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Research Article

Physicochemical Properties of Soil as Affected by Land Use Change in a Tropical Forest Ecosystem of Northeastern Bangladesh

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Abstract: Some selected soil physicochemical properties such as nitrogen (N), phosphorus (P), potassium (K), soil organic carbon (SOC), carbon to nitrogen ratio (C: N), and soil organic matter (SOM) with soil p^H have been evaluated from *Shorea robusta* and *Dipterocarpus turbinatus* plantations, and a deforested site, and compared to the surface soil (0-10 cm) and sub-surface soil (10-30 cm) at Tilagarh Eco-park of northeastern Bangladesh. Total 90 soil samples were collected from 20m × 20m plot in two soil depths among 30 from each land use and 15 from each soil depth. The data were analysed statistically through one-way ANOVA test and compared by using DMRT at $p < 0.05$. The average of the mean value of soil p^H (5.33 ± 0.058) was significantly higher in *S. robusta* plantation (5.6 ± 0.096) than *D. turbinatus* plantation (5.25 ± 0.042). Available K content was significantly higher in *S. robusta* plantation (62.56 ± 0.004 mg kg^{-1}) than *D. turbinatus* plantation (54.74±0.016 mg kg^{-1}). There was a significant difference between P content in *D. turbinatus* (4530 ± 0.319 mg kg^{-1}) and *S. robusta* (4210 ± 0.088 mg kg^{-1}) plantations. Total N content was slightly higher in *S. robusta* plantation (0.11 ± 0.01%) than the *D. turbinatus* plantation (0.10 ± 0.00%). The mean value of SOM concentration was higher in *S. robusta* plantation (1.83 ± 0.180%) than in *D. turbinatus* plantation (1.72 ± 0.026%), and SOC concentration was found higher in the *D. turbinatus* plantation (2.58 ± 0.15%) than in *S. robusta* plantation (2.35 ± 0.21%). Finally, the study showed that there was a significant difference in the mean values of physicochemical properties according to two soil depths and three land uses.

Keywords: Physicochemical Properties, Plantation, Deforestation, Soil p^H, Land Use Change, *Shorea robusta, Dipterocarpus turbinatus.*

1. INTRODUCTION

Plants play the most significant role in developing the macro and micronutrient properties of soil due to its influence on local climate, nutrient or ecological cycling, moisture, microorganisms, soil erosion and hydrological cycle [1-2]. Constant deforestation and forest degradation are deteriorating the forest resources with a damage of habitat, loss of biodiversity, risk of species extinction, reducing soil productivity through erosion and desertification, and reducing natural seed germination and regeneration survival [3]. Inappropriate agricultural practices, burning, overgrazing, overexploitation of forest resources, exotic species invasion or by a combination of factors in the tropical forests have a great effect on physical, chemical and biological properties of the soil resources [4-5]. Land use change is the most important drivers affecting plant communities, species composition and structure, biodiversity and functioning of terrestrial ecosystems, soil properties, and microorganisms [6-7]. Instead, global plantation forests which are an important element of land use change are increasingly significant in the world's future timber supply and in most area's plantations are established on disturbed and degraded soils [8]. Plantations may play a major role in increasing soil fertility and can differ in their influence (between native and exotic species plantation, N_2-fixing and non-

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N_2-fixing species) on soil physical and chemical changes [9]. These changes are more biologically and chemically than physically [10-11] which leads to the decline of physical, chemical and biological potential of soil and endanger local biodiversity [12].

Soil physicochemical properties such as nitrogen (N), phosphorus (P), potassium (K), soil organic matter (SOM), and soil organic carbon (SOC) are essential elements and determinants of plant growth [13-14]. Likewise, soil reaction or pH is a most important chemical property of soil and one of the determining factors in the plant nutrient availability in the soil [15]. The p^H range of an ideal soil for plant growth is slightly acidic (p^H 6.5) to slightly alkaline (p^H 7.5) [16]. On the other hand, a number of plant nutrients are unavailable at extremely acidic or extremely alkaline soils due to the different reactions in the soil which fix the nutrients and transform them to the state that is unavailable for the plants [17]. Hence, to know the ideal soil for plants, it is important to understand soil chemistry and interacting factors that affect soil p^H, and the effects of p^H on nutrient availability [18].

Land use change and forest management practices directly alter soil biodiversity and soil quality that in turn affecting forest ecosystem functions and productivity. Soil P and N are the key nutrients for tree growth and there is a close relationship between them with SOC cycling [19], which have a potential role to mitigate the effects of global climate change [20]. Likewise, the imbalance of soil physicochemical properties is expectedly affected and control the ecosystem productivity, processes and carbon-storage capacity of tropical forests ecosystems including Amazonian, Neotropical and Bornean forests [21-25]. Consequently, it is obligatory to enhance current knowledge on the availability of soil physicochemical to assess the forest ecosystem productivity, as well as their role in the global carbon cycle [20, 26].

