Original Research Article

Quality of Tea Soil Induced by Cultivation Period

ABSTRACT

Tea is Bangladesh's second-highest agricultural export earner, and the nation is rated 15th among all tea-exporting nations. To develop and support the tea business in Bangladesh, it is crucial to comprehend the current nutrient status of tea soils. The purpose of the study was to examine the inherent physical and chemical characteristics of tea soils in relation to the effects of topography, soil depth, and cultivation times. The results showed the effects of soil depths, topography, and cultivation periods on all the measured physical and chemical properties, including texture, bulk density, organic matter (OM), organic carbon (OC), pH, and cation exchange capacity (CEC). The available and total contents of major nutrients such as nitrogen (N), phosphorus (P), and potassium (K) were significant (P<0.001). The contents of P and K were observed to be lower than the critical values ideal for tea cultivation. However, the results indicated that the soils kept for nutrient restoration for years showed a nutrient status close to the ideal value of tea cultivation.

Keywords: Nutrient status, Tea soils, Soil depth, Topography, Cultivation period.

1. INTRODUCTION

As a traditional beverage, tea (*Camellia sinensis* L.) is the second most widely consumed health drink worldwide after water [1, 2]. It primarily originated in south-eastern China but is now being cultivated in many countries across tropical and subtropical regions. Among the 50 tea-producing countries, some of the major countries are China, India, Kenya, Sri Lanka, Vietnam, Turkey, Indonesia, and Iran [3]. In Bangladesh, tea is cultivated in three ecological zones: Surma Valley in greater Sylhet, Halda Valley in Chattogram, and Karatoa Valley in Panchagarh district [4]. Tea is the second-highest agricultural export-earning product in Bangladesh. Bangladesh ranks 12th in the list of the highest tea producing countries and 15th among the highest tea-exporting countries [5]. However, a knowledge gap in proper tea soil management still limits the success of the tea industry in Bangladesh.

Long-term cultivation of tea crops leads to a decline in soil quality [6]. Maintaining nutrient status of soils through proper management plays a vital role in tea cultivation. The harvestable portion of tea is the succulent shoot, which contains the largest percentage of nutrients in the plant [7]. Therefore, tea plant requires a high nutrient supply for commercial production. The traditional approach of tea cultivation using chemical fertilizers and pesticides causes a significant soil degradation [8] by the reduction of soil organic matter (OM), nitrogen (N) and (P) loss due to erosion, fixation of P in acidic pH, and reduction of nutrients by soil microorganisms. A combination of several physiochemical properties of tea soils, management practices, and amendments can affect tea-yield. Tea-yield per hectare in Bangladesh is low compared to other tea growing countries of the world. The causes of low tea production are determined by low soil pH, low nutrient status and anthropogenic disturbances [9]. To ensure sustainable tea production [10], nutrient management of tea soils is important particularly for improving soil health. In general, N, P and K contents and other nutrient status of 90% tea cultivated areas are in medium-low [11]. Tea-farmers in Bangladesh use NPK fertilizer without any proper knowledge about existing nutrient status of the soils. Tea production may decrease with unplanned and imperfect fertilizing program. In Bangladesh, tea industry expansion is therefore threatened by knowledge gap and inadequate management practices.

Currently in Bangladesh, ecological and/or sustainable (integrated and natural resource-based) approaches through the usage of various organic additives (compost, vermicompost, biochar, etc.) in combination with inorganic fertilizers are increasingly important to replace traditional (chemical fertilizer-based) approaches in tea cultivation [12, 13]. Still, nutrient loss due to erosion and leaching in tea soils is significant. The determination of the current nutrient status for the adaptation of the effective fertilizing program and other tea soil management practice to increase tea production and expansion of the tea industry in Bangladesh is essential. Therefore, the objectives of the current study were to determine the nutrient status and the variation in properties of tea soils in Bangladesh in relation to soil depth, topography, and cultivation period. The findings will provide a scientific groundwork for tea soil management and proper fertilization approaches to improving Bangladesh's tea soils. The outcomes will ultimately assist tea farmers and promote the development of the tea industry in Bangladesh.

2. MATERIAL AND METHODS

2.1 Soil sampling sites

Three hills in a sub-station of Bangladesh Tea Research Institute at Udulia of Fatikchari upazila in Chattagram district of Bangladesh was selected as the soil sampling sites. The hills were selected based on different tea cultivation periods. They were categorized as- i) Hill 1 (10 years cultivated hill): under cultivation from 1972 to 1982 and tea leaf collection has already been stopped for nutrient restoration; ii) Hill 2 (2 years cultivated hill): under cultivation from 2008 to 2010 and tea leaf collection is ongoing; iii) Hill 3 (1 year cultivated hill): cultivation started at 2018 and tea leaf collection has not been started until 2019.

The average yield of made tea in this sub-station is near about 1500 Kg/ha. In Fatikchari, the wet season is hot, oppressive, and overcast and the dry season is warm, humid, and mostly clear. The most common form of precipitation throughout the year is rain. Fatikchari experiences extreme seasonal variation in monthly rainfall and humidity. The topography within 2 miles of Fatikchari is essentially flat with a maximum elevation change of 49 feet and an average elevation above sea level is 41 feet, and within 10 miles is essentially flat (1,033 feet).

2.2 Collection of soils

A total of 27 representative soil samples with 3 replications were collected from each of 3 hills at 3 different topographic positions (top, slope, and base) at 3 depths including top-soil (0-15 cm), sub-soil (16-30 cm) and the substratum-soil (31-45 cm) in January 2019 [14]. The location of sampling sites is presented in Figure 1 and the geographic coordinates of sampling points are shown in Table 1. Both disturbed and undisturbed soils were sampled by using auger and core. Samples were taken to the laboratory of the department of Soil and Environmental Sciences in University of Barishal, Bangladesh.

