prunings left *in situ* and leaf drops

Table 3: Responses of soil pH to nitrogen rates, plucking frequencies and location (Depth: 0-10 cm)

Site	*Plucking Freq (days)*	*Nitrogen Rates (/ha/year)* 0	75	150	225	300	*Mean Pl Freq*	*Mean Site*	*C.V%*
Timbilil	7	3.24	3.18	3.17	3.19	3.26	3.21		
	14	3.39	3.15	3.21	3.11	3.18	3.21	3.22	3.62
	21	3.49	3.19	3.11	3.15	3.29	3.25		
	Mean N rates	3.37	3.17	3.16	3.15	3.24			
	LSD, $p \leq 0.05$	0.15					NS		
Changoi	7	3.65	3.29	3.10	3.15	3.17	3.27		
	14	3.75	3.38	3.22	3.28	3.13	3.35	3.30	5.01
	21	3.41	3.33	3.31	3.24	3.14	3.29		
	Mean N rates	3.36	3.34	3.21	3.22	3.14			
	LSD, $p \leq 0.05$	NS					NS		
Arroket	7	4.00	3.95	3.73	3.21	3.44	3.67		
	14	4.14	4.00	3.94	3.93	3.70	3.94	3.79	8.31
	21	3.91	3.53	3.68	3.44	4.24	3.76		
	Mean N rates	4.01	3.83	3.78	3.53	3.79			
	LSD, $p \leq 0.05$	0.41					NS		
Kitabi	7	4.43	4.40	4.00	3.89	3.81	4.11		
	14	4.43	4.42	4.15	4.00	4.08	4.22	4.06	3.05
	21	4.28	4.15	3.75	3.69	3.47	3.87		
	Mean N rates	4.38	4.32	3.97	3.86	3.79			
	LSD, $p \leq 0.05$	NS					NS		
Mulindi	7	4.52	4.26	4.19	3.89	4.12	4.20		
	14	4.42	4.44	3.96	3.98	3.91	4.14	4.18	4.51
	21	4.75	4.14	4.07	4.02	3.97	4.19		
	Mean N rates	4.56	4.28	4.07	3.96	3.99			
	LSD, $p \leq 0.05$	NS					NS		
Katoke	7	4.42	4.41	4.41	4.41	4.27	4.38		
	14	4.35	4.45	4.31	4.41	4.24	4.35	4.40	3.10
	21	4.48	4.53	4.41	4.39	4.46	4.45		
	Mean N rates	4.42	4.46	4.38	4.40	4.33			
	LSD, $p \leq 0.05$	NS					NS		
Maruku	7	4.97	4.75	4.86	4.74	4.54	4.77		
	14	4.96	4.85	4.64	4.61	4.46	4.71	4.73	2.98
	21	4.86	4.84	4.82	4.67	4.34	4.71		
	Mean N rates	4.93	4.81	4.77	4.68	4.45			
	LSD, $p \leq 0.05$	NS					NS		
Mean of sites	7	4.18	4.03	3.92	3.78	3.80	3.94		5.57
	14	4.21	4.10	3.92	3.90	3.81	3.99		
	21	4.17	3.96	3.88	3.80	3.84	3.93		
	Mean N rates	4.19	4.03	3.91	3.83	3.82			
	LSD,$p \leq 0.0$	0.13					NS	0.07	
	Site x N rates=0.21, Site x Pl Freq = 0.18								

*Insignificant interactions are not shown

Table 4: Responses of soil pH to nitrogen rates, plucking frequencies and location (Depth: 10-20 cm)

