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Research Article

Soil Carbon and Nutrient Accumulation under Forest Plantations in Jharkhand State of India

The decrease and degradation of the tropical forests affect not only the production of timber but also the global environment in a large scale. The ability of soil to sustain and its supply of nutrients to a growing forest are controlled by a complex of biogeochemical processes. The purpose of the present study aims to assess the degraded forest fringe areas, to promote plantations of various types and to evaluate their impacts on the soil nutrients and carbon content accumulation. The soil organic carbon (SOC) and nutrient content were evaluated and compared between plantations of mixed native species (MNS), some native tree species as *Shorea robusta*, *Dalbergia sissoo*, *Dendrocalamus* spp., certain agro-forestry species and some exotic varieties. The impacts of the plantations on the SOC and the nutrients were firstly analyzed through comprehensive chemical analyses and the results were compared with the soil samples collected prior to plantation forestry. Significant changes were observed in SOC content, in nutrients, and in amounts of exchangeable cations. Soil carbon levels were highest under the MNS, *Dendrocalamus* and *Tectona grandis* stands and lowest under *D. sissoo* and *Terminalia arjuna*. Total N showed highest levels under *Dendrocalamus* and *Pongamia pinnata* and significantly higher in stands of native species; lowest total N level was observed in *D. sissoo* plantations. The C/N ratios of the soil varied between 9.2 and 13.5 among the exchangeable cations. Ca^{2+} recorded the maximum levels and Na^{+} showed the lowest levels.

Keywords: Exchangeable cations; Forest plantations; Nutrients; Soil organic carbon

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1 Introduction

Natural forest ecosystems being nutrient rich, the nutrient stock of degraded forest have been reduced gradually. Forest biomass have been estimated to contain more than 80% of the carbon stored in terrestrial vegetation and forest soils more than 70% of the world's soil carbon pool [1]. Soil degradation is a major threat to sustainable use of soil ecosystem because it decreases actual and potential level of vegetation cover. However, forest recovery contributes to the accumulation of nutrients again. Soil organic carbon (SOC) is intricately linked to the cycling of soil nutrients that influence ecosystem productivity [2]. At present, sustainable forest management is an important strategy for protecting natural forests. Forest soil properties, including the quantity and quality of SOC stocks, are influenced by the complex interactions of climate, soil type, management, and tree species [3]. Carbon and nutrient storage in forests have been the focus of researches because of the role of CO_2 in global climate change [4–7]. Estimates of changes in forest carbon and nutrient pools have been made at global, national, and regional scales to understand the significant changes in the soil characteristics due to the degraded forest [8, 9]. Many studies reported that forest type may influence forest ecosystem carbon and nutrient storage [10, 11]. Soil carbon and nutrients can be changed after plantation establishment because tree species have different nutrient requirement and carbon storage mechanisms. Soil fertility is again one of the key factors for plantation rotation, tree regeneration, establishment, and growth of forests. In addition, the role and the importance of forests for carbon and nutrient storage may likely to be quite variable with forest types because nutrient converting rates among species are different [12]. Plantations of multipurpose tree species can play an important role in restoring productivity, ecosystem stability, and biological diversity to degraded tropical lands [13]. A growing body of evidence has demonstrated that tree species can differ in their influence on soil properties. Soil carbon being a very significant component of total carbon accumulation in native forests and forest plantations has received much less attention from forest scientists than carbon in tree components [14–17]. More intensive harvesting for conventional timber products and biofuels remove more organic matter and carbon as well as leaving lesser nutrients for the next rotation [18–21].

Forests often store large amounts of organic matter aboveground in woody plant tissue and fibrous litter [22]. Reported data on carbon and nutrients storage are mostly based on allometric

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Abbreviation: BD, bulk density; **BS**, base saturation; **CEC**, cation exchange capacity; **MNS**, mixed native species; **SOC**, soil organic carbon.

