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ORIGINAL ARTICLE

Community structure, regeneration status, carbon sequestration potential and soil properties in Shivalik Sal forests of Uttarakhand, India

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ABSTRACT
The present study assessing the community structure, regeneration, carbon sequestration potential and soil properties of different Shivalik Sal forests of Uttarakhand, India was conducted in four different sites viz. Shuduwala, Manduwala, Bhawala and Tilwari of Shivalik foothills in Dehradun Forest Region of Uttarakhand. The sampling of the forest stands was done by setting three sample plots of 0.1 ha size selected randomly in each site. For assessing the physico-chemical properties of soil, the soil samples were collected from two depths i.e. 0 - 15 cm and 16 - 30 cm from ten quadrates laid at each site. The highest tree density of Sal was recorded in Manduwala site (226.66 trees ha^{-1}). In Tilwari site, the highest value of IVI was recorded in S. robusta (203.63) followed by Malloutus phillippinsis (46.74). Maximum number of carbon stock was observed in Bhawala site (244.78 Mg ha^{-1}) whereas the minimum number of carbon stock was observed in Shuduwala site (189.29 Mg ha^{-1}). The nutrient content was comparatively higher in Shuduwala Sal forests along with more associated tree species than other sites.
Key words: Sal Forest, Shivalik foothills, *S. robusta*, forest soil, forest composition

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INTRODUCTION

Shorea robusta Gaertn. f. (syn. *Vatica robusta*) is commonly known as Sal, belongs to the family Dipterocarpaceae. Sal forest usually occurs between 300-1200 m asl elevation and are generally associated with *Malloutus phillippinsis, Adina cordifolia*, *Syzygium cumini*, and *Terminalia alata.* It occupies two main regions in India *i.e.* the northern and central Indian regions. In the northern region, stretching from sub-Himalayan tract of Punjab to Assam in the north-east there is approximately a continuous belt of Sal [1]. Study of forest community structure is very important in order to manage the forest resources in a sustainable way. Community structure includes important features like species richness, shape, size and both horizontal and vertical spatial distribution of species within a forest [2]. Larger numbers of proper seedlings growth of a species are considered as an indicator of good natural regeneration in the forest [3].Thus regeneration is very important for the forest to maintain the ecological balance. Analyses of population structure and natural regeneration are also important to assess the forest status in terms of growing stock, dynamics of forest and sustainable management. Micro-environmental factors including soil ecology and physico-chemical properties are important factors that affect natural regeneration in forests. The main physiographic areas of Uttarakhand include– the Greater Himalaya, Middle Himalaya, Shivalik ranges and Tarai regions of doon. Along with varied topography, the Shivalik area is associated with sub tropical climate, fragile land formation and fertile alluvial soil. In Dehradun forest region of Uttarkhand, gentle northern slopes are mainly dominated by Sal forests, while the southern slopes posses varying mixed vegetation of trees, shrubs and grasses of different canopy. The Sal forests mainly cover the level patches in mid and lower southern slopes. In recent years, these foothill areas of Uttarakhand are going under the immense pressure of developmental activities along with fundamental disturbances like forest fires, collection of fodder and fuelwood, grazing of cattle, etc. which is causing adverse and to some extent irreversible changes to the vegetation and biodiversity of the region. For an example; various on-going and proposed expressway projects have appeared at the cost of felling thousands of Sal trees which were part of the forest area for around a century and it is expected that such old trees may be not be able to regenerate further causing unstable slopes in future. Thus considering the aforementioned facts, the present study focused on studying the community structure, regeneration carbon sequestration potential and soil physico-chemical properties in Sal forests of Shivalik region of Dehradun, Uttarakhand, India in order to assist the fpolicy makers and divisions of administrative bodies associated with conservation of forest and environment to chalk out the management strategies for the Sal forest of this region for their sustainable development so that the environmental protection and conservation may be ensured along with the better management of Sal vegetation under the socio-economically dynamic ecosystem of Shivalik foothill of Uttarakhand, India.

MATERIAL AND METHODS

The present study assessing the community structure, regeneration, carbon sequestration potential and soil properties of different Shivalik Sal forests of Uttarakhand state of India was conducted in four different sites of Shivalik foothills ranging from the elevation of 620 to 690 m asl (Table 1) in Dehradun district forest region (Figure 1). The sites have humid climate with maximum annual rainfall occurring in the month of July and August. The sampling of the forest stands was done by setting three sample plots of 0.1 ha size selected randomly in each site to study structure, composition and other variables.