2.3 Preparation and analysis of soil samples

Soil samples were air-dried, ground and sieved through a 2 mm sieve. Soil samples were analyzed for physical, physico-chemical and chemical parameters. Soil pH was measured using the glass electrode method (HACH instruments, PHC10101). Wet oxidation method of Walkley and Black [15] was followed to determine organic carbon (OC %). Soils were analyzed for both total and available form of N, P and K. Digestion of soil samples were done by a wet-oxidation method using concentrated sulphuric acid. The total N was determined by micro Kjeldahl's method [16]. For total P and total K analysis, wet digestion of soils was done by using nitric acid and perchloric acid [17]. The available N was extracted by 1M KCl and determined by steam distillation method with the Devada's alloy [18]. The available P was extracted by using the method described in Bray and Kurtz [19] and determined at 880 nm when soil pH was less than 7. The available K was extracted by using neutral 1M Ammonium acetate (NH_4OAc) solution [20] and determined by a flame photometer (Jenway 500701 PFP7 Industrial Flame Photometer). The textural class and CEC were measured by using the hydrometer [21] and ammonium acetate extraction method [22], respectively. Bulk density of the soil sample was determined by Core method [23].

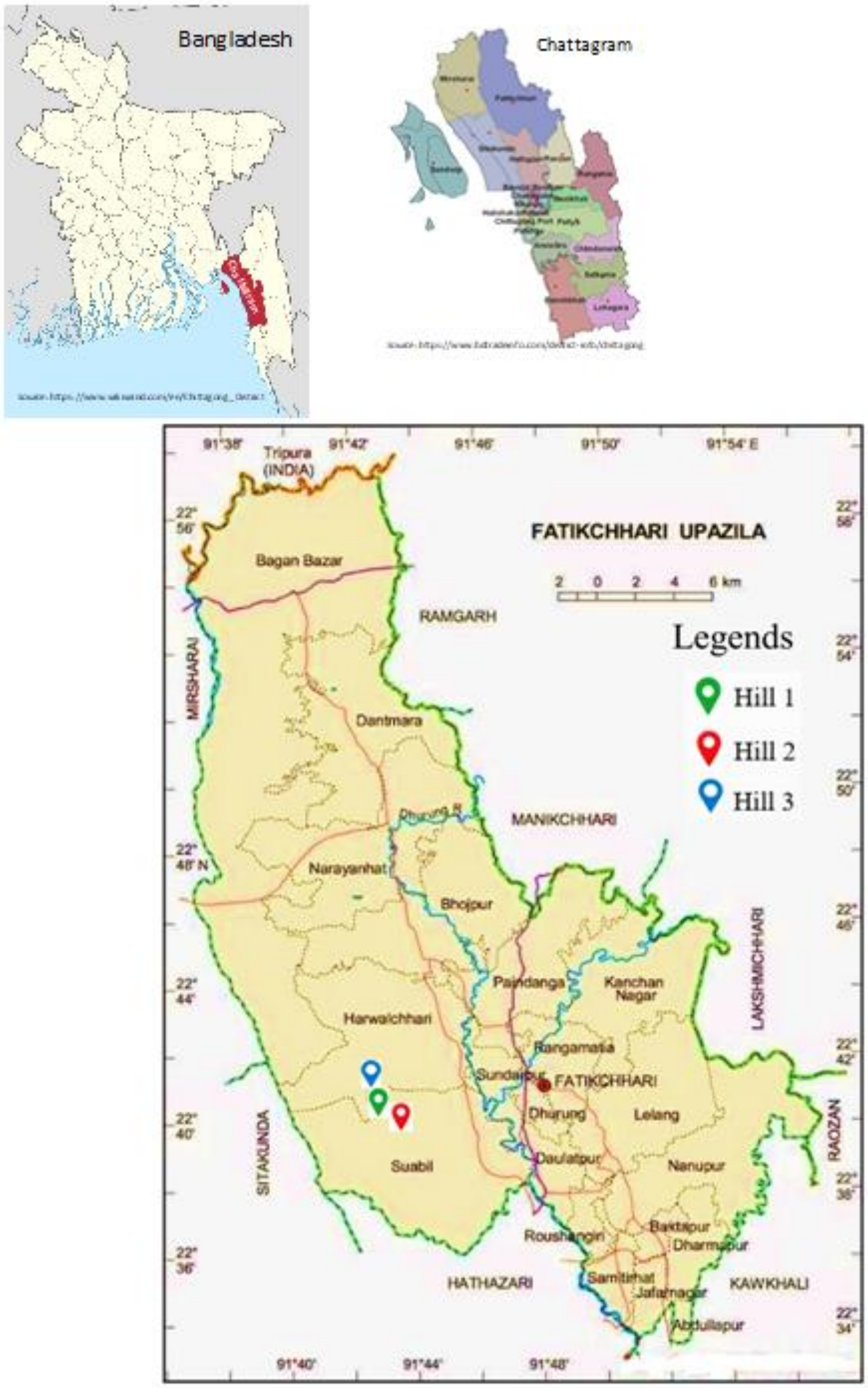

Fig. 1. Location of sampling sites

Table 1. Geographic coordinates of the sampling points in three hills in BTRI sub-station at Fatikchhari upazila, in Chattagram district, Bangladesh.

Topography	Sampling point	Coordinates
	10 years cultivated hill	
	1	22°36'59"N 91°45'31"E
Top	2	22°36'58"N 91°45'32"E
	3	22°36'57"N 91°45'34"E

	1	22°36'57"N 91°45'33"E
Slope	2	22°36'57"N 91°45'32"E
	3	22°36'57"N 91°45'31"E
	1	22°36'56"N 91°45'32"E
Base	2	22°36'56"N 91°45'31"E
	3	22°36'56"N 91°45'33"E
2 years cultivated hill		
	1	22°36'50"N 91°45'37"E
Top	2	22°36'49"N 91°45'36"E
	3	22°36'49"N 91°45'35"E
	1	22°36'50"N 91°45'38"E
Slope	2	22°36'51"N 91°45'37"E
	3	22°36'50"N 91°45'36"E
	1	22°36'50"N 91°45'34"E
Base	2	22°36'50"N 91°45'35"E
	3	22°36'50"N 91°45'36"E
1 year cultivated hill		
	1	22°37'05"N 91°45'29"E
Top	2	22°37'00"N 91°45'29"E
	3	22°37'06"N 91°45'28"E
	1	22°37'03"N 91°45'29"E
Slope	2	22°37'04"N 91°45'29"E
	3	22°37'06"N 91°45'29"E
	1	22°37'05"N 91°45'30"E
Base	2	22°37'06"N 91°45'30"E
	3	22°37'04"N 91°45'30"E

2.4 Statistical analysis

Values of different soil parameters are reported as mean ± standard deviation. Measured data were tested for normality of distributions and homogeneity of variances prior to further statistical analysis. Effects of three soil depths (0-15cm, 16-30 cm, and 31-45cm), the topographical variation (three different slope positions), and the three different cultivation periods on soil parameters were compared separately by using the one-way analysis of variance (one-way ANOVA). In addition, multivariate regression analysis was performed to analyse the combined effects of soil depths, topography and cultivation period on soil parameters. Statistical analysis was performed by using SPSS V. 23 at the level of $p<0.05$.