relationships [23–27]. Recently, afforestation is considered an option to reduce the concentration of atmospheric carbon dioxide by increasing carbon sequestration in tree biomass and soils [28–30]. Young forests were favored for carbon sequestration, because of their ability to accumulate large amounts of organic matter in woody biomass and resistant litter [31]. Nutrients, especially nitrogen are known to be key determinants of carbon sequestration in various forest ecosystems [32, 33]. Native tree plantations have become an extensively used land use management option in Costa Rica during the last 20 years as a restorative tool for degraded lands and also as providers of ecosystem services due to other potential uses [34]. The usefulness of native tree plantations establishment in degraded pastures have been recognized [35], although some researchers argue the viability of this land use in degraded pastures to restore soil quality [36]. Moreover, the irrigation prospects in this area are very meager and for that the soil is deficient in nutrients. This may likely to have a negative impact on site productivity especially on soils with low nutrient reserves [37]. The difference of exchangeable cation concentrations in the mineral soil may be arisen from inherent mineralogical character, tree root distribution, nutrient requirements, nutrient uptake, and nutrient allocation throughout plantation development [12]. The study area of Jharkhand state in India comprises of highly degraded forest soils which is not suitable for growth of all normal crops. Therefore, in order to increase the fertility of the soil and to enhance growth of crops, mixed plantations involving plants and trees of various types have been employed to study their extent of interaction. The present study aims to quantify the SOC, total nitrogen, and related soil nutrients under mixed tree plantations established in a degraded pasture soil in the selected areas of Jharkhand state; to compare soil properties under forest plantation species with selected among the most used by forestry in Jharkhand; to establish the association of nutrients and SOC with selected physical and chemical soil properties and to determine how soil exchangeable acidity, Ca^{2+}, Na^{+}, and K^{+} are changed under forest plantations stands in different species.

2 Materials and methods

2.1 Study site

Ranchi district of Jharkhand lies between 22.5° north to 23.6° north and 84.9° east to 85.9° east, is one of the biggest districts of the state in India. It is bounded on the north by Hazaribagh and small portion of Chatra district, on the east by Purulia district (West Bengal) part of Paschim Singhbhum, on the south by the district of Paschim Singhbhum and on the west by the district Palamau, Lohardaga, and Gumla. The total geographical area of the district is 7698 km^2. The total population of the district is 2 783 577 and almost 65% of the population is rural out of which 47% are dependent on agriculture. Population density of the study area is 338 persons per km^2. The annual rainfall is 1462.7 mm with maximum and minimum temperature of 41.80 and 5.30°C. The district has two broad geomorphological divisions namely, the lower Chotanagpur and Ranchi plateau. The Chotanagpur plateau have an average of 500–1000 feet above mean sea level (MSL), comprises a small area in the north-eastern part of the district extending over Silli, Sonahatu, and Tamar blocks, rest of the district which is formed as Ranchi plateau has an average elevation of 2000 feet above MSL.

The study area comprised of mixed boulder, gravel, kankar, etc., with normal soil. The presence of bigger size soil particle causes detritus effect for the growth of plants. In order to utilize the land for agricultural purposes in a better ways, big size particles (boulder, gravel, kankar) are to be removed from the field. The area gets a plenty amount of water during rainy season, but the soil characteristics in the experimental area is not fit for growth of normal crops. No historical data on initial soil characteristics of the plots considered in the present study is available in the literature. In nonrainy seasons water sources get dried, and therefore water required for agricultural purpose becomes absent. However, during rainy season huge amount of water passes through the nearby canal. Therefore steps have to be taken to store water at rainy season and use it at latter time of dry season.