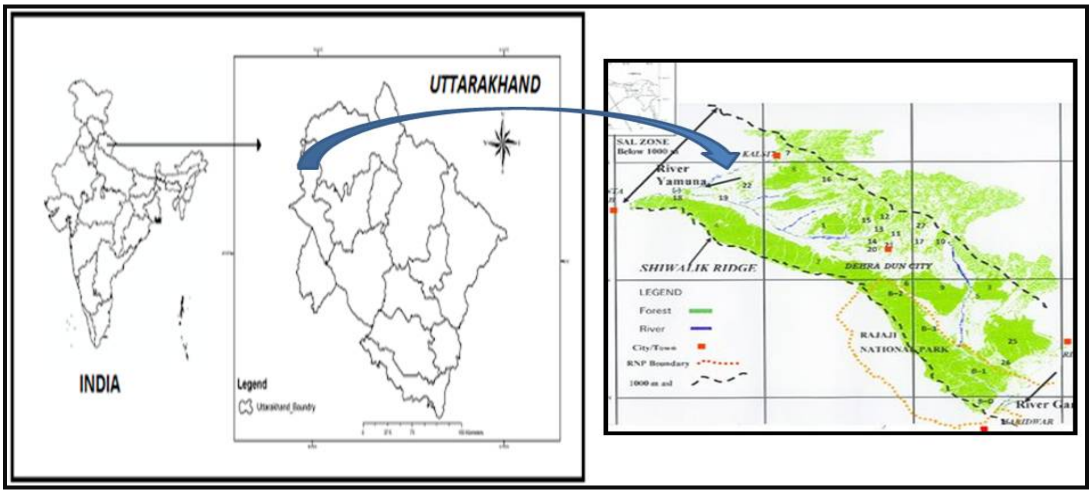

Figure 1: Location map of the study area

Vegetation studies

The vegetation data was analyzed for density, frequency and abundance following the standard methods [4]. The relative values of density, frequency abundance was summed up to represent Importance Value Index (IVI) of the species as per Phillips [5]. The "Margalef's index of richness" was used to calculate the species richness of vascular plants [6]. The population structure in different sites was determined by using standard techniques [7]. Different diameter classes were arbitrarily established for knowing the population structure viz., 10–20, 20–30, 30–40, 40–50, 50–60 and > 60 cm. The number of individuals in a given size class was divided by the total number of individuals in all size classes, and multiplied by 100 to obtain percentage density for each size class [8]. In order to represent the regeneration status of Sal, GBH (girth at breast height) classes was established [9]. According to GBH/CBH (circumference at breast height) ratio the sal vegetation ranging between 0-10.5, 10.5-31.5 and > 31.5 was considered as seedling, sapling and tree respectively. The occurrence of vegetation in the trend viz. seedling > sapling > trees was considered under good regeneration status, Fair regeneration, if the trend is - seedling > sapling < trees and if Sal vegetation is survived only till sapling stage but not as seedling or if it is present only in adult form it was considered as no regeneration status.

Enumeration of trees for volume and growing stock assessment was done by measuring cbh (circumference/girth at breast height i.e., 1.37m above the ground level) individually for all the trees in each sample plot as per [10]. The volume of standing trees was estimated by using the following general volume equation for *Shorea robusta* in Western Himalaya [11] and expressed in m^3.

$$\frac{V}{D^2} = \frac{0.1919}{D^2} - \frac{2.7070}{D} + 11.7563$$

Where, V= Volume (m^3), D = Diameter at breast height (m). The growing stock density was estimate using aforementioned volume equation for *Shorea robusta* (Sal). GSVD was calculating as sum total volume per tree within a sample plot (GSVD = ∑ Volume). The sum total volume was multiplied by 10 to convert GSVD into m^3ha^{-1}.The estimated GSVD (m^3 ha^{-1}) was converted into above ground biomass density (ABGD) of tree. This was calculated by multiplying GSVD of the sample plot with appropriate biomass expansion factor (BEF) [12]. BEF (Mg m^{-3}) is defined as the ratio of AGBD of all living trees at DBH ≥ 12.7cm. BEF for Sal was calculated by using equation. BEF was calculated using the following equations:

BEF = exp {1.91 – 0.34 × ln (GSVD)} (for GSVD ≤ 200 m^3 ha^{-1}),

BEF = 1.0 (for GSVD >200 m^3 ha^{-1}).

AGBD was calculated using following equation: AGBD = GSVD × BEF

Using the regression equation given by [13], the below ground biomass density (BGBD; fine and coarse roots) was estimated for each forest types as follows:

BGBD = exp {-1.059 + 0.884 × ln (AGBD) +0.284}

AGBD and BGBD were added to get the TBD (Total biomass density). The total biomass value was converted to carbon stock (C) using the IPCC (2006) default value of 0.05 C fraction. TCB (Mg C ha^{-1}) = TBD (Mg ha^{-1}) x carbon %.

Soil physico-chemical properties

For assessing the physico-chemical properties of soil, the soil samples were collected from the two depths i.e. 0 - 15 cm and 16 - 30 cm depth from ten quadrates at each site. The soil samples were air-dried, grounded and sieved through 2 mm sieve and the physico-chemical analysis of soil was conducted in the laboratory of Soil Science, College of Forestry, Ranichauri, VCSG Uttarakhand University of Horticulture & Forestry, Uttarakhand, India. The pH of soil was determined with the help of digital pH meter in 1:2 soil water suspensions. The Walkley and Black's rapid titration method as modified by [14] was adopted for organic carbon estimation. Available phosphorus was determined in the soil by [15] method. Available nitrogen in soil was measured by using the standard Kjeldhal procedure [16]. The 0.15 % calcium chloride extraction method of [17] was used for the determination of available Sulphur in soil.