3. RESULTS AND DISCUSSION

3.1 Subheading Physical and physico-chemical properties of tea soils

Textural classes of the studied soils were sandy loam and sandy clay loam (Table 2), suitable for tea cultivation [24, 25]. The textural classes of the soils might affect many other properties of soils including moisture availability, soil temperature, nutrient supply, and accessibility of soil organic matter to microbial decomposition [26]. Bulk densities of studied soils ranged from 1.25 to 1.71 gcm^{-3} (Table 2) with a mean of 1.45 gcm^{-3} in Hill 1, 1.49 gcm^{-3} in Hill 2 and 1.40 gcm^{-3} in Hill 3. The results of the bulk densities showed an increasing trend across the soil depths as well as the topography from top to base position of

Table 2. Physical and physico-chemical properties of tea soils collected from three soil depths and three topographic positions of three hills under different cultivation periods in a sub-station of Bangladesh Tea Research Institute at Udulia, Fatikchari upazila, Chattagram district, Bangladesh.

Hill	Topography	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural classes	Bulk density (gcm^{-1})	pH	CEC (meq/100g soil)
			Mean ± stdv	Mean ± stdv	Mean ± stdv		Mean ± stdv	Mean ± stdv	Mean ± stdv
10 years	Top	0-15	71.2 ± 3.14	14.3 ± 3.89	14.5 ± 0.81	Sandy Loam	1.30 ± 0.05	4.93 ± 0.08	10.4 ± 1.19

cultivated hill		16-30	67.3 ± 6.80	15.0 ± 5.77	17.8 ± 2.00	Sandy Clay Loam	1.34 ± 0.02	4.68 ± 0.03	15.6 ± 0.79
		31-45	67.4 ± 6.13	9.36 ± 2.64	23.3 ± 3.70	Sandy Clay Loam	1.43 ± 0.05	4.66 ± 0.08	15.1 ± 1.38
	Slope	0-15	73.9 ± 2.04	13.8 ± 0.63	12.4 ± 1.45	Sandy Loam	1.27 ± 0.01	5.00 ± 0.13	9.64 ± 1.38
		16-30	71.7 ± 2.00	13.5 ± 1.48	14.8 ± 1.98	Sandy Loam	1.46 ± 0.05	5.01 ± 0.13	12.1 ± 0.35
		31-45	72.1 ± 2.47	10.7 ± 2.46	17.2 ± 4.08	Sandy Clay Loam	1.51 ± 0.04	4.97 ± 0.12	12.4 ± 0.00
	Base	0-15	65.5 ± 2.41	22.9 ± 2.50	11.6 ± 1.95	Sandy Loam	1.31 ± 0.06	5.49 ± 0.14	9.26 ± 2.11
		16-30	62.6 ± 0.63	22.6 ± 0.85	14.8 ± 1.35	Sandy Loam	1.47 ± 0.02	4.99 ± 0.03	11.0 ± 1.19
		31-45	61.9 ± 1.35	21.2 ± 0.44	16.9 ± 1.92	Sandy Loam	1.56 ± 0.09	4.67 ± 0.12	13.8 ± 0.60
2 years cultivated hill	Top	0-15	66.6 ± 2.60	18.8 ± 1.25	14.7 ± 1.44	Sandy Loam	1.32 ± 0.08	3.76 ± 0.03	10.6 ± 0.68
		16-30	57.2 ± 1.38	20.3 ± 1.81	22.5 ± 0.50	Sandy Loam	1.57 ± 0.11	3.42 ± 0.02	11.2 ± 0.48
		31-45	59.1 ± 4.39	16.3 ± 2.50	24.7 ± 1.91	Sandy Clay Loam	1.48 ± 0.04	3.38 ± 0.04	12.4 ± 0.76
	Slope	0-15	63.2 ± 4.08	19.6 ± 3.11	17.3 ± 1.15	Sandy Loam	1.33 ± 0.03	3.98 ± 0.17	11.2 ± 0.56
		16-30	56.6 ± 4.39	19.8 ± 2.54	21.3 ± 1.88	Sandy Clay Loam	1.35 ± 0.06	4.06 ± 0.24	13.3 ± 0.40
		31-45	58.6 ± 3.15	19.7 ± 2.91	21.8 ± 2.14	Sandy Clay Loam	1.55 ± 0.06	4.14 ± 0.16	14.0 ± 0.40
	Base	0-15	68.1 ± 5.64	15.8 ± 4.39	16.1 ± 1.44	Sandy Loam	1.51 ± 0.04	4.37 ± 0.42	12.8 ± 0.44
		16-30	66.8 ± 1.91	15.0 ± 1.25	18.2 ± 0.81	Sandy Loam	1.64 ± 0.04	4.25 ± 0.03	8.29 ± 0.37
		31-45	69.0 ± 1.80	13.3 ± 2.89	17.7 ± 1.26	Sandy Loam	1.71 ± 0.02	4.28 ± 0.06	12.0 ± 0.40
1 year cultivated hill	Top	0-15	66.9 ± 1.91	24.5 ± 1.25	8.58 ± 0.72	Sandy Loam	1.33 ± 0.03	4.96 ± 0.19	9.86 ± 1.04
		16-30	58.3 ± 3.00	25.6 ± 1.88	16.1 ± 1.91	Sandy Loam	1.30 ± 0.03	4.69 ± 0.05	7.56 ± 0.69
		31-45	57.5 ± 2.14	22.3 ± 1.35	20.2 ± 1.13	Sandy Clay Loam	1.46 ± 0.10	4.50 ± 0.10	10.9 ± 1.19
	Slope	0-15	61.5 ± 1.32	25.1 ± 1.18	13.4 ± 1.33	Sandy Loam	1.33 ± 0.01	4.62 ± 0.11	8.25 ± 0.00
		16-30	57.3 ± 2.81	25.7 ±2.70	17.0 ± 1.25	Sandy Loam	1.37 ± 0.04	4.42 ± 0.11	6.19 ± 0.69
		31-45	54.3 ± 2.50	22.3 ± 2.32	23.4 ± 1.01	Sandy Clay Loam	1.51 ± 0.03	4.27 ± 0.04	12.6 ± 1.01
	Base	0-15	64.1 ± 4.58	24.6 ± 4.02	11.3 ± 1.70	Sandy Loam	1.47 ± 0.06	4.58 ± 0.16	13.8 ± 1.38
		16-30	66.7 ± 2.60	18.8 ± 1.25	14.6 ± 3.15	Sandy Loam	1.59 ± 0.06	4.40 ± 0.01	7.13 ± 0.43
		31-45	63.4 ± 3.61	18.3 ± 2.89	18.3 ± 3.31	Sandy Loam	1.69 ± 0.04	4.56 ± 0.13	11.7 ± 0.69