2.2 Soil sampling and analyses

The present investigation was started during February 1993 and a random sampling of species plantation in different plot within the study area was carried out. The soil chemical properties were analyzed and the treatment of different plant species of 6–15 years age group was considered. Fifteen core soil samples from each site were collected in June 2008 in the 0–15 cm soil layer under plantation area. Thirteen treatments were selected in the Dhalbhumgarh for the study: four exotic species plots including *Azadiracta indica*, *Albizzia lebbek*, *T. arjuna*, *T. grandis*; four agroforestry species plots, three native species plots and two mixed native species (MNS) plots as summarized in Tab. 1. Each treatment had two replicates. Suitable three plots of 10 m × 10 m grid were selected as cores in the study area with intersecting lines of 10 m distance, centering to the middle of the plot in the MNS area. The soil samples were brought to the laboratory of School of Water Resources Engineering, Jadavpur University, Kolkata in an air tight plastic packet for soil quality analysis. Coarse concretions, stones, and pieces of roots, leaves, and other undecomposed organic residue were removed. The samples were dried in oven at 20–25°C and 20–60% relative humidity [38]. After air-drying, soil samples were crushed gently in pestle and mortar and sieved through a sieve of <2 mm. Samples used for soil carbon were used by the modified Walkley–Black method [39] and total N by the method of Subbiash and Asija [40]. Soil pH was measured by dissolving soil in water with the help of pH meter. The Bray and Kurtz P1 method [41] was used for acid soils for determination of available phosphorous in soils. Exchangeable K^{+}, along with Ca^{2+} was usually determined in neutral normal ammonium acetate extract of soil. The extraction was carried out by shaking followed by filtration. The K^{+} was estimated by using a flame photometer and Ca^{2+} by using atomic absorption spectrometer. In soils with appreciable amount of soluble K^{+} and Ca^{2+} these cations were estimated in a saturation extract and deducted from N NH_4OAc extractable K^{+} and Ca^{2+} to obtain respective exchangeable cations. The cation exchange capacity (CEC) was calculated in the milliequivalents of H^{+}, K^{+}, Na^{+}, and Ca^{2+} per 100 g of soil (meq/100 g soil) by using the method described in Camberato [42]. The percent base saturation (BS) was calculated by dividing the sum of the K, Ca, and Na (the bases) in meq/100 g soil by the CEC and multiplied the result by 100%. The representative samples were also analyzed following the same protocol.

2.3 Data analysis

Analysis of variance was carried out with Minitab 15 for Windows XP Service Pack version 2 as detailed in Tab. 2 for all soil chemical

Table 1. Characteristics and geographic location of studied treatment plots at Dhalbhumgarh Block in Jharkhand.

Geographic location		Treatments	Tree category
22°5.39′	84°9.10′	Mixed Native	Natural regeneration
22°5.42′	84°9.19′	Mixed Native	Natural regeneration
22°5.56′	84°9.31′	*A. indica*	Exotic
22°5.68′	84°9.46′	*A. lebbek*	Exotic
22°5.89′	84°9.54′	*T. arjuna*	Exotic
22°6.09′	84°9.72′	*T. grandis*	Exotic
22°6.29′	84°9.94′	*Dendrocalamus* sp.	Native
22°5.14′	84°9.88′	*D. sissoo*	Native
22°5.27′	84°9.59′	*S. robusta*	Native
23°6.21′	85°8.05′	*P. pinnata*	Agroforestry
23°6.28′	85°8.23′	*C. siamea*	Agroforestry
23°6.47′	85°8.32′	*Bucharia latifolia*	Agroforestry

Table 2. Descriptive statistics of soil properties, found in the area of Jharkhand.

Variable	Soil C (g/kg)	Total N (g/kg)	C:N ratio	Avail. P (mg/kg)	pH	CEC (meq 100 g/m)	BS (%)	Exch. Ca (meq 100 g/m)	Exch. K (meq 100 g/m)	Exch. Na (meq 100 g/m)
Mean	40.59	3.865	11.155	11.082	4.581	20.955	88.32	9.778	6.651	2.0582
SE mean	3.33	0.300	0.363	0.457	0.119	0.922	1.29	0.623	0.366	0.0898
SD	11.05	0.995	1.204	1.516	0.395	3.057	4.26	2.067	1.212	0.2977
Variance	122.12	0.990	1.449	2.300	0.156	9.343	18.19	4.273	1.470	0.0886
Minimum	20.20	1.790	9.200	9.200	4.010	16.850	80.50	5.500	4.690	1.5600
Q1 (1st quartile)	34.30	3.080	10.500	9.800	4.340	18.320	86.20	8.530	6.050	1.8600
Median	39.80	4.030	11.300	10.900	4.520	20.440	88.00	10.340	6.370	2.0800
Q3 (3rd quartile)	48.90	4.740	11.900	11.900	4.820	23.110	90.20	11.230	7.690	2.1700
Maximum	58.20	4.960	13.500	13.900	5.410	26.950	95.90	12.920	8.790	2.5400