Bangladesh is a tropical South Asian country has an area of 14.76 million hectares of which only 2.6 million hectares is forestland equivalent to 17.62% of the country's land area, compared to the minimum requirement of 25% forest cover of a country. Out of which, 1.58 million hectares or 60.77% are managed by Bangladesh Forest Department (here *BFD*); 84% are natural forests (primary and secondary) and rest 16% are plantation forests [27]. Bangladesh has tropical evergreen and semi-evergreen hill forest, tropical moist deciduous Sal (*Shorea robusta* Gaertn. f.) forest, natural mangrove forest in Sundarbans, coastal mangrove plantation, and fresh water swamp forest. The hill forests cover 38.2% and characterized by mixed evergreen and semi-evergreen plant communities of trees with diverse herbs, shrubs, rattans and bamboos [28-29]. Historically forest resources continuously depleted by overexploitation of resources, illicit felling, fuelwood collection, grazing, agricultural and settlement expansion inside the forest boundary [30-32]. It was estimated that forest cover of the country has been declining at the rate of 2,600 hectares per year [33]. To combat this depletion, BFD declared reserved forest, protected area and involved community in participatory social forestry plantation and the latest (2003 to 2018) implemented co-management projects in 18 out of 34 protected areas [34]. At the same time, to meet the country demand of timber and fuelwood, forest plantations were raised with exotic timber species (like *Acacia* spp.) followed by fruit-bearing, medicinal and fuelwood species [35].

Mixed tropical forests in Bangladesh covers the east, northeastern and southeastern hill regions with an area of 18,079 sq km. The hills comprise the Tipam-Surma (50%), Dupi Tila (40%) and alluvial soils (10%). The hill soils (brown hill soils) are moderately fertile in respect of their physicochemical properties and mineral nutrient content [36]. Hossain et al [37] and Rahman et al [38] analyzed soil physical properties in the northeastern tropical forest ecosystems however, no research works have been done yet to evaluate the relation of soil physicochemical properties in the plantations and deforested sites. Soil physicochemical information is crucial for understanding the ecosystem processes, conservation efforts and sustainable forest management in tropical forest ecosystems. Moreover, there is a lack of information on how forest plantations affect soil pH and physicochemical properties comparing the degraded forest soils. Taking this into consideration, the objective of this study was to analyse some selected soil physicochemical properties such as available P and K, total N, SOM, SOC, and carbon to nitrogen ratio (C: N) and soil p^H in two plantation sites (*S. robusta* and *Dipterocarpus turbinatus* Gaertn) and a deforested site in a tropical forest ecosystem namely Tilagarh Eco-park (TGEP) of northeastern Bangladesh. The study also assesses the difference among the soil samples of two plantation sites and deforested site and between surface soil and sub-surface soil within three land uses.

2. MATERIALS AND METHODS

2.1. Study Site

The Tilagarh Eco-park is located in Sylhet Sadar Upazila (sub-district) of Sylhet District under North Sylhet Range-1 of the Sylhet Forest Division. Geographically, the park lies between 23°55′ and 25°02′ N latitude and 90°55′ and 92°30′ E longitude (Fig. 1). BFD has declared this as an eco-park in 2006 (with an area of 45.34 ha) from the Tilagarh Reserve Forest [38] with the objective of preservation and development of almost extinct and rare species of flora, protection and development of existing flora and fauna, breeding and development of local species of flora through intestine management, expansion of planned eco-tourism, and the creation of opportunity for study and research [39]. Adjacent to the park, there is a tea estate named *'Laccatora Tea Estate'*, which is the oldest tea estate in the Indian sub-continent.

TGEP is a tropical semi-evergreen dense forest with more than 90 tree species of 13 families among *S. Robusta* & *D. turbinatus* are the dominant tree species. Other common natural and planted tree species include *Michelia champaca* Linn., *Artocarpus chaplasha* Roxb., *Lagerstroemia speciosa* (L.) Pers., *Mimusops elengi* L., *Mesua ferrea* L., *Barringtonia acutangula* (L.) Gaertn., *Delonix regia* (Hook.) Raf., *Bombax ceiba* L., *Aquilaria agallocha* Roxb., *Mangifera indica* L., *Zanthoxylum rhetsa* (Roxb.) DC., *Artocarpus heterophyllus* Lamk., *Elaeocarpus floribundus* Blume, *Casuarina littoralis* (Salisb.), *Albizia lebbeck* (L.) Benth. & Hook., *Senna siamea* (Lamk.) Irwin & Barneby, *Camellia sinensis* (L.) O. Kuntze with different types of naturally grown rattans e.g., *Calamus tenuis*. *S. robusta* plantation was established in 1990-91 which covers nearly 60% of the total vegetation cover. About 206 species of fauna has been recorded in the park which include seven amphibians, 28 mammals, 30 reptiles, and 141 birds.