		Nitrogen Rates(/ha/year)					*Mean Pl*	*Mean*	
Site	*Plucking Freq (days)*	*0*	*75*	*150*	*225*	*300*	*Freq*	*Site*	*C.V. %*
Timbilil	7	3.89	3.56	3.41	3.40	3.37	3.53		
	14	3.46	3.43	3.54	3.23	3.32	3.40	3.45	6.54
	21	3.64	3.32	3.35	3.48	3.34	3.43		
	Mean N rates	3.67	3.44	3.43	3.37	3.34			
	LSD, p ≤ 0.05	NS					NS		
	N x Pl Freq, p ≤ 0.05	0.43							
Changoi	7	3.37	3.28	3.33	3.29	3.22	3.30		
	14	3.37	3.41	3.41	3.30	3.19	3.34	3.33	4.32
	21	3.49	3.38	3.35	3.33	3.24	3.36		
	Mean N rates	3.41	3.35	3.36	3.31	3.22			
	LSD, p ≤ 0.05	0.19					NS		
	N x Pl Freq, p ≤ 0.05	0.27							
Arroket	7	4.15	4.05	3.84	3.55	3.44	3.81		
	14	4.10	4.14	3.96	3.90	3.76	3.97	3.89	8.98
	21	4.28	4.08	3.91	3.72	3.49	3.90		
	Mean N rates	4.18	4.09	3.90	3.72	3.56			
	LSD, p ≤ 0.05	NS					NS		
	N x Pl Freq, p ≤ 0.05	0.66							
Kitabi	7	4.46	4.41	4.13	4.25	4.14	4.27		
	14	4.45	4.29	4.07	4.08	4.17	4.21	4.23	3.70
	21	4.35	4.30	3.90	4.21	4.21	4.19		
	Mean N rates	4.42	4.33	4.03	4.18	4.17			
	LSD, p ≤ 0.05	NS					NS		
	N x Pl Freq, p ≤ 0.05	0.25							
Mulindi	7	4.64	4.54	4.35	4.38	4.18	4.42		
	14	4.74	4.48	4.27	4.13	4.13	4.35	4.36	4.19
	21	4.58	4.35	4.28	4.23	4.10	4.30		
	Mean N rates	4.65	4.46	4.30	4.24	4.14			
	LSD, p ≤ 0.05	NS					NS		
	N x Pl Freq	0.54							
Katoke	7	4.35	4.41	4.38	4.33	4.31	4.35		
	14	4.44	4.41	4.41	4.41	4.33	4.40	4.37	3.29
	21	4.47	4.45	4.42	4.25	4.22	4.36		
	Mean N rates	4.42	4.42	4.40	4.33	4.29			
	LSD, p ≤ 0.05	NS					NS		
Maruku	7	4.97	4.75	4.86	4.74	4.54	4.77		
	14	4.96	4.85	4.64	4.61	4.46	4.71	4.73	2.98
	21	4.86	4.84	4.82	4.67	4.34	4.71		
	Mean N rates	4.93	4.81	4.77	4.68	4.45			
	LSD, p ≤ 0.05	NS					NS		
	N x Pl Freq, p ≤ 0.05	0.27							
Mean of sites	7	4.28	4.16	4.03	3.99	3.99	4.09		
	14	4.22	4.15	4.07	3.97	3.96	4.07		
	21	4.25	4.10	4.00	4.00	3.89	4.05		6.82
	N rates	4.25	4.14	4.03	3.99	3.95			
	LSD,p ≤ 0.05	0.14					NS	0.14	

*Insignificant interactions are not shown

Table 5: Responses of soil pH to nitrogen rates, plucking frequencies and location (Depth: 20-30 cm)

		Nitrogen Rates (/ha/year)							
Site	*Plucking Freq (days)*	*0*	*75*	*150*	*225*	*300*	*Mean Pl Freq*	*Mean Site*	*C.V.%*
Timbilil	7	3.86	3.58	3.41	3.44	3.42	3.54		
	14	3.49	3.51	3.43	3.36	3.37	3.43	3.48	6.31
	21	3.72	3.42	3.36	3.26	3.52	3.45		
	Rates	3.69	3.50	3.40	3.35	3.44			
	LSD, p ≤ 0.05	NS					NS		
	N x Pl Freq, p ≤ 0.05	0.41							
Changoi	7	3.38	3.23	3.32	3.31	3.28	3.30		
	14	3.53	3.42	3.42	3.33	3.23	3.39	3.35	4.39
	21	3.42	3.48	3.23	3.33	3.30	3.35		
	Rates	3.45	3.38	3.32	3.32	3.27			
	LSD, p ≤ 0.05	0.15					NS		
	N x Pl Freq, p ≤ 0.05	0.28							
Arroket	7	4.42	4.23	4.15	4.09	4.07	4.19		
	14	4.90	4.72	4.49	3.79	4.09	4.40	4.37	9.66
	21	4.91	4.74	4.62	4.47	3.79	4.51		
	Rates	4.74	4.56	4.42	4.12	3.99			
	LSD, p ≤ 0.05	NS					NS		
Kitabi	7	4.40	4.34	4.19	4.27	4.16	4.27		
	14	4.63	4.28	4.24	4.25	4.14	4.31	4.27	3.48
	21	4.42	4.35	4.19	4.08	4.05	4.22		
	Rates	4.49	4.32	4.21	4.20	4.12			
	LSD, p ≤ 0.05	NS					NS		
	N x Pl Freq, p ≤ 0.05	0.280							
Mulindi	7	4.76	4.73	4.57	4.36	4.44	4.57		
	14	4.62	4.62	4.48	4.28	4.35	4.47	4.51	4.85
	21	4.69	4.53	4.59	4.42	4.20	4.49		
	Rates	4.69	4.63	4.55	4.35	4.33			
	LSD, p ≤0.05	NS					NS		
Katoke	7	4.35	4.43	4.43	4.37	4.37	4.39		
	14	4.33	4.37	4.36	4.33	4.27	4.33	4.40	2.99
	21	4.53	4.51	4.45	4.44	4.40	4.47		
	Rates	4.40	4.44	4.41	4.38	4.35			
	LSD, p ≤ 0.05	NS					NS		
Maruku	7	4.96	4.91	4.91	4.80	4.83	4.88		
	14	4.86	4.75	4.74	4.71	4.71	4.76	4.79	3.37
	21	4.82	4.75	4.75	4.72	4.61	4.73		
	Rates	4.88	4.81	4.80	4.74	4.72			
	LSD, p ≤ 0.05	NS					NS		
Mean of sites	7	4.31	4.21	4.14	4.09	4.08	4.17		
	14	4.34	4.24	4.16	4.01	4.02	4.15		
	21	4.36	4.25	4.17	4.10	3.98	4.17		7.13
	N rates	4.34	4.23	4.16	4.07	4.03			
	LSD,p ≤ 0.05	0.14					NS	0.15	
		Site x N rates = 0.29,							