properties, representing the high value particularly for the soil carbon and low value for the exchangeable Na under forest plantations stands in different species and least significant difference (*p*-value) was used to separate the means when differences were significant. All data were expressed as means ± standard deviation (Tab. 2). The relationship between the soil chemical property values was also explored using the Pearson's linear correlation coefficient (Tab. 6). Cluster analysis is a relatively reliable and simplest among the available statistical methods for classification of objects in a dataset. The aim was to establish a set of clusters such that cases within a cluster are more similar to each other than they are to cases in other clusters. In the present study, plant species having similar or dissimilar response to soil chemical property value is analyzed by this clustering approach. The cluster analysis of species with respect to their chemical behavior is shown in Tab. 3. The level at maximum similarity was observed either between two species or between two clusters or between clusters and species according to the chemical behavior of the species in the third column of the Tab. 3. In each row of the Column 1, a particular cluster is identified, which consists of either species or other clusters. In cluster [1], species c and d are included with maximum similarity but in cluster [4], cluster [1] and species h are incorporated. Further, cluster [6] comprises of cluster [5] and cluster [4] which have maximum similarity. The interrelations between the clusters and species as obtained from the hierarchical cluster analysis are depicted in the dendrogram as shown in Fig. 1. The dendrogram has been plotted with respect to maximum level of similarity of their chemical behavior along the vertical axis. The symbols of these species had been considered as, a = *A. indica*, b = *A. lebbek*, c = *T. arjuna*, d = *T. grandis*, e = *Dendrocalamus* sp.,

Table 3. Cluster analysis of species with respect to their chemical behavior.

Cluster (Column 1)	Species and cluster as subset of cluster given in column 1	Level at maximum similarity
[1]	c, d	4.543556
[2]	b, e	4.349713
[3]	[2], j	7.753957
[4]	[1], h	8.198339
[5]	[3], i	11.522024
[6]	[5], [4]	22.038781
[7]	[6], f	47.144141
[8]	a, [7]	112.113856
[9]	[8], g	252.946824

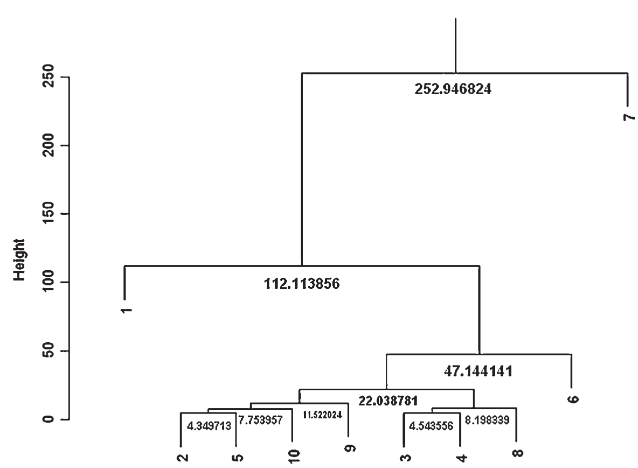

Figure 1. Dendrogram: Cluster analysis of species according to their chemical behavior.

f = *D. sissoo*, g = *S. robusta*, h = *P. pinnata*, i = *Cassia siamea*, j = *Bucnaria latifolia*. The vertical axis is the measure of the similarity or distance at which clusters join. Through a dendrogram, it was therefore possible to follow the clustering process at each iteration step, every level providing a different representation of the species sequence.

3 Results and discussion

It is observed from the different analyses of the soil chemical properties that the total soil carbon and nitrogen, C/N ratios, available P, pH and CEC showed significant differences between plantations of different species of plants. Soil C levels were highest under the MNS, *Dendrocalamus* and *T. grandis* stands and lowest under *D. sissoo* and *T. arjuna*. Total N showed highest levels under *Dendrocalamus* and *P. pinnata* and significantly higher in stands of native species; lowest total N level were observed in *D. sissoo* plantations. The C/N ratios of the soil varied between 9.2 and 13.5, was depicted in Tab. 4. Positive trends were noticed in available P levels under plantations of *S. robusta* and *D. sissoo* while soils from *Dendrocalamus* and *Albizzia* stands showed lower levels of P in soils. A rapid decline in soil pH levels was noticed under *Dendrocalamus* sp. It was clearly observed that exchangeable Ca^{2+} was the most significant and dominant base of the three, but it showed significant lower levels under plantations of *Dendrocalamus* sp. Lower levels of exchangeable Na^{+} was also noticed in the present investigation as shown in Tab. 5. The soil pH values were significantly affected by total N, exchangeable Ca^{2+}, and Na^{+}, CEC and BS. The plantation of these species under different soil chemical condition and its dependence was well observed from the present study.