the hills except some exceptions (Table 2). The results were congruent with the observation by Lee et al. [27]. The increasing trend of bulk density with soil depth might be attributed to the lower clay and organic matter content [28] and compaction of the lower layer soils. Soil quality typically decreases with increasing bulk density [29].

The pH of the studied soils ranged from 4.7 to 5.5, 3.4 –to 4.4 and 4.3 to 5.0 in Hill 1, Hill 2, and Hill 3, respectively, whereas the optimum pH range for tea cultivation is 4.5-5.5 [30]. The results showed that Hill 1 was in the best condition regarding pH for tea cultivation among the hills. Being cultivated for 10 years from 1972 to 1982, the Hill 1 is not currently under tea collection and left for quality restoration for several years. In contrast, Hill 2 soils were out of the favorable pH range for tea cultivation, whereas some of the Hill 3 soils have the favorable pH (Table 2). Hill 2 had been cultivated for 2 years and was under production during soil sampling, whereas Hill 3 had been cultivated for only 1 year and tea collection was yet to be started at the sampling time. It is quite clear that the Hill 2 soil needs proper management for brining pH in favorable range for tea cultivation. Lime and organic fertilizer amendments can maintain the optimum soil pH for tea cultivation. The conventional tea cultivation approach usually uses chemical fertilizers including ammonium nitrate, ammonium sulphate, urea, calcium-ammonium nitrate, and ammonium chloride. These fertilizers eventually increase soil acidity [31] through the enhancement of microbial decomposition of organic matter resulting in organic acids production in soils [32]. This might be the reason why the pH of the upper soil was slightly lower than that of the lower depth soil.

The CEC ranged from 9.26 to 15.6 meq/100 g in Hill 1, 8.29 to 14.0 meq/100 g in Hill 2 and 6.19 to 12.6 meq/100 g in Hill 3 (Table 2). Average values of CEC were found 12.14, 11.75, and 9.77 meq/100g, respectively in Hill 1, Hill 2, and Hill 3. Hossain et al. [33] reported on a range of CEC of 5.15 to 33.25 meq/100g soil at Satgoan, Baraora and Kurmah tea estates, in Sylhet, Bangladesh. Additionally, CEC ranged from 11.42 to 24.86 meq/100 g soil of Moulvibazar district, Bangladesh [34]. This variation of CEC was accompanied with the amount of clay content, pH, and percentage of organic matter in the investigated soils [35].

3.2 Chemical properties of tea soils

The relative variation of organic matter (OM) and organic carbon (OC) of collected soils of three hills are presented in Figure 2. The observed values of OC ranged from 0.565 to 1.093%, 0.565 to 1.068%, and 0.641 to 1.858% with average values of 0.861%, 0.761%, and 0.995% in Hill 1, Hill 2, and Hill 3, respectively. Additionally, the OM ranged from 0.97 to 2.01%, 0.71 to 2.07%, and 1.1 to 3.14% with average values of 1.48%, 1.31%, and 1.71% in Hill 1, Hill 2, and Hill 3, respectively. In top positions of Hill 1 and Hill 3, OC contents of upper soils (0 to 15 cm) were around the critical value

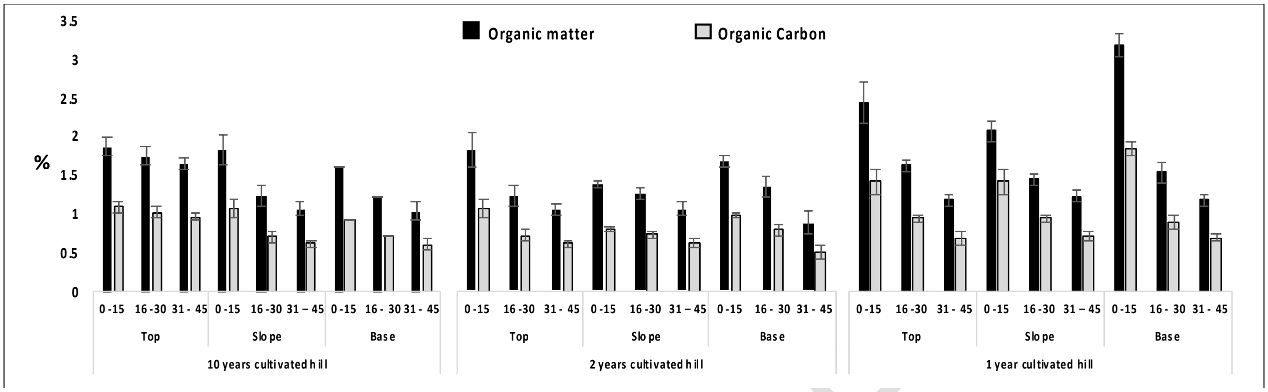

Fig. 2. Relative variation in organic carbon (OC) and organic matter (OM) in soils of three different depths and topography in three hills under different cultivation periods in a sub-station of Bangladesh Tea Research Institute at Udulia of Fatikchari upazila in Chattagram district of Bangladesh.