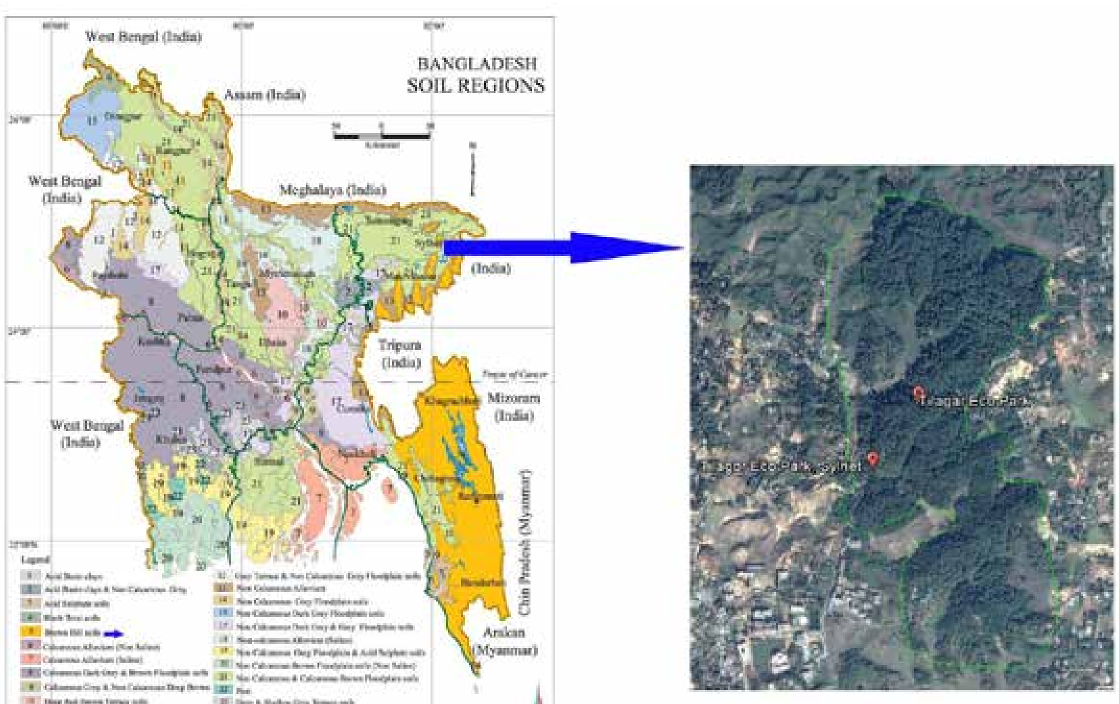

Fig. 1. Map of Bangladesh soil regions indicating the location of Tilagarh Eco-park in northeastern Bangladesh

Climatic is hot and humid summer and a relatively cool winter. The highest average temperature of the park is 31.6˚C between August and October, and the lowest average temperature is 7˚C between January and February. The park is located in a moist tropical climatic zone with average annual rainfall of about 3,937 mm, where nearly 80% occur between May and September [38]. A tide of stream flows across the park and there are having several hillocks (locally called *tilla*), ranging from 10-50 m height. These hillocks abound with many naturally grown trees. The soil of hillocks varies from clay loam to pale brown (acidic) clay loam, which are moderately fertile with low soil p^H, ranges from 5 to 7.5. Red sandy clay contains manganiferous iron ore. However, soil erosion is common during monsoon, and hillocks soil contains a lot of minerals and nutrients due to upland leaching supporting more growth.

2.2. Research Methods

For the study, soil samples were collected from three land use sites among the two was dominant plantation sites, *i.e.,* one is *S. robusta* plantation and other is *D. turbinatus* plantation, another from the deforested site. Soil samples were collected by using a soil core from surface soil (0-10 cm depth) and sub-surface soil (10-30 cm depth) and properly labelled in air tied polybags to prevent the loss of soil moisture. Total 90 soil samples were collected from 20m × 20m square plot among 30 samples were from each land use (two plantation sites and a deforested site) and15 samples from each soil depth (0-10 cm and 10-30 cm). After that, a composite soil sample had been made by mixing every five soil samples, and a total of 18 composite soil samples was prepared and stored for further laboratory analysis.

2.2.1. Soil Sample Preparation

In the laboratory, at first collected soil samples were sieved through a 10 mm mesh sieve to remove visible gravels, coarse roots, and small stones, and then passed through another 2 mm sieve for an oven dry at 105 ºC for eight hours till constant weight.

2.2.2. Determination of Soil pH & Physicochemical Properties

Soil reaction (p^H) was determined by using a digital portable waterproof p^H meter HANNA HI 9210N ATC (range 0.00 to 14.00 p^H; accuracy (@20°C) ±0.02 pH / ±0.5°C). A mixed solution of soil: distilled water (1:2) was used to measure the soil p^H (www.hannainst.com). Soil physicochemical properties such as total N (%) was determined by the longer than a century year old Micro-Kjeldahl digestion, distillation and titration method [40]; available P (mg kg^{-1}) was determined by using the Bray and Kurtz method [41]; available K (mg kg^{-1}) was determined by the Ammonium acetate method [42]; total SOC (%) was determined by using the loss of ignition method [43], and SOM content was then calculated by multiplying the percent of SOC by a factor of 1.724 [44]. This follows the standard practice that SOM is composed of 58% carbon. On the other hand, the determination of C: N ratio was calculated through the ratio of SOC (%) and total N (%) or simply, SOC/total N.