The correlation matrix among the soil chemical properties was prepared and shown in the Tab. 6, where most of the major soil chemical property values shows good correlation, for example, soil carbon has positive correlation with total N (0.758) and the CEC (0.806), which has direct bearing on exchangeable K^{+} (0.794) and Ca^{2+} (0.776), whereas the soil carbon has negatively correlated with avail. P, BS, exchangeable K^{+}, and exchangeable Na^{+}. Again, the total N, being one of the major soil nutrients is strongly correlated with CEC (0.862), exchangeable Ca^{2+} (0.708) and weakly correlated with exchangeable K^{+}. The plantations of the silvicultural species exhibited improved results and had a significant contribution toward soil chemical changes. The overall dynamical variation presented by the results of correlation matrix indicates that afforestation had improved the soil condition qualitatively and there was a significant increase in soil chemical values as compared with the findings of other author [43]. The improved soil condition observed from the correlation matrix may be the major contribution to the growth of different plant species (both exotic and native) considered in the present study for better and healthy forest plantation in the degraded land.

On comparison of results from other earlier studies conducted in various tropical and temperate regions indicate that soil carbon and nitrogen following afforestation were quite variable and the values of soil carbon and nitrogen either increase or decrease. Mishra et al. [44] observed an increase in total soil carbon and nitrogen during 9 years of *Eucalyptus tereticornis* plantation on an Indian degraded soil. In Australia, in a study of *Pinus radiata* established on basalt-derived soils, Turner et al. [30] observed a 35% loss in soil carbon after 10 years of plantation establishment. In another study conducted by Turner and Lambert [45], they observed a steady and continuous decline in soil carbon for 12 years; thereafter, soil carbon stabilized and increased. Paul et al. [29] noted a soil decline of 3.46% per year following afforestation. Hartemink [46] observed a decline or increase in soil attributes depending upon the plant or tree species selected. Therefore, on comparing the results obtained from the

Table 4. Soil chemical properties in the 0–15 cm soil layer under plantation stands of different species.

Treatments	Soil C (g/kg)	Total N (g/kg)	C:N ratio	Avail. P (mg/kg)	pH	CEC (meq 100 g/m)	BS (%)
A. indica	39.7	3.81	10.5	10.7	4.52	20.06	88.0
A. lebbek	34.3	3.08	11.3	9.2	5.03	20.87	93.5
T. arjuna	28.4	2.63	10.6	11.3	5.41	25.24	90.2
T. grandis	48.9	4.42	11.2	11.9	4.82	20.93	86.2
Dendrocalamus sp.	58.2	4.87	11.9	9.3	4.01	16.85	80.5
D.a sissoo	20.2	1.79	11.3	13.3	4.45	26.95	83.9
S. robusta	53.4	4.03	13.5	13.9	4.35	19.53	95.9
P. pinnata	39.8	4.96	9.2	10.2	4.72	18.20	86.8
C. siamea	46.8	4.23	12.1	10.9	4.22	18.32	86.9
Bucharia latifolia	41.9	3.96	11.6	11.4	4.52	23.11	89.6

Table 5. Changes in exchangeable bases in the 0–15 cm soil layer under forest plantations stands of different species.

Treatments	Exch. Ca (meq 100 g/m)	Exch. K (meq 100 g/m)	Exch. Na (meq 100 g/m)
A. indica	8.87	6.64	2.15
A. lebbek	10.6	6.37	2.54
T. arjuna	12.92	7.69	2.15
T. grandis	7.72	8.25	2.08
Dendrocalamus sp.	5.5	6.25	1.82
D. sissoo	11.67	8.79	2.17
S. robusta	10.82	6.05	1.86
P. pinnata	8.53	5.36	1.91
C. siamea	9.36	4.69	1.87
Bucharia latifolia	11.23	6.95	2.53

Table 6. Pearson correlation coefficients between some soil chemical properties that were investigated (the *p*-values are shown in parenthesis).