*Insignificant interactions are not shown

Table 6: Responses of soil pH nitrogen rates, plucking frequencies and location (Depth: 40–60 cm)

Site	*Plucking Freq (days)*	*Nitrogen Rates (/ha/year)* 0	75	150	225	300	*Mean Pl Freq*	*Mean Site*	*C.V.%*
Timbilil	7	3.99	3.58	3.46	3.48	3.47	3.59		
	14	3.58	3.56	3.43	3.41	3.41	3.48	3.54	6.88
	21	3.87	3.54	3.39	3.62	3.33	3.55		
	Mean N rates	3.81	3.56	3.43	3.50	3.40			
	LSD,p ≤ 0.05	0.32					NS		
Changoi	7	3.53	3.36	3.35	3.24	3.13	3.32		
	14	3.57	3.45	3.32	3.30	3.30	3.39	3.36	3.46
	21	3.63	3.43	3.22	3.26	3.31	3.37		
	Mean N rates	3.58	3.41	3.30	3.27	3.25			
	LSD,p ≤ 0.05	NS					NS		
Arroket	7	3.17	4.07	4.09	3.88	3.29	3.90		
	14	3.85	3.53	3.64	3.60	3.37	3.60	3.80	8.40
	21	3.94	3.91	3.93	3.92	3.74	3.89		
	Mean N rates	3.99	3.84	3.88	3.80	3.46			
	LSD,p ≤ 0.05	0.42					NS		
Kitabi	7	4.46	4.16	4.16	4.07	3.97	4.16		
	14	4.54	4.33	4.33	4.37	4.18	4.35	4.24	2.37
	21	4.57	4.34	4.14	4.00	4.01	4.21		
	Mean N rates	4.52	4.28	4.21	4.14	4.05			
	LSD,p ≤ 0.05	NS					NS		
Mulindi	7	4.76	4.79	4.73	4.40	4.73	4.69		
	14	4.82	4.88	4.42	4.32	4.49	4.59	4.67	4.21
	21	4.78	4.63	4.83	4.71	4.70	4.73		
	Mean N rates	4.79	4.77	4.66	4.47	4.64			
	LSD,p ≤ 0.05	0.26					NS		
Katoke	7	4.49	4.48	4.41	4.40	4.37	4.43		
	14	4.52	4.50	4.44	4.40	4.30	4.43	4.40	3.27
	21	4.47	4.34	4.33	4.26	4.21	4.33		
	Mean N rates	4.49	4.44	4.39	4.35	4.30			
	LSD,p ≤ 0.05	NS					NS		
Maruku	7	5.09	4.95	4.91	4.85	4.81	4.92		
	14	4.89	4.87	4.81	4.78	4.73	4.82	4.84	2.87
	21	4.99	4.77	4.75	4.77	4.68	4.79		
	Mean N rates	4.99	4.86	4.82	4.80	4.74			
	LSD,p ≤ 0.05	0.16					NS		
Means for all 7 Sites	7	4.36	4.20	4.16	4.04	3.97	4.15		
	14	4.25	4.16	4.06	4.03	3.97	4.09		
	21	4.32	4.14	4.09	4.08	4.00	4.16		5.77
	Mean N rates	4.31	4.17	4.10	4.05	3.98			
	LSD, p ≤ 0.05	0.11					NS	0.12	
		Site x N rates=0.17, Site x Pl Freq = 0.19							

*Insignificant interactions are not shown

on the top soil. Reported values in some previous studies were relatively low (<3%) compared to the present study probably due to removal of tea prunings from the fields,[47] rapid decomposition caused by high rainfall and temperatures.[45] In the present study, prunings were left *in situ*[4,21,30,32] and there was slow microbial decomposition of fallen plant foliage.[42] These results reaffirmed