(1%) for tea cultivation [25], whereas OC contents in other sampling points were much lower. Additionally, OC contents were higher in upper layer of top, slope and base soils in Hill 3 than those in Hill 1. The amount of plant residues returned to the soil are observed lower in very young and very old tea fields than in the more productive tea gardens [36]. The variation in OM regarding quantity and quality in tea soils depends on the age of plantation, plant residue inputs, soil loss, conditions governing residue decomposition, and related management practices [37]. Both of OC and OM contents were observed to be decreased subsequently with the depth (Figure 2) as concurrently found in Haorongbam et al. [38]. The higher OM contents in upper soils were presumably due to the accumulation of fallen leaves and microbial residues [39]. Soil conditions necessary for attaining optimum tea yields in the uplands of Vietnam include OM content higher than 2% with a range of pH from 4.0 to 5.5 [40]. Therefore, organic fertilizers can be recommended to maintain the balance of OC and OM in the studied soils [36].

The relative variation in available N, P and K contents of collected tea soils are presented in Figure 3. In Hill 1, the available N varied between 520 and 830 mgKg-1 with an average of 660 $mgKg^{-1}$. In Hill 2, that ranged from 370 to 830 $mgKg^{-1}$ with an average of 600 mgKg-1. In Hill 3, that ranged from 370 to 1000 $mgKg^{-1}$ with an average of 620 $mgKg^{-1}$.

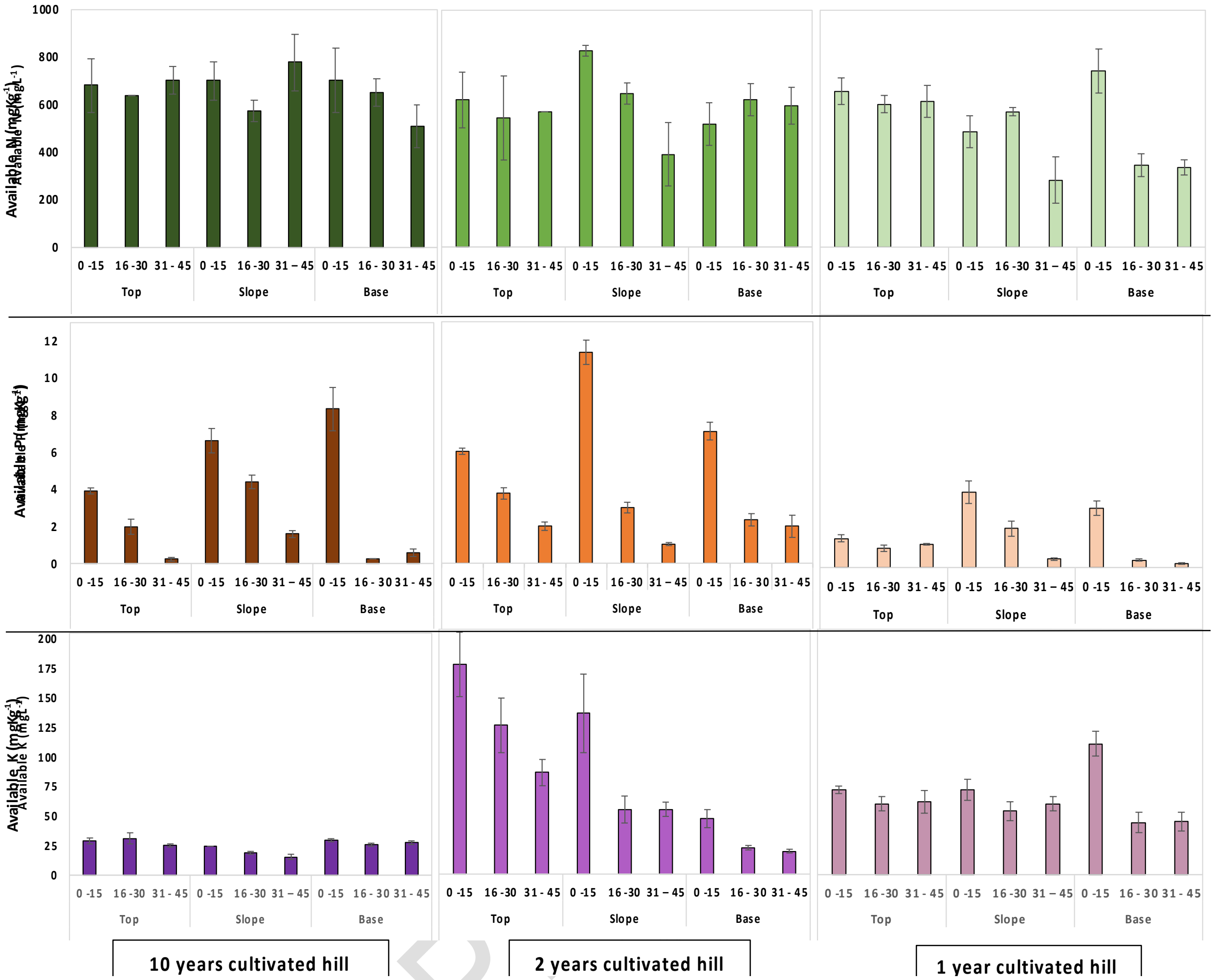

Fig. 3. Relative variation in available contents of N, P and K in soils of three different depths and topography in three hills under different cultivation periods in a sub-station of Bangladesh Tea Research Institute at Udulia of Fatikchari upazila in Chattagram district of Bangladesh.