Variables (*p*-values)	Soil C	Total N	C:N ratio	Avail. P	pH	CEC	BS	Exch. Ca	Exch. K	Exch. Na
Soil C	1									
Total N	0.758 (0.007)	1								
C:N ratio	−0.484 (0.131)	−0.145 (0.671)	1							
Avail. P	−0.101 (0.768)	−0.422 (0.196)	0.510 (0.109)	1						
pH	0.511 (0.108)	0.452 (0.162)	−0.331 (0.320)	−0.023 (0.947)	1					
CEC	0.806 (0.003)	0.862 (0.001)	−0.071 (0.835)	0.480 (0.135)	0.498 (0.119)	1				
BS	−0.082 (0.810)	0.131 (0.700)	0.205 (0.544)	0.223 (0.511)	0.387 (0.240)	0.096 (0.778)	1			
Exch. Ca	0.715 (0.013)	0.708 (0.015)	0.007 (0.984)	0.430 (0.187)	0.520 (0.101)	0.776 (0.005)	0.602 (0.050)	1		
Exch. K	−0.476 (0.139)	−0.637 (0.035)	−0.017 (0.960)	0.441 (0.175)	0.385 (0.242)	0.794 (0.004)	−0.184 (0.588)	0.298 (0.374)	1	
Exch. Na	−0.324 (0.331)	−0.544 (0.084)	0.134 (0.694)	0.036 (0.916)	0.509 (0.110)	0.481 (0.134)	0.214 (0.527)	0.365 (0.269)	0.392 (0.233)	1

findings of the various researchers, it is concluded that the amount of carbon sequestrated in forest soil would vary depending upon the soil type, climate, tree species, and most importantly on the initial soil status. The results show that *Dendrocalamus* plants render the soil acidic (low pH value of 4.01) in comparison to the other species incorporated in the study where they exhibit a pH range of 4.01–5.41, representing the status of soil acidification, which is also observed by other researchers [43]. The annual carbon sequestration rate from ambient air were estimated at 8.97 t C per ha by *S. robusta*, 11.97 t C per ha by *A. lebbek*, 2.07 t C per ha by *T. grandis* and 3.33 t C per ha by *Artocarpus integrifolia*. The percentage of carbon content (except root) in the aboveground biomass of *S. robusta*, *A. lebbek*, *T. grandis*, and *A. integrifolia* were 47.45, 47.12, 45.45, and 43.33, respectively. The total above ground biomass carbon stocks per ha as estimated for these species were 5.22, 6.26, 7.97, and 7.28 t C per ha, respectively, in these forest stands [47].

Estimates of SOC stock [48] have generally referred to a given depth of soil (e.g., top 100 cm). The amount of SOC in a given depth depends on how compacted the soil is which is measured by determining the soil's bulk density (BD). The SOC stock of a given area of soil with the same soil type can then be expressed as below:

$$\text{SOC stock} = \frac{\text{SOC content of the soil} \times \text{BD} \times \text{area} \times \text{depth}}{10}$$

where SOC stock is given in Pg (10^{15} g), SOC content is in g C/g, BD is in Mg/m^3 (10^6 g), area is in Mha and depth is in m.

In the present study, the SOC stock estimated for the top 15 cm soil layer were in the range of 0.004–0.012 Mg C (megagram carbon) (average SOC stock: 0.0083 Mg C (83 Mg C/ha), the BD range: 1.29–1.47 g/cm^3 and the average BD: 1.38 g/cm^3) as compared to the other studies which is found as 0.005–1.73 Pg considering top 50 cm soil depth while for top 1 m soil depth the estimates varied from 0.009 to 2.64 Pg C in tropical dry evergreen and tropical moist deciduous forests, respectively, in India [49]. The low SOC stock as observed in the present investigation is mainly concentrated in the small domain of the study whereas the other studies have been found higher value of SOC because it has been estimated based on the average global or regional soil carbon densities. Further, the dynamic change in the SOC stock depends upon soil texture, climate, vegetation, and landuse pattern. Soils under natural forest or grassland tend to have higher SOC content than soil under cropland. Ravindranath et al. [50] reported that the mean SOC in top 30 cm for tropical moist deciduous and tropical dry deciduous forests were estimated 57.1 and 58.0 Mg C/ha, which is not far from our result (83 Mg C/ha).