Table 7: Responses of soil organic carbon contents (%) to nitrogen rates, plucking frequencies and location (Depth: 0–10 cm)

		Nitrogen Rates (Kg N/ha/year)							
Site	*Plucking Freq (days)*	*0*	*75*	*150*	*225*	*300*	*Mean Pl*	*Mean site*	*C.V. (%)*
Timbilil	7	3.05	4.12	4.62	4.90	4.88	4.31		
	14	3.47	3.63	3.73	4.51	4.66	4.00	4.16	9.07
	21	3.26	3.88	4.17	4.70	4.77	4.16		
	Mean N rates	3.26	3.88	4.17	4.70	4.77			
	LSD, $p \leq 0.05$	0.60					NS		
Changoi	7	3.56	4.36	4.72	5.06	7.14	4.97		
	14	3.86	3.62	4.23	4.99	6.23	4.59	4.67	19.63
	21	3.71	3.99	4.48	5.02	6.69	4.78		
	Mean N rates	3.71	3.99	4.48	5.02	6.69			
	LSD, $p \leq 0.05$	1.47					NS		
Arroket	7	4.01	3.39	3.98	4.31	4.50	4.04		
	14	4.54	5.20	5.72	5.80	5.84	5.42	4.73	6.38
	21	4.27	4.30	4.85	5.05	5.17	4.73		
	Mean N rates	4.27	4.30	4.85	5.05	5.17			
	LSD, $p \leq 0.05$	0.48					NS		
	NxPl freq, $p \leq 0.05$	0.68							
Kitabi	7	5.52	5.79	6.49	6.56	7.45	6.36		
	14	4.82	5.25	6.82	8.76	8.83	6.90	6.63	4.99
	21	5.17	5.52	6.65	7.66	8.14	6.63		
	Mean N rates	5.17	5.52	6.65	7.66	8.14			
	LSD, $p \leq 0.05$	0.53					NS		
	NxPl freq, $p \leq 0.05$	0.75							
Mulindi	7	13.23	15.77	18.32	19.09	18.19	16.92		
	14	16.45	18.79	17.92	18.67	19.62	18.29	17.61	6.32
	21	14.85	17.29	18.12	18.88	18.90	17.61		
	Mean N rates	14.85	17.29	18.12	18.88	18.90			
	LSD, $p \leq 0.05$	1.78					NS		
	NxPl freq, $p \leq 0.05$	2.52							
Katoke	7	3.35	4.17	4.62	5.56	6.62	4.87		
	14	4.69	3.82	4.23	4.93	5.69	4.63	4.77	6.19
	21	4.02	4.00	4.42	5.25	6.16	4.77		
	Mean N rates	4.02	4.00	4.42	5.25	6.16			
	LSD, $p \leq 0.05$	0.47					NS		
Maruku	7	8.53	8.25	11.10	11.61	11.25	10.15		
	14	10.03	11.49	10.89	10.73	12.26	11.08	10.62	10.89
	21	9.28	9.87	10.99	11.17	11.76	10.61		
	Mean N rates	9.28	9.87	10.99	11.17	11.76			
	LSD, $p \leq 0.05$	1.85					NS		
Mean of sites	7	6.00	7.34	7.66	7.48	8.00	7.30		
	14	7.44	7.75	7.76	8.25	8.04	7.85		10.00
	21	6.72	7.55	7.71	7.86	8.02	7.57		
	N rates	6.72	7.55	7.71	7.86	8.02			
LSD, $p \leq 0.05$		0.32					NS	0.76	
	Site x Nrates=0.64, N rates x pl freq =0.46, Site x N rates x pl freq=0.90								

Table 8: Responses of soil organic carbon contents (%) to nitrogen rates, plucking frequencies and location (Depth: 0–10 cm)