2.2.3. Data Analysis

The data were analysed statistically through one-way ANOVA test to know the significant difference among the soil samples of three different land uses by using SPSS 17.0. The ANOVA results were then compared by using Duncan's Multiple Range Test (DMRT) at $p<0.05$ [45] and arranged systematically.

3. RESULTS AND DISCUSSION

3.1. Soil p^H

Soil p^H affects the number of available nutrients and chemicals that are soluble in soil water. Precipitation is considered a great influencing factor to determine soil p^H because rain water leaves elements in the soil that produce acid and carries and solubilized nutrients in soils. The present study suggests that the soil under *D. turbinatus* plantation and deforested site were subjected to erosion that allowed to leach the base-cations from two sites. Deforested site and *D. turbinatus* plantation were more susceptible to erosion than *S. robusta* plantation. Even, it may be due to the acid neutralization characteristics of the components contained in the leaf litters of the *S. robusta*. Changes in land use and deforestation might have a significant effect on the alteration (increase or decrease) of soil acidity [46]. Comparable, SOM through litter decomposition decrease the soil p^H and increased soil acidity in the hill forests of Bangladesh [47] which is seen more in the natural forest than that of plantation forest

[48].

The present study revealed that there was a significant difference in soil p^H in three land use regardless of surface and sub-surface soil. The average of the mean value of soil p^H (5.3 ± 0.058) was significantly higher ($p < 0.05$) in *S. robusta* plantation (5.6 ± 0.096) than that in *D. turbinatus* plantation (5.3 ± 0.042) (Table 1). Hence, it can be considered that the soil of this zone is mostly acidic in nature and not the most nutritious soil for all kinds of plants. That means the trend of acidity decreases with the conversion of deforested land into *S. robusta* plantation. The results showed that the soil under *D. turbinatus* plantation and deforested site were more acidic than the soil of under *S. robusta* plantation. Here, SOM through continuous litter fall mostly influences the high soil p^H in the surface soil. Likewise, N and K are fewer directly affected by soil p^H, but P is directly affected by soil p^H [16].

Roy et al [31] recorded more acidic soil in banana-based agroforestry soil than the *S. robusta* forest soil due to the application of various fertilizers, growth hormones and pesticides for better production in the agroforestry field. Zaman et al [46] found that soil p^H decreased with depth and p^H values was significantly higher in forested sites in comparison to the deforested sites. Haque et al [48] found soil p^H is significantly higher in the deforested land than adjacent forest soil in an upland watershed of Bangladesh. Biswas et al [49] recorded lower p^H in the soil of Chittagong Hill Tracts due to continuous shifting cultivation farming systems but slightly higher from the adjacent natural forests. Similarly, Biswas et al [49], Gafur et al [50], and Osman et al [51] also recorded higher soil p^H in shifting cultivation lands compared to forested lands in this region. Akhtaruzzaman et al [52-53] recorded the higher p^H values at both surface and sub-surface soils of the cultivated site as compared to planted forest and barren land. Haque and Karmakar [47] also estimated that matured mixed plantation forests showed lower p^H than younger plantation forests.

Table 1. Soil p^H at two soil depths in two plantation sites and a deforested site.

Land use and land cover	Soil depth (cm)	Mean value	Avg. of mean
S. robusta plantation	0-10	5.8 ± 0.057^{d}	5.6 ± 0.096
	10-30	5.4 ± 0.057^{c}	
D. turbinatus plantation	0-10	5.3 ± 0.057^{bc}	5.3 ± 0.042
	10-30	5.2 ± 0.057^{ab}	
Deforested site	0-10	5.2 ± 0.057^{ab}	5.2 ± 0.042
	10-30	5.1 ± 0.057^{a}	
Total			**5.3 ± 0.058**

Note: ±: Standard deviation; Values with different lowercase (a, b, c….) letters are significantly different in the same soil layers at three land use change ($p < 0.05$) according to DMRT.

3.2. Available Potassium in Soil

Available K in soil is a vital nutrient for plants and most forest soils have substantial quantities of K in solution which plays many important regulatory roles in plants growth and development [54]. The present study found that the average of the mean value of available K in the soil was 54.74 ± 0.007 mg kg^{-1} which was significant at $p<0.05$. The lower value of K was recorded in the soil of deforested site (46.92 ± 0.006 mg kg^{-1}) where highest was recorded in the soil of *S. robusta* plantation (62.56 ± 0.004 mg kg^{-1}) (Table 2). The inconsistency in the availability of K in the soil of three land uses due to the less abundance of vegetation on the deforested site and presence of comparatively more litter fall under the *S. robusta* plantation.