The contents were much higher than the minimum level (149 mgKg^{-1}) [41]. According to Ranganathan and Natesan [42], N is required in large quantities for tea cultivation because it is accounted for approximately 4 to 5% of the dry weight of the harvested shoots. Available N did not significantly vary across the depth of three hills in the current study. The available P in Hill 1, Hill 2 and Hill 3 ranged from 0.13 to 9.42 mgKg^{-1}, 1.01 to 12.1 mgKg^{-1}, and 0.26 to 4.44 mgKg^{-1}, respectively. The average available P contents in Hill 1, Hill 2, and Hill 3 were 3.11, 4.30 and 1.51 mgKg-1, respectively. Those values are comparable with the results ranging from 1.00 to 4.33 mgKg^{-1} in Islam et al. [43].

Additionally, the average available K contents are 25.4 mgKg^{-1} in Hill 1, 79.6 mgKg^{-1} in Hill 2, and 62 mgKg^{-1} in Hill 3 ranging from 13.3 to 35.8 mgKg^{-1}, 17.3 to 202.5 mgKg^{-1}, and 37.6 to 118.1 mgKg^{-1}, respectively. The available K of only Hill 1 is comparable to the result ranging from 31.2 to 58.5 mgKg^{-1} for soils of 0-91 cm depth in Islam et al. [43]. The minimum levels of available P and K were determined as 32 and 110 mgKg^{-1}, respectively in Zhang et al. [41]. Another study showed the critical values of available P and K for tea cultivation were 10 mgKg^{-1} and 80 mgKg^{-1}, respectively [44]. Therefore, the current study sites are considered P and K deficit regarding available P and K contents [39]. The low contents of nutrients might be accounted for the high rate of assimilation of available forms by microorganisms and vegetations, and/or high rate of fixation by Aluminium (with P) in the prevailing acidic conditions.

The relative variation in total N, P, and K contents of collected soils are shown in figure 4. In Hill 1, total N ranged between 963 and 2888 mgKg^{-1}, with an average of 1536 mgKg^{-1}. In Hill 2, total N ranged from 709 to 2835 mgKg^{-1} with an average of 1523 mgKg^{-1}.

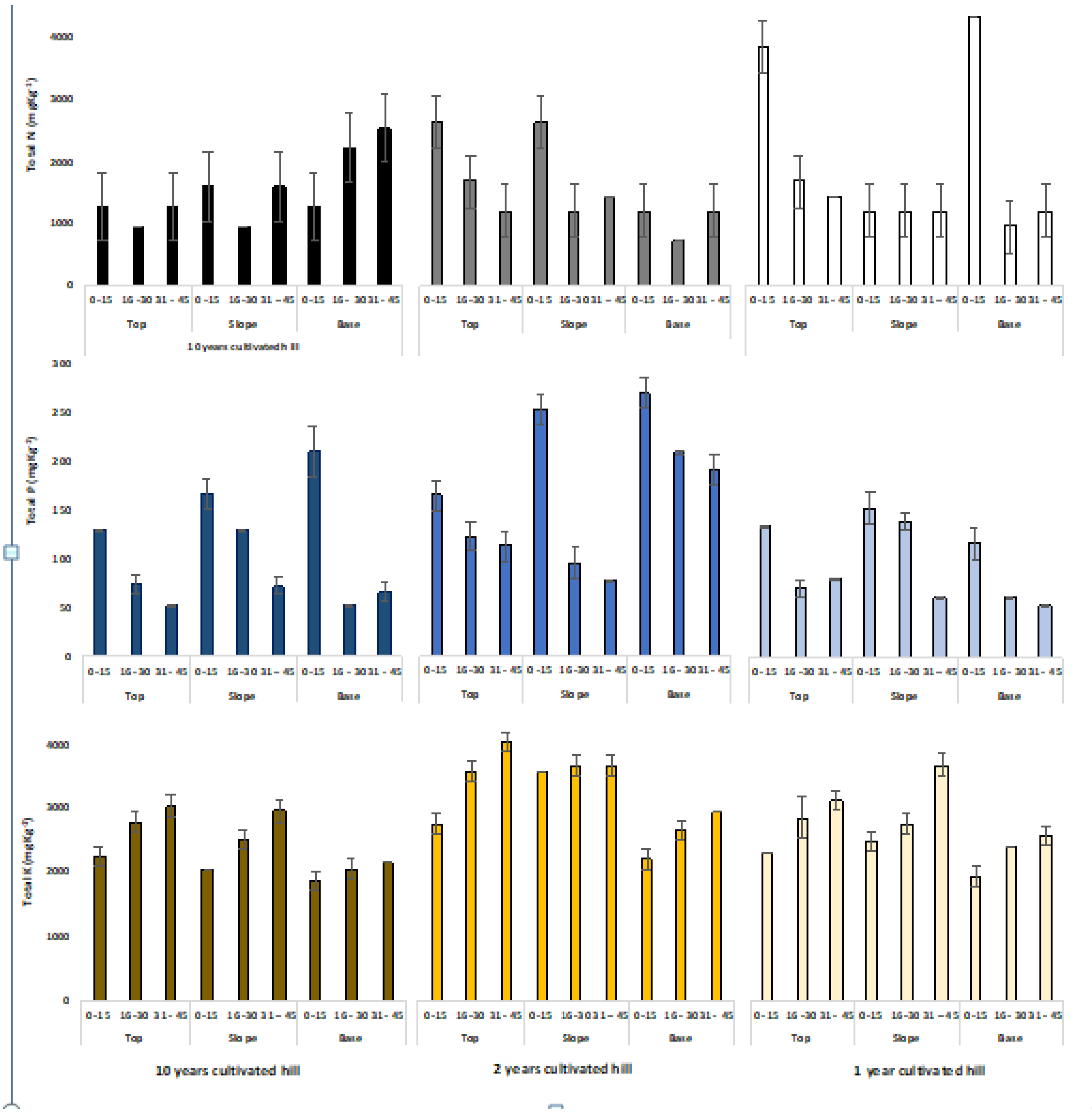

Fig. 4. Relative variation in total contents of N, P and K in soils of three different depths and topography in three hills under different cultivation periods in a sub-station of Bangladesh Tea Research Institute at Udulia of Fatikchari upazila in Chattagram district of Bangladesh.