		Nitrogen Rates (Kg N/ha/year)							
Site	*Plucking Freq (days)*	*0*	*75*	*150*	*225*	*300*	*Mean Plucking freq*	*Mean Site*	*C.V. %*
Timbilil	7	2.11	2.79	3.58	3.59	4.16	3.25		
	14	2.51	3.35	3.69	4.47	4.74	3.75		
	21	2.31	3.07	3.64	4.03	4.45	3.50	3.50	9.71
	Mean N rates	2.31	3.07	3.64	4.03	4.45			
	LSD, p ≤ 0.05	0.55					NS		
Changoi	7	3.06	3.03	3.75	4.39	5.30	3.90		
	14	3.39	4.00	4.74	4.54	5.02	4.34		
	21	3.22	3.52	4.24	4.46	5.16	4.12	4.12	6.60
	Mean N rates	3.22	3.52	4.24	4.46	5.16			
	LSD, p ≤ 0.05	0.44					NS		
	NxPl freq, p ≤ 0.05	0.62							
Arroket	7	2.82	3.30	3.87	4.89	5.54	4.08		
	14	2.06	3.24	4.54	4.56	4.52	3.79		
	21	2.44	3.27	4.20	4.73	5.03	3.93	3.93	9.95
	Mean N rates	2.44	3.27	4.20	4.73	5.03			
	LSD, p ≤ 0.05	0.63					NS		
	NxPl freq, p ≤ 0.05	0.89							
Kiabi	7	2.76	3.12	3.15	3.42	3.66	3.22		
	14	4.32	4.42	5.32	5.22	5.06	4.87		
	21	3.54	3.77	4.24	4.32	4.36	4.05	4.04	5.07
	Mean N rates	3.54	3.77	4.24	4.32	4.36			
	LSD, p ≤ 0.05	0.33					NS		
	NxPl freq, p ≤ 0.05	0.47							
Mulindi	7	11.80	14.51	16.04	17.16	17.60	15.42		
	14	13.68	13.73	14.23	14.52	14.90	14.21		
	21	12.74	14.12	15.14	15.84	16.25	14.82	14.82	4.82
	Mean N rates	12.74	14.12	15.14	15.84	16.25			
	LSD, p ≤ 0.05	1.15					NS		
	NxPl freq, p ≤ 0.05	1.62							
Katoke	7	2.63	3.09	4.03	5.01	5.18	3.99		
	14	2.95	3.05	4.01	4.56	4.81	3.88		
	21	2.79	3.07	4.02	4.78	4.99	3.93	3.93	9.20
	Mean N rates	2.79	3.07	4.02	4.78	4.99			
	LSD, p ≤ 0.05	0.58					NS		
Maruku	7	5.51	7.72	6.46	8.64	9.07	7.48		
	14	6.04	9.19	9.38	8.91	8.71	8.45		
	21	5.78	7.92	8.45	8.78	8.89	7.96	8.96	13.76
	Mean N rates	5.78	7.92	8.45	8.78	8.89			
	LSD, p ≤ 0.05	1.98					NS		
Mean of sites	7	5.49	5.98	5.84	6.73	7.22	6.05		
	14	5.71	5.85	6.56	6.68	6.82	6.33		
	21	5.60	5.92	6.20	6.71	7.02	6.29		10.26
	N rates	5.60	5.92	6.20	6.71	7.02			
LSD, p ≤ 0.05		0.32					NS	1.04	

Site x N rates=0.53, N rates x Pl freq =0.38, Site x N rates x pl freq=0.76

*Insignificant interactions are not shown, pl- plucking intervals, freq- frequency, N rates- nitrogenous fertilizer rates

Table 9: Responses of soil organic carbon contents (%) to nitrogen rates, plucking frequencies and location (Depth: 20–30 cm)

		Nitrogen Rates (/ha/year)					*Mean Plucking*		
Site	*Plucking Freq (days)*	*0*	*75*	*150*	*225*	*300*	*freq*	*Mean site*	*C.V.%*
Timbilil	7	2.30	2.65	3.26	3.40	3.44	3.01		3.77
	14	2.77	3.73	3.66	3.70	4.00	3.57		
	21	2.53	3.19	3.46	3.55	3.72	3.29	3.29	
	Rates	2.53	3.19	3.46	3.55	3.72			
	LSD, p ≤ 0.05	0.20					NS		
	NxPl freq, p ≤ 0.05	0.28							
Changoi	7	2.94	2.60	3.54	3.44	3.75	3.25		
	14	2.78	3.30	3.67	3.71	3.75	3.44		
	21	2.86	2.95	3.60	3.57	3.75	3.35	4.35	6.56
	Mean N rates	2.86	2.95	3.60	3.57	3.75			
	LSD, p ≤ 0.05	0.35					NS		
	NxPl Freq, p ≤ 0.05	0.50							
Arroket	7	3.05	2.66	3.51	3.46	3.75	3.29		
	14	3.08	3.50	3.50	3.55	3.67	3.46		
	21	3.07	3.08	3.50	3.51	3.71	3.37	3.37	9.53
	Mean N rates	3.07	3.08	3.50	3.51	3.71			
	LSD, p ≤ 0.05	0.52					NS		
Kitabi	7	2.62	3.56	3.56	3.75	4.32	3.56		
	14	1.69	2.32	2.89	3.85	4.02	2.96		
	21	2.16	2.94	3.23	3.80	4.17	3.26	3.26	9.88
	Mean N rates	2.16	2.94	3.23	3.80	4.17			
	LSD, p ≤ 0.05	0.52					NS		
	NxPl freq, p ≤ 0.05	0.73							
Mulindi	7	10.83	11.14	11.78	16.15	13.00	12.58		
	14	11.51	12.46	13.35	10.54	13.70	12.31		
	21	11.17	11.80	12.56	13.34	13.35	12.44	12.45	5.63
	Mean N rates	11.17	11.80	12.56	13.34	13.35			
	LSD, p ≤ 0.05	1.12					NS		
Katoke	7	1.79	3.27	3.36	3.45	3.72	3.12		
	14	1.65	2.64	3.41	3.61	4.38	3.14		
	21	1.72	2.96	3.39	3.53	4.05	3.13	3.13	10.75
	Mean N rates	1.72	2.96	3.39	3.53	4.05			
	LSD, p ≤ 0.05	0.54					NS		
	NxPl freq, p ≤ 0.05	0.76							
Maruku	7	7.23	8.40	8.08	9.34	10.32	8.67		
	14	5.78	5.52	7.40	7.50	8.79	7.00		
	21	6.51	6.96	7.74	8.42	9.55	7.84	7.84	6.34
	Mean N rates	6.51	6.96	7.74	8.42	9.55			
	LSD, p ≤ 0.05	0.80					NS		
	NxPl freq, p ≤ 0.05	1.13							
Mean of sites	7	5.27	4.84	5.20	5.52	5.94	5.35		
	14	4.06	4.71	5.29	5.60	5.96	5.13		
	21	4.66	4.78	5.25	5.56	5.95	5.24		7.61
	N rates	4.66	4.78	5.25	5.56	5.95			
LSD,p ≤ 0.05		0.17					NS	0.82	
	Site x N rates=0.34, Site x N rates x pl freq=0.48								