In respect of surface soil, statistically no significant variation was found among the available K in *S. robusta* and *D. turbinatus* plantations and a deforested site. But in respect of sub-surface soil, statistically significant variation (4.9% decrease) was found between the values of K in two plantation sites due to the accumulation of more K

Table 2. Available potassium and phosphorous at two soil depths in two plantation sites and a deforested site

Land use and land cover	Soil depth (cm)	Potassium ($mg\ kg^{-1}$) Mean value	Potassium ($mg\ kg^{-1}$) Avg. of mean	Phosphorous ($mg\ kg^{-1}$) Mean value	Phosphorous ($mg\ kg^{-1}$) Avg. of mean
S. robusta plantation	0-10	58.65 ± 0.006^{cd}	62.56 ± 0.004	4410 ± 0.02^{d}	4210 ± 0.088
	10-30	62.56 ± 0.006^{d}		4010 ± 0.02^{b}	
D. turbinatus plantation	0-10	66.47 ± 0.011^{d}	54.74 ± 0.016	5240 ± 0.02^{e}	4530 ± 0.319
	10-30	39.10 ± 0.006^{a}		3810 ± 0.00^{a}	
Deforested site	0-10	$50.83 \pm 0.006b^{c}$	46.92 ± 0.006	4300 ± 0.02^{c}	4040 ± 0.117
	10-30	43.01 ± 0.006^{ab}		3780 ± 0.01^{a}	
Total			**54.74 ± 0.007**		**4300 ± 0.121**

Note: ±: Standard deviation; Values with different lowercase (a, b, c….) letters are significantly different in the same soil layers at three land use change ($p<0.05$) according to DMRT.

in the surface soil and subsequent leaching of them from the surface soil to the sub-surface soil of *S. robusta* plantation. The survey results revealed that the value of available K decreased from surface to sub-surface soil in *D. turbinatus* plantation and deforested site (Table 2).

Akhtaruzzaman et al [53] found the higher value of available K in the cultivated soil than plantation forest soils and barren land soils as cultivated soil received more K from applying ash during soil management for cultivation. Similarly, Roy et al [31] also estimated higher K in agroforestry soil than the soil of *S. robusta* forest. Instead, Zaman et al [46] and Biswas et al [49] recorded higher K in the soil of forested sites in compared to deforested sites. Similarly, Biswas et al [49], Osman et al [51] and Biswas et al [55] estimated higher value of available K in the soil of Chittagong Hill Tracts of Bangladesh which has no history of shifting cultivation practices. Similar to the present study, Akhtaruzzaman et al [52-53] and Akbar et al [56] found that total available K in the soil decreased with increasing soil depths.

3.3. Available Phosphorus in Soil

Available P in soil is the most common physicochemical limiting plant growth in terrestrial ecosystems [57]. P is vital for the plant's life specifically for the storage and reproduction of plant genetic material and for energy-related processes called photo-phosphorylation [58]. Scholars reported that the soil of tropical and subtropical regions have a P deficiency and contains a lower amount of available P [59] that could be lessened these forest ecosystem responses to the increasing global carbon dioxide concentrations [60]. Survey data revealed that *D. turbinatus* plantation soil contained the highest average of the mean value of available P (4530 ± 0.319 $mg\ kg^{-1}$) followed by *S. robusta* (4210 ± 0.088 $mg\ kg^{-1}$) plantation soil and the soil of deforested site (4040 ± 0.1168 $mg\ kg^{-1}$) respectively at $p<0.05$ level of significance (Table 2). The results suggested that the rate of nutrient loss in the guise of soil erosion was higher on deforested land and *S. robusta* plantation than the *D. turbinatus* plantation. On the other hand, as the leaves of *D. turbinatus* plant is highly flammable, so that higher P value was found in the soil under *D. turbinatus* plantation.

The present study showed that the P value in soil varied for land use change in respect of soil depths. It was found that surface soil contains more P than the sub-surface soil. At surface soil, the mean value of P was higher in *D. turbinatus* plantation (5240 ± 0.02 $mg\ kg^{-1}$) and less in the deforested land (4300 ± 0.02 $mg\ kg^{-1}$), with no statistically significant variation between the *S. robusta* and *D. turbinatus* plantations. Considering the sub-surface soil, the highest mean value of P was found in *S. robusta* plantation (4010 ± 0.02 $mg\ kg^{-1}$) and less in the deforested land (3780 ± 0.01 $mg\ kg^{-1}$) as well as significantly different from the three land uses (Table 2).

Similar to the present study findings, a number of studies e.g., Haque et al. [48], Akhtaruzzaman et al [52-53] and Akbar et al [56] reported that the hill soils in Bangladesh are poor in available P. This study revealed that the mean value of available P

Table 3. Total nitrogen and carbon to nitrogen ratio at two soil depths in two plantation sites and a deforested site

Land use and land cover	Soil depth (cm)	Total nitrogen (%) Mean value	Total nitrogen (%) Avg. of mean	Carbon to nitrogen ratio Mean value	Carbon to nitrogen ratio Avg. of mean
S. robusta plantation	0-10	0.13 ± 0.01^{d}	0.11 ± 0.01	11.4 ± 0.02^{b}	17.95 ± 0.02
	10-30	0.08 ± 0.01^{b}		24.5 ± 0.03^{c}	
D. turbinatus plantation	0-10	0.10 ± 0.01^{c}	0.10 ± 0.00	14.3 ± 0.02^{bc}	19 ± 0.02
	10-30	0.10 ± 0.00^{c}		23.7 ± 0.03^{c}	
Deforested site	0-10	0.01 ± 0.00^{a}	0.03 ± 0.01	7.7 ± 0.01^{a}	9.3 ± 0.01
	10-30	0.05 ± 0.01^{b}		10.9 ± 0.02^{b}	
Total			**0.08 ± 0.01**		**15.42 ± 0.02**