In Hill 3, that ranged from 709 to 4253 mgKg^{-1} with an average of 1864 mgKg^{-1}. All the studied soils have sufficient total N content for tea cultivation. However, the variation in total N across the depth, topography and cultivation period was not significant. The total P in Hill 1 ranged from 52.63 to 210.85 mgKg^{-1} with an average of 107.05 mgKg^{-1}. In Hill 2, that ranged from 78.95 to 289.45 mgKg^{-1} with an average of 167.66 mgKg^{-1}. In Hill 3, that ranged from 52 to 157.9 mgKg^{-1} with an average of 94. 64 mgKg^{-1}. In addition, the total K in Hill 1, Hill 2, Hill 3 ranged from 1801.07 to 3141.55 mgKg^{-1}, 2069.17 to 3945.84 mgKg^{-1}, and 1801 to 3677.75 mgKg^{-1}, respectively. The average total K contents of soils in Hill 1, Hill 2, and Hill 3 were 2416.7, 3161.41, and 2615.29, respectively. Thus, the current study sites are considered much reach in total nutrient contents, however having minimal available nutrients.

3.3 Tea soil quality under integrated influence of soil depths, topography and cultivation periods

The multivariate analysis manifested that all the concerned factors such as soil depth, topography and cultivation period significantly (P<0.001) influenced all the relationships among the measured soil parameters (Table 3).

Table 3. Results of multivariate tests Wilks' Lambda (a) and Between-Subjects Effects (b) of cultivation period (CP), topography (TP), and soil depth (SD) on and among the relationships of tea soil parameters.

Multivariate Tests: Wilks' Lambda (a)

Effect (Wilks' Lambda)	Value	F	Hypothesis df	Error df	Sig.
Cultivation period (CP)	.000	122.485	30.000	80.000	**.000**
Topography (TP)	.007	28.538	30.000	80.000	**.000**
Soil depth (SD)	.002	61.847	30.000	80.000	**.000**
CP*TP	.000	22.210	60.000	158.368	**.000**
CP*SD	.002	11.149	60.000	158.368	**.000**
TP*SD	.004	8.330	60.000	158.368	**.000**
CP*TP*SD	.000	5.571	120.000	296.985	**.000**

Multivariate Tests: Between-Subjects Effects (b)

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
CP	Sand (%)	719.030	2	359.515	32.159	**.000**
	Silt (%)	741.885	2	370.943	54.990	**.000**
	Clay (%)	212.606	2	106.303	27.645	**.000**
	Bulk Density (gcm^{-1})	.110	2	.055	20.887	**.000**
	pH	12.963	2	6.481	343.287	**.000**
	CEC (meq/100g soil)	87.169	2	43.584	54.534	**.000**
	OM (%)	2.204	2	1.102	73.720	**.000**
	OC (%)	.740	2	.370	73.896	**.000**
	Available N ($mgKg^{-1}$))	.001	2	.000	3.659	**.032**
	Available P ($mgKg^{-1}$)	106.068	2	53.034	329.269	**.000**
	Available K ($mgKg^{-1}$)	41303.985	2	20651.992	172.487	**.000**
	Total N ($mgKg^{-1}$)	.020	2	.010	6.017	**.004**
	Total P ($mgKg^{-1}$)	82436.177	2	41218.089	330.153	**.000**
	Total K ($mgKg^{-1}$)	8030545.267	2	4015272.634	188.541	**.000**
TP	Sand (%)	63.118	2	31.559	2.823	.068
	Silt (%)	6.296	2	3.148	.467	.630
	Clay (%)	99.216	2	49.608	12.901	**.000**
	Bulk Density (gcm^{-1})	.408	2	.204	77.181	**.000**
	pH	1.137	2	.568	30.108	**.000**
	CEC (meq/100g soil)	3.378	2	1.689	2.113	.131
	OM (%)	.701	2	.351	23.457	**.000**
	OC (%)	.235	2	.117	23.453	**.000**
	Available N ($mgKg^{-1}$))	.001	2	.000	5.717	**.006**
	Available P ($mgKg^{-1}$)	29.767	2	14.883	92.406	**.000**
	Available K ($mgKg^{-1}$)	14616.309	2	7308.154	61.038	**.000**
	Total N ($mgKg^{-1}$)	.017	2	.008	5.016	**.010**
	Total P ($mgKg^{-1}$)	14942.921	2	7471.461	59.846	**.000**
	Total K ($mgKg^{-1}$)	8392580.557	2	4196290.278	197.041	**.000**
SD	Sand (%)	289.988	2	144.994	12.970	**.000**
	Silt (%)	132.657	2	66.328	9.833	**.000**
	Clay (%)	679.414	2	339.707	88.343	**.000**
	Bulk Density (gcm^{-1})	.498	2	.249	94.218	**.000**
	pH	.934	2	.467	24.743	**.000**
	CEC (meq/100g soil)	98.678	2	49.339	61.735	**.000**
	OM (%)	9.722	2	4.861	325.126	**.000**
	OC (%)	3.263	2	1.631	325.675	**.000**
	Available N ($mgKg^{-1}$))	.003	2	.001	19.103	**.000**
	Available P ($mgKg^{-1}$)	329.258	2	164.629	1022.126	**.000**
	Available K ($mgKg^{-1}$)	17337.489	2	8668.745	72.402	**.000**
	Total N ($mgKg^{-1}$)	.129	2	.065	38.553	**.000**
	Total P ($mgKg^{-1}$)	125426.043	2	62713.021	502.325	**.000**
	Total K ($mgKg^{-1}$)	7333077.557	2	3666538.778	172.166	**.000**
CP * TP	Sand (%)	879.604	4	219.901	19.670	**.000**
	Silt (%)	729.556	4	182.389	27.038	**.000**
	Clay (%)	105.910	4	26.477	6.886	**.000**
	Bulk Density (gcm^{-1})	.094	4	.024	8.903	**.000**