Pl - plucking intervals, freq- frequency, N rates- nitrogenous fertilizer rates
*Insignificant interactions are not shown

Table 10: Responses of soil organic carbon contents (%) to nitrogen rates, plucking frequencies and location (Depth: 40–60 cm)

Site	*Plucking Freq (days)*	*Nitrogen Rates (/ha/year)*					*Mean Plucking Freq*	*Mean site*	*C.V.%*
		0	*75*	*150*	*225*	*300*			
Timbilil	7	2.28	2.74	2.81	3.01	3.58	2.88		
	14	2.16	3.15	3.41	3.28	3.51	3.10		
	21	2.22	2.95	3.11	3.16	3.55	3.00	2.99	10.45
	Mean N rates	2.22	2.95	3.11	3.16	3.55			
	LSD, $p \leq 0.05$	0.50					NS		
Changoi	7	2.81	3.16	3.18	3.61	3.72	3.30		
	14	2.22	2.80	2.95	3.68	3.66	3.06		
	21	2.51	2.98	3.07	3.65	3.69	3.18	3.18	7.69
	Mean N rates	2.51	2.98	3.07	3.65	3.69			
	LSD, $p \leq 0.05$	0.39					NS		
Arroket	7	2.57	3.07	3.60	3.65	3.66	3.31		
	14	2.09	3.15	3.78	3.75	4.00	3.35		
	21	2.33	3.11	3.69	3.70	3.83	3.33	3.33	11.53
	Mean N rates	2.33	3.11	3.69	3.70	3.83			
	LSD, $p \leq 0.05$	0.62					NS		
Kitabi	7	1.99	3.22	3.49	3.69	4.19	3.32		
	14	2.42	2.89	3.69	3.59	3.82	3.28		
	21	2.21	3.05	3.59	3.64	4.00	3.30	3.30	6.63
	Mean N rates	2.21	3.05	3.59	3.64	4.00			
	LSD, $p \leq 0.05$	0.35					NS		
	NxPl Freq, $p \leq 0.05$	0.42							
Mulindi	7	10.19	11.78	13.24	13.54	13.86	12.52		
	14	15.35	17.59	18.28	18.73	18.87	17.77		
	21	12.77	14.69	15.76	16.13	16.37	15.14	15.11	2.90
	Mean N rates	12.77	14.69	15.76	16.13	16.37			
	LSD, $p \leq 0.05$	0.70					NS		
Katoke	7	1.89	2.05	2.88	3.13	3.76	2.74		
	14	1.87	2.89	3.95	4.05	4.62	3.48		
	21	1.88	2.47	3.41	3.59	4.19	3.12	3.11	7.23
	Mean N rates	1.88	2.47	3.41	3.59	4.19			
	LSD, $p \leq 0.05$	0.36					NS		
	NxPl Freq, $p \leq 0.05$	0.51							
Maruku	7	4.63	4.82	5.11	5.35	5.49	5.08		
	14	2.56	3.71	4.55	5.49	5.79	4.42		
	21	3.59	4.26	4.83	5.42	5.64	4.75	4.75	5.02
	Mean N rates	3.59	4.26	4.83	5.42	5.64			
	LSD, $p \leq 0.05$	0.38					NS		
	NxPl Freq, $p \leq 0.05$	0.54							
Mean of sites	7	3.77	4.41	4.98	5.16	5.42	4.75		
	14	4.10	5.17	5.90	6.01	6.30	5.49		
	21	3.93	4.79	5.44	5.58	5.86	5.12		6.44
	N rates	3.93	4.79	5.44	5.58	5.86			
LSD, $p \leq 0.05$		0.14					NS	NS	
	Site x N rates = 0.28, , N rates x Pl Freq = 0.20, Site x N rates x pl Freq = 0.39								