Note: ±Standard deviation; Values with different lowercase (a, b, c….) letters are significantly different in the same soil layers at three land use change (p<0.05) according to DMRT.

was decreased with soil depths in three land uses which corresponding with the findings of Biswas et al [49] might be due to the lower amount of or SOM and higher fixation of P in sub-surface soil. On the other hand, Mia et al [61] estimated that the value of available P was higher in the soil of mixed forest stand than the pure forest and plantation forest stands.

3.4. Total Nitrogen in Soil

N is one of the major components of the atmosphere, and this atmospheric N is a source of soil N which is a key element of plant growth. SOM is a major pool for soil N content which is present in the form of nitrates. Forest soils contain large organic N pools which have a positive impact on the terrestrial carbon sequestration [62]. Study data revealed that the average of the mean value of total N content was slightly higher in *S. robusta* plantation soil (0.11 ± 0.01%) than the *D. turbinatus* plantation soil (0.10 ± 0.00%) compared to the soil of deforested site (0.03 ± 0.01%) in two soil depths at $p<0.05$ level of significance (Table 3). *S. robusta* plantation soil contained the higher mean value of total N (0.13 ±0 .01%) than the *D. turbinatus* plantation soil (0.10 ± 0.01%) at the surface soil. On the other hand, at sub-surface soil, the highest mean value of total N was found in the soil of *D. turbinatus* plantation (0.10 ± 0.00%) followed by *S. robusta* plantation soil (0.08 ± 0.01%) (Table 3).

The hill forest soil in Bangladesh has a lower content of total N which also supported by the present study. Similar to the study, Zaman et al [46] stated that due to the presence of litter and humus in the upper soil layer, this layer content higher amount of N which accelerated soil water holding capacity. Shaifullah et al [63] found that total soil N content was increased due to afforestation on a coast of Bangladesh. Roy et al [31] found more N content in agroforestry soil than the *S. robusta* forest soil. Similar to the present study findings, Haque et al [48], Akhtaruzzaman et al [52-53] and Akbar et al [56] found higher N content in the planted forest soil in comparison to barren and cultivated land soils. Mia et al [61] calculated the lower content of total N in pure forest stand soil compared to the plantation and mixed forests stands soils.

3.5. Soil Organic Matter

SOM is mainly derived from plant litter and humus and affects both physical and chemical properties of the soil and improve soil health [62]. SOM is supplying most of the nutrients held in the soil and affects the stabilization in soil aggregates, soil structure and porosity, increases water holding capacity, and increases the diversity and biological activity of soil microorganisms. Most soils contain 2 to 10% SOM [64]. However, much of the forestry research on the impacts of plantations on SOM concerns the plant OM component or biomass analysis, leaving out the soil-incorporated OM [65].

Table 4 shows the value of SOM in three land uses in the study area. Survey data revealed that surface soil contains a higher amount of SOM in three studied land use. The mean value of SOM was higher in *S. robusta* plantation soil (1.83 ± 0.180%) than in *D. turbinatus* plantation soil (1.72 ± 0.026%). It was found that surface soil contains more SOM than the sub-surface soil. At surface soil, the value of SOM was found higher in *S. robusta* plantation (2.24 ± 0.011%) than the *D. turbinatus* plantation (1.77 ± 0.023%). In the sub-surface soil, the value of SOM was found higher in *D. turbinatus* plantation (1.67 ± 0.023%) than the *S. robusta* plantation (1.41 ± 0.011%). In case of soil depths, the average of the mean value of SOM varied in three land uses with the increased of soil depth (from the surface to sub-surface soil) which also significantly different at the $p<0.05$ level of significance. In case of the average of the mean value of SOM, the higher value was found in *S. robusta* plantation soil (1.83 ± 0.180) than the *D. turbinatus* plantation soil (1.72 ± 0.026) (Table 4 & Fig 2).

In the forested soil, it is common that the surface soil contains more SOM than the sub-surface soil [66]. On the other hand, soils of Bangladesh are generally low in SOM having less than 1.5% in most of the soils, and some soils have even less than 1% SOM [67]. Specifically, the soils of the northern and eastern hills are low in SOM and poor in general fertility [68]. Haque et al [48] recorded higher SOM content in forest soil compared to deforested soil. Alike, Roy et al [31] also estimated higher SOM in banana-based agroforestry soil than the *S. robusta* forest soil as the banana cultivation required frequent organic and chemical fertilizers, different pesticides and growth hormones for better plant growth and banana yield. All the above-mentioned findings agreed with the present study findings. Biswas et al [49] recorded lower content of SOM in the soils of Chittagong Hill Tracts due to continuous shifting cultivation and farming.