	pH	2.547	4	.637	33.723	**.000**
	CEC (meq/100g soil)	62.515	4	15.629	19.555	**.000**
	OM (%)	1.139	4	.285	19.046	**.000**
	OC (%)	.382	4	.096	19.086	**.000**
	Available N (mgKg^{-1}))	.002	4	.000	6.223	**.000**
	Available P (mgKg^{-1})	5.251	4	1.313	8.151	**.000**
	Available K (mgKg^{-1})	30283.193	4	7570.798	63.232	**.000**
	Total N (mgKg^{-1})	.116	4	.029	17.352	**.000**
	Total P (mgKg^{-1})	43766.545	4	10941.636	87.641	**.000**
	Total K (mgKg^{-1})	951247.397	4	237811.849	11.167	**.000**
CP * SD	Sand (%)	41.048	4	10.262	.918	.460
	Silt (%)	14.916	4	3.729	.553	.698
	Clay (%)	59.359	4	14.840	3.859	**.008**
	Bulk Density (gcm^{-1})	.026	4	.006	2.421	.059
	pH	.170	4	.042	2.247	.076
	CEC (meq/100g soil)	109.837	4	27.459	34.358	**.000**
	OM (%)	2.008	4	.502	33.577	**.000**
	OC (%)	.671	4	.168	33.503	**.000**
	Available N (mgKg^{-1}))	.001	4	.000	4.560	**.003**
	Available P (mgKg^{-1})	50.822	4	12.706	78.884	**.000**
	Available K (mgKg^{-1})	9918.492	4	2479.623	20.710	**.000**
	Total N (mgKg^{-1})	.128	4	.032	19.068	**.000**
	Total P (mgKg^{-1})	6430.263	4	1607.566	12.876	**.000**
	Total K (mgKg^{-1})	157948.235	4	39487.059	1.854	.132
TP * SD	Sand (%)	122.145	4	30.536	2.731	**.038**
	Silt (%)	38.805	4	9.701	1.438	.234
	Clay (%)	74.580	4	18.645	4.849	**.002**
	Bulk Density (gcm^{-1})	.025	4	.006	2.364	.064
	pH	.268	4	.067	3.550	**.012**
	CEC (meq/100g soil)	54.287	4	13.572	16.981	**.000**
	OM (%)	.587	4	.147	9.821	**.000**
	OC (%)	.197	4	.049	9.817	**.000**
	Available N (mgKg^{-1}))	.001	4	.000	3.851	**.008**
	Available P (mgKg^{-1})	47.591	4	11.898	73.868	**.000**
	Available K (mgKg^{-1})	794.153	4	198.538	1.658	.173
	Total N (mgKg^{-1})	.019	4	.005	2.877	**.031**
	Total P (mgKg^{-1})	11246.301	4	2811.575	22.520	**.000**
	Total K (mgKg^{-1})	578547.488	4	144636.872	6.792	**.000**
CP * TP * SD	Sand (%)	63.747	8	7.968	.713	.679
	Silt (%)	36.678	8	4.585	.680	.707
	Clay (%)	26.501	8	3.313	.861	.554
	Bulk Density (gcm^{-1})	.086	8	.011	4.069	**.001**
	pH	.685	8	.086	4.534	**.000**
	CEC (meq/100g soil)	35.745	8	4.468	5.591	**.000**
	OM (%)	1.263	8	.158	10.560	**.000**
	OC (%)	.422	8	.053	10.532	**.000**
	Available N (mgKg^{-1}))	.006	8	.001	9.651	**.000**
	Available P (mgKg^{-1})	43.170	8	5.396	33.504	**.000**
	Available K (mgKg^{-1})	7688.436	8	961.055	8.027	**.000**
	Total N (mgKg^{-1})	.137	8	.017	10.192	**.000**
	Total P (mgKg^{-1})	24309.434	8	3038.679	24.340	**.000**
	Total K (mgKg^{-1})	1306183.399	8	163272.925	7.667	**.000**
Error	Sand (%)	603.690	54	11.179		
	Silt (%)	364.264	54	6.746		
	Clay (%)	207.647	54	3.845		
	Bulk Density (gcm^{-1})	.143	54	.003		
	pH	1.020	54	.019		
	CEC (meq/100g soil)	43.157	54	.799		
	OM (%)	.807	54	.015		
	OC (%)	.271	54	.005		
	Available N (mgKg^{-1}))	.004	54	7.418E-5		
	Available P (mgKg^{-1})	8.698	54	.161		
	Available K (mgKg^{-1})	6465.459	54	119.731		
	Total N (mgKg^{-1})	.091	54	.002		
	Total P (mgKg^{-1})	6741.662	54	124.846		
	Total K (mgKg^{-1})	1150013.163	54	21296.540		

The cultivation period substantially controlled all the measured soil parameters individually and combinedly with topography (CP*TP). Though soil depth (SD) individually showed significant control on all soil parameters, influences of CP*SD on sand, silt, bulk density, pH and total K content were insignificant or weak (Table 3). Additionally, TP showed significant control on all soil parameters except sand, silt and CEC. The effects of TP*SD also showed weak relationships on silt, bulk density and available K. Furthermore, the combined effects of CP*TP*SD on all parameters were significant except the soil texture. Thus, all the concerned factors are sufficient to regulate tea soil quality and the cultivation period is considered as substantial because the fallow period in hill 2 soil has helped to restore nutrients and enhanced soil quality for tea cultivation.

4. CONCLUSION

The soils of three different hills were investigated for the effects of soil depth, topography, and cultivation period on tea soil quality. The investigation showed that the soil nutrient status varied widely across the hills under the effects of the concerned factors, mostly the cultivation period. The oldest hill showed a low amount of nutrients compared to the other two hills except N. Comparatively higher contents of nutrients in hill 2, which was kept under a fallow period, indicated that the restoration period of this hill helped to enhance the soil quality. But the highest N in the ongoing cultivation of Hill 3 manifests the potential use of nitrogen fertilizers. The statistical analysis further manifested the importance of the cultivation period of the hill in controlling the soil quality. Differences in soil properties between tea plantation age classes would primarily reflect the impact of cultivation history. Therefore, it is recommended that the use of the hills for tea cultivation be more beneficial after a fallow period. This reuse could increase tea production without the use of commercial fertilizer and will be sustainable for the soil and water environment.

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