*Insignificant interactions are not shown

Table 11: Effects of nitrogen fertilizer rates, plucking frequencies and sites on mean yields (kg mt/ ha)

Site	*Plucking Freq (days)*	*Nitrogen Rates(Kg N/Ha/Year)*					*Mean Plucking Freq*	*Mean site*	*C.V.%*
		0	*75*	*150*	*225*	*300*			
	7	3946	4187	4515	4463	4569	4336		
	14	3645	4028	4216	4383	4213	4097	4249	5.79
Timbilil	21	3881	4115	4298	4559	4709	4313		
	Mean N rates	3824	4110	4343	4468	4497			
	LSD≤0.05	322					NS		
	7	4426	4870	4907	5054	5313	4914		
	14	4818	4974	5545	5505	5207	5210	5037	5.74
Changoi	21	4582	4762	4807	5253	5531	4986		
	Mean N rates	4609	4869	5086	5270	5350			
	LSD≤0.05	378					NS		
	7	5421	6038	6291	5882	6419	6010		
	14	5580	5837	6240	6825	6342	6165	6219	6.83
Arroket	21	5537	6331	6211	7044	7283	6481		
	Mean N rates	5513	6068	6247	6584	6681			
	LSD≤0.05	256					367		
	7	4143	4089	4552	5429	5256	4694		
	14	3234	4306	4551	5148	4764	4401	4467	13.06
Kitabi	21	3382	2994	5391	5276	4487	4306		
	Mean N rates	3587	3796	4831	5284	4836			
	LSD≤0.05	763					NS		
	7	2229	2346	2847	2430	2572	2485		
	14	2063	1656	2012	1591	1802	1825	1902	25.23
Mulindi	21	1140	1500	1120	1388	1841	1399		
	Mean N rates	1811	1834	1993	1803	2072			
	LSD≤0.05	NS					754		
	7	3346	3052	3564	3693	3750	3481		
	14	3249	3474	3400	3598	3718	3488	3420	10.94
Katoke	21	2854	3139	3506	3680	3284	3292		
	Mean	3150	3222	3490	3657	3584			
	LSD≤0.05	490					NS		
	7	2440	2717	2351	2799	2858	2633		
	14	2190	2402	2706	2812	2363	2494	2476	13.4
Maruku	21	2101	2441	2232	2602	2231	2301		
	Mean N rates	2244	2487	2430	2738	2484			
	LSD,p ≤ 0.05	NS					NS		
Mean for all 7 Sites	7	3705	3833	4044	4170	4328	4016		
	14	3528	3819	4026	4198	4021	3918		11.7
	21	3346	3651	3939	4203	4183	3862		
	N rates	3526	3763	4003	4191	4177			
	LSD≤0.05	191					NS	223	

Source: Msomba *et al*., 2014

the notion that leaving tea prunings *in situ* improves SOC contents. Also the high percentage clay contents (Table 2) at the upper soil profiles could have influenced soil organic carbon contents.[48,49]

The high cation exchange capacity (CEC) in these soils (Table 2) were attributed to high SOC contents (Tables 7 to 10), as previously observed in Sri Lanka.[50] CEC in the range of ≥25 cmols/kg represent

Table 12: Correlation coefficients (r) of soil organic carbon, pH and yields

		SOC						
Depth (cm)	*Parameter*	*Timbilil*	*Changoi*	*Arroket*	*Kitabi*	*Mulindi*	*Katoke*	*Maruku7*
0–10	pH	-0.642	-0.897	-0.703	-0.982	-0.989	-0.848	-0.908
	Yield	0.984	0.862	0.910	0.903	0.503	0.810	0.614
10–20	pH	-0.937	-0.919	-0.968	-0.872	-0.997	-0.930	-0.786
	Yield	0.985	0.960	0.982	0.960	0.589	0.974	0.781
20-30	pH	-0.922	-0.947	-0.917	-0.965	-0.973	-0.912	-0.941
	Yield	0.982	0.940	0.878	0.850	0.502	0.862	0.551
40-60	pH	-0.964	-0.920	-0.680	-0.989	-0.757	-0.988	-0.958
	Yield	0.946	0.974	0.957	0.864	0.573	0.933	0.745

clay dominance or fine soils, as observed at all sites, especially at 0-20 cm soil depth.