The soil samples of Jharkhand study area examined indicate that the parent material constituted mostly of metamorphic, phyllitic schists, which were invaded by dolerite and granitic dykes. Hence, the soils were acidic in nature and deficient in base cations. Furthermore, the tree plantations acidify the soil by accumulating basic cations. The present study also reveals that leaf litterfall decomposition on the forest floor may aggravate production of organic acids. Soil acidification and nutrient depletion under the stands of *Dendrocalamus* is significant due to the reasons of shallow penetration of root system which facilitates intense root uptake from the immediate underlying layers of the soil. Biological soil acidification under forest ecosystems had been previously reported in the tropics from the studies of India [44] and Brazil [51]. Soils from *Dendrocalamus* had lower levels of CEC and BS than under stands of other species and significant increase in levels of exchangeable bases following afforestation was noticed in the present investigation. Similarly, increase in soil exchangeable bases following afforestation had also been observed in other tropical regions from earlier related research findings [44, 46].

4 Conclusions

Carbon and nitrogen being the major constituents of plant and soil organic matter, their responses toward the different plantation of species were different. *Dendrocalamus* sp. exhibited highest amounts of trapped SOC thus proving to be an effective species to reduce levels in atmospheric carbon but on the other hand it exhibited deterioration in soil pH. Thus, it was clear from the present study that soil carbon and nutrient accumulation was significantly affected by the selection of the plantation species in any forest. The nutrient enrichment occurs under plantations of native species as these were well adapted to the particular soil and ambient environmental conditions. Soil carbon has positive correlation with total N (0.758) and the CEC (0.806), which has direct bearing on exchangeable K^+ (0.794) and Ca^{2+} (0.776), whereas the soil carbon has negatively correlated with avail. P, BS, exchangeable K^+, and exchangeable Na^+. Again, the total N, being one of the major soil nutrients is strongly correlated with CEC (0.862), exchangeable Ca^{2+} (0.708) and weakly correlated with exchangeable K^+. Thus the significant soil chemical changes and the enrichment of nutrient accumulation aggravate the growth of forest plantation depending on the selection of plantation species, which was well reflected from the results of correlation matrix. The results of the cluster analysis as shown by a dendrogram was therefore possible to follow the clustering process at each iteration step, every level providing a different representation of the species sequence.

In the present study, the SOC stock estimated for the top 15 cm soil layer were in the range of 0.004–0.012 Mg C (megagram carbon) (average SOC stock: 0.0083 Mg C, the BD range: 1.29–1.47 g/cm^3 and the average BD: 1.38 g/cm^3) as compared to the other studies which is found as 0.005–1.73 Pg C considering top 50 cm soil depth while for top 1 m soil depth the estimates varied from 0.009 to 2.64 Pg C in tropical dry evergreen and tropical moist deciduous forests, respectively, in India [49]. Thus, it is concluded that the amount of carbon sequestrated in forest soil would vary depending upon the agro-climatic status and the results show that *Dendrocalamus* plants render the soil acidic (low pH value of 4.01) in comparison to the other species incorporated in the present study. Soil acidification and nutrient depletion under the stands of *Dendrocalamus* was significant due to the reasons of shallow penetration of root system and the limited nutrient budget.

Forests influence the soil and soil fertility. In order to foster long term soil conservation, then appropriate species is to be selected keeping in mind the extent of soil enrichment it would be able to do. In this respect, the native tree species is to be given the first preference followed by agro-forestry species. The growth of the exotic species is be well monitored. *Dendrocalamus* and *T. grandis* is to be well adapted to the soil and environmental conditions and may have pioneered others in capturing carbon, which has the major contribution in the context of global climate change. Further, these Indian forest soil C estimates are significant as soils provide an option for rising greenhouse gas CO_2 mitigation by potential soil C sequestration.

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