Table 4. Soil organic matter and soil organic carbon at two soil depths in two plantation sites and a deforested site

Land use and land cover	Soil depth (cm)	Soil organic matter (%)		Soil organic carbon (%)	
		Mean value	Avg. of mean	Mean value	Avg. of mean
S. robusta plantation	0-10	2.24 ± 0.011^{e}	1.83 ± 0.180	1.90 ± 0.19^{d}	2.35 ± 0.21
	10-30	1.41 ± 0.011^{c}		2.79 ± 0.23^{e}	
D. turbinatus plantation	0-10	1.77 ± 0.023^{de}	1.72 ± 0.026	1.69 ± 0.19^{c}	2.58 ± 0.15
	10-30	1.67 ± 0.023^{d}		3.47 ± 0.10^{f}	
Deforested site	0-10	0.31 ± 0.006^{b}	0.27 ± 0.189	0.32 ± 0.20^{a}	0.56 ± 0.15
	10-30	0.23 ± 0.006^{a}		0.85 ± 0.11^{b}	
Total			**1.27 ± 1.780**		**1.83 ± 0.17**

Note: ±: Standard deviation; Values with different lowercase (a, b, c….) letters are significantly different in the same soil layers at three land use change ($p<0.05$) according to DMRT.

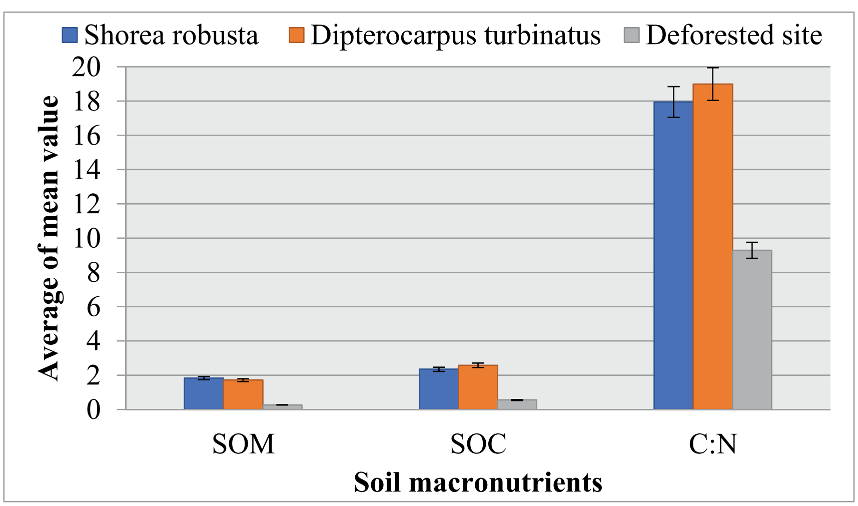

Fig. 2. Average of the mean value of soil organic matter (SOM, %), soil organic carbon (SOC, %) and carbon to nitrogen ratio (C: N)

3.6. Soil Organic Carbon

SOC is a part of the global carbon cycle which involves the cycling of carbon through plants and soil. Litterfall in the forest floor is one of the major sources of SOC and this is the main component of SOM [69]. The SOC in the study forest significantly ($p<0.05$) varied with soil depths as well as within the three land uses. It was found that sub-surface soil in the study area contains higher SOC than that of surface soil. At surface soil, the highest mean value of SOC was found in *S. robusta* plantation (1.90±0.19%) and lowest was found in the deforested land (0.32±0.20%). At sub-surface soil, the highest mean value of SOC was found in *D. turbinatus* plantation (3.47±0.10%) followed by *S. robusta* plantation (2.79±0.23%) (Table 4). The average of the mean value of SOC was found in *D. turbinatus* plantation soil (2.5±0.15%) followed by *S. robusta* plantation soil (2.35±0.21%) (Table 4 & Fig. 2).

The recorded mean value of SOC corresponds with the findings of Osman et al [70] in Bangladesh. Similarly, Akhtaruzzaman et al [53] recorded higher SOC in the planted forest soil as compared to barren soil and cultivated land soil can be ascribed to the addition of OC from tree cover. Mia et al [61] also found a higher amount of SOC in a mixed forest stand in comparison to pure forest stand and lowest in the plantation forest stand. In addition to that, some studies e.g., Akhtaruzzaman et al [52-53] and Shaifullah et al [63] estimated that the surface soil contain higher SOC might be attributed to the higher accumulation of SOM on the surface soil.