The SOC contents were above adequate range (>0.75 %)[51] at all the sites. Timbilil had the lowest ($p \leq 0.05$) SOC contents compared to the other six sites while Mulindi had exceptionally high ($p \leq 0.05$) levels. Mulindi site had peat soils that are generally water logged with high contents of partially decomposing plant materials. Such soils have very high SOC.[46,52] The variations in SOC observed in different regions were due to differences in environmental factors[23,53] and soil chemical properties.[54] Previous reports from this study showed that yields[9] and mature leaf nutrients[44] varied with location of production. These variations in SOC contents could be one of the possible causes in yield variations observed (Table 11).[9]

Increasing rates of nitrogenous fertilizers increased ($p \leq 0.05$) SOC at all sites. Similar observation had been made on single site studies.[21,45] These results demonstrate that where SOC is low, application of nitrogen fertilizer is one way of increasing the levels. Nitrogen fertilization increases leaf foliage residue inputs to the soil, resulting in increases in soil organic matter. Optimal nitrogen fertilizer input program sequesters atmospheric CO_2 into SOC by increased plant growth and subsequently, the return of organic carbon to the soil for storage as soil organic matter in a no-till system like in tea production.[55] To maintain high organic carbon status of tea soils and improve soil fertility, adequate supply of nitrogen fertilizers (75-150 Kg N/ha/year) can be applied in East Africa.

Intervals of harvesting did not influence SOC contents in all locations and soil depths. This suggested that the return of organic matter to the soil through prunings and leaf drop was not influenced by harvesting interval. Therefore, provided management practices are uniform, plucking intervals may have little influence on SOC contents. However, there were sporadic significant interactions effects between nitrogen fertilizer rates and plucking intervals at different sites and soil depths (Tables 7 to 10). This demonstrated that the extent of SOC change with plucking intervals varied with sites and soil depths, which could be due to varied soil characteristics (Table 2) in the regions. Significant ($p \leq 0.05$) interactions effects between sites and nitrogen rates at all soil depths, demonstrated that the extents of increase in SOC with nitrogen fertilizer rates varied with location of production. Similar non-uniform responses had been observed in the mature tea leaf nutrients.[44]

Relationship (r) between Soil Organic Carbon Contents, pH and Yields of Tea.

The yields[9] are presented in Table 11. The linear correlation coefficients between SOC, pH and yields of tea are represented in Table 12. Yields were positively related to soil organic carbon, reaching significant levels ($r \geq 0.878$, $p \leq 0.05$) in Timbilil, Arroket and Kitabi at 0–10cm, Timbilil, Changoi, Arroket, Katoke at 10-20cm, Timbilil, Changoi, Arroket at 20–30cm, Timbilil, Changoi, Arroket and Katoke at 40–60cm soil depths. The observations were similar to previous findings.[5,21] SOC is considered the most important proportion of SOM in providing nutrients to plants.[56] Soil nutrients from SOC are mineralized and released as plant available forms into the soil mineral nutrient pool,[57] that improve tea yield.[21,30] The results demonstrated that improving SOC improved tea productivity. For sustained crop production, it is necessary to maintain sufficient SOC in the fields throughout East Africa.

SOC contents had inverse relationship ($r \geq -0.878$, $p \leq 0.05$) with pH at all sites and some depths (Table 12). Similar inverse relationship between SOC and pH had been observed in previous in Assam[46] and in Turkey.[58] This relationship may be attributed to soil nitrogen which influenced soil pH[22] and released organic acids during decomposition of plant litter.[14] The decrease in soil pH could lead to fixation of nutrients like phosphorus, accumulation of others like manganese and aluminium while leaching of base cations. Judicious use of nitrogen fertilizers in association with other appropriate management practices can ensure sustained production of tea in East Africa.

In summary, levels of SOC and pH which influence tea yields, varied ($p \leq 0.05$) with location of production, suggesting yields of tea will vary in different locations even if agronomic inputs are uniform. Nitrogenous fertilizer application rates above 200kgN/ha/year reduced soil pH to low levels below 3.10 in some regions. Therefore, use of nitrogenous fertilizer below 200kg N/ha/year may ensure sustained tea productivity. SOC increased ($p \leq 0.05$) with rise in nitrogenous fertilizer rates at all sites, demonstrating that nitrogen fertilizer application improves SOC levels in tea farms. Harvesting interval had no influence on soil organic carbon and pH levels

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