3.7. Soil Carbon to Nitrogen Ratio (C: N)

Soil carbon to nitrogen ratio (C: N) determining whether the carbon sink in land ecosystems could be sustained over the long-term [71]. Change in the amount of N in the ecosystem is a key parameter regulating long-term terrestrial carbon sequestration [72]. Soil C:N ratio determines the decomposability of SOM, therefore has an important impact on plant N availability. In the forest floor, C: N ratio is generally wide and decreases as decomposition occurs, in other soils the ratio is usually much lower [73]. The survey found that C:N ratio decreased from plantations sites to deforested site as well as from sub-surface soil to the surface soil. It was found that the mean C: N was higher in surface soil in *D. turbinatus* plantation (14.3±0.02 C/N) than the *S. robusta* plantation (11.4±0.02 C/N). On the other hand, at sub-surface soil C: N was higher in *S. robusta* plantation (24.5±0.03 C/N) than in *D. turbinatus* plantation (23.7±0.03 C/N). The average of mean value of C: N was higher in *D. turbinatus* plantation (19±0.02 C/N) than in *S. robusta* plantation (17.95±0.02 C/N). The mean C: N values were significantly different at soil depths and land uses at $p\leq0.05$ (Table 3 & Fig. 2).

Findings of the Mia et al [61] revealed that the soil C: N was found higher in the pure and mixed forest stands and lowest in the plantation forest stands. Biswas et al [55] found a higher amount of soil C: N in the forested sites in comparison to other land use change including shifting cultivation. Comparable, soil C: N was recorded higher in fallow site soil after 3-years of burning prepared for shifting cultivation than soil of other shifting cultivation sites [49].

3.8. One-way ANOVA Analysis of Soil Physicochemical Properties according to Soil Depths

Table 5 shows the summary results of one-way ANOVA analysis of selected soil physicochemical properties according to surface soil and sub-surface soil at $p<0.05$ level of significance. The ANOVA results showed that the value of soil pH was significant ($P=0.000$) at $p<0.05$ ($F=18.800$) in two soil depths which indicated that there is a significant difference in the mean value of soil pH. The ANOVA results of available K showed that the value of K was significant ($P=0.000$) at $p<0.05$ ($F=15.733$) in the two soil depths which also indicated that there is a significant difference in the mean value of available K.

Similarly, ANOVA results of available P value showed that the value was significant ($P=0.000$) at $p<0.05$ ($F=866.705$) among the two soil depths which indicated that there is a significant difference in the mean value of available P. The ANOVA results in total N was significant ($P=0.000$) at $p<0.05$ ($F=46.714$) which showed that there is a difference in the mean value of total N among the two soil depths. Furthermore, the ANOVA test showed that there was a significant difference ($P=0.000$) in

Table 5. One-way ANOVA analysis of soil physicochemical properties according to soil depths and land uses

Soil macronutrients	Soil depth		Land use and land cover	
	F	P	F	P
Soil p^H	18.800	0.000	12.885	0.001
Available K	15.733	0.000	2.803	0.092
Available P	866.705	0.000	1.462	0.263
Total N	46.714	0.000	20.960	0.000
SOM	2891.729	0.000	63.744	0.000

the mean value of SOM at p<0.05 (F=2891.729) according to two soil depths (Table 5).

3.9. One-way ANOVA Analysis of Soil Physicochemical Properties according to Land Use Change

Table 5 also showed the summary results of one-way ANOVA analysis of selected soil physicochemical properties according to three land uses at p<0.05 level of significance. The ANOVA results of soil pH showed that the value of soil pH was significant (P=0.000) at p<0.05 (F=12.885) in three land uses which indicated that there is a significant difference in the mean value of soil pH. The ANOVA results of available K showed that the value was significant (P=0.092) at p<0.05 (F=2.803) in three land uses which also indicated that there is a significant difference in the mean value of available K.

The ANOVA results of available of P showed that the value was insignificant (P=0.263) at p<0.05 (F=1.462) among the two land uses which indicated that there is no significant difference in the mean value of available for P. Besides, the ANOVA results of total N was significant (P=0.000) at p<0.05 (F=20.960) which showed that there is a difference in the mean value of total N among the three land uses. Similarly, the ANOVA results showed that there was a significant difference (P=0.000) in the mean value of SOM at p<0.05 (F=63.744) according to three land uses (Table 5).

4. CONCLUSIONS

The present study suggested that there was considerable variation among soil physicochemical in two plantation sites and a deforested site, and soil samples from two soil depths within three land uses. The study results showed that the soils under *S. robusta* and *D. turbinatus* plantation forests had higher physicochemical contents in all the cases than deforested site. Soil pH, available K and P value were slightly higher in two plantation sites compared to deforested site. The total N, SOM, SOC and soil C: N value also found higher in two plantation sites than the deforested site. These mean the continuous declining in soil quality which would have a negative effect on the structure, function and productivity of forest ecosystem. Results revealed that the physicochemical properties in the studied eco-park was poor due to less tree coverage, less water-holding capacity and excessive soil erosion during monsoon, however, massive site-specific tree plantation with soil management practices can improve the soil physicochemical properties. Sustainable land use practices like tree plantation with native tree species (timber, fruit-bearing and medicinal plants), agroforestry and regular soil protection by cover crops, inter-cropping and mulches can restore soil fertility and productivity by increasing SOM and water holding capacity in the deforested site. Further research is needed to find out the impact of land use change variations on soil biological properties as well as ways to improve soil quality and ecosystem productivity through more detailed and expanded similar studies.

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