Statistical analysis

One- way ANOVA was performed for data of soil analysis and the means were compared by Duncan tests at a level of significance of $p < 0.05$ using SPSS 16.0 statistical software. A single-tailed Pearson correlation coefficient was calculated between various physical and chemical parameters of soil and different vegetative parameters using SPSS-16 software.

RESULTS AND DISCUSSION

Community structure

As depicted in table 2, the associated tree species with Sal trees at different sites under the study were *Ziziphus jujube, Malloutus phillippinsis, Adina cordifolia, Terminalia arjuna, Syzygium cumini* and *Diploknena butyracea,* while the associated shrubs species were *Flemingia strabilifera, Haldina cordifolia, Carissa carandas, Clerodendrum infortunaturn* and *Lantana camara*. Shuduwala site was having more number of associated trees species as compared to other sites and Tilwari site were having the more number of shrubs species as compared to other sites. Similar associations of plant species with S *robusta* forests were also reported [18]. In tropical moist deciduous *S. robusta* forest of Assam, highest IVI was of *S. robusta* (125.3) followed by *Dillenia pentagyna* (27.24) and *Careya arborea* (23.12) and the highest density of *S. robusta* was 422 trees/ha [19]. In the three forest ranges, Thano, Asarori and Selaqui-jhajra, of Doon valley, Western Himalaya, in Thano, the maximum IVI were recorded in *S. Robusta* (176) followed by *M. Philippensis* (32.10) and *S. cumini* (24.33) [20] . In Asarori forest, the maximum IVI were recorded in *S. robusta* (132.44) followed by *M. philippensis* (39.44) and *E. Laevies* (29.33). In Selaqui-jhajra, the maximum IVI was recorded in *S. robusta* (114.66) followed by *M. philippensis* (27.44) and *S. cumini* (25.33).Whereas in the present study IVI of tree species of different sites ranged from 20.05 to 266.24 as depicted in table 3. The variation in IVI may be due to the variation of number of species and number of individual present in the study site. In the Terai-Bhabhar forest of Katarniaghat Wildlife Sanctuary, India, [21] the species richness (Margalef index) in natural forest was observed to be 17.33 and in planted forest was 14.11 while in the present study sites species richness (Margalef index) ranged from 1.15 to 22.56 (table 4).

Table 1: Geographic information of study sites of *Shorea robusta* forests

Name of locations	Latitude	Longitude	Elevation (m asl)
Shuduwala	30o21'36''N	77o56'20''E	620m
Manduwala	30o22'10''N	77o55'53''E	680m
Bhawala	30o23'57''N	77o55'26''E	690m
Tilwari	30o24'30''N	77o54'24''E	650m

Table 2: Associated species growing in different sites of Sal forest

Sl. no	Name of site	Associate trees species	Family	Associate shrubs species	Family
1	Tilwari	*Ziziphus jujube*	Rhamnaceae	*Flemingia strabilifera*	Fabaceae
		Malloutus phillippinsis	Eurphorbiaceae	*Ardisia solanacea*	Primulaceae
		Adina cordifolia	Rubiaceae	*Carissa carandas*	Apocynaceae
				Clerodendrum infortunaturn	Lamiaceae
				Lantana camara	Verbenaceae
2.	Bhawala	*Malloutus phillippinsis*	Eurphorbiaceae	*Flemingia strabilifera*	Fabaceae
				Clerodendrum infortunaturn	Lamiaceae
				Carissa carandas	Apocynaceae
				Lantana camara	Verbenaceae
3.	Manduwala	*Malloutus phillippinsis*	Eurphorbiaceae	*Clerodendrum infortunaturn*	Lamiaceae
				Carissa carandas	Apocynaceae
				Flemingia strabilifera	Fabaceae
				Lantana camara	Verbenaceae
4.	Shuduwala	*Terminalia arjuna*	Combretaceae	*Flemingia strabilifera*	Fabaceae
		Malloutus phillippinsis	Eurphorbiaceae	*Ardisia solanacea*	Primulaceae
		Adina cordifolia	Rubiaceae	*Clerodendrum infortunaturn*	Lamiaceae
		Syzygium cumini	Myrtaceae		
		Diploknena butyracea	Sapotaceae		

Table 3: Vegetation studies of trees species in Sal forest

Site	Species	Density/ha	F%	Ab.	RD	RF	Rd.	IVI
Tilwari	*Shorea robusta*	186.66	01.00	18.66	78.87	30.00	94.76	203.63
	Zizphus jujube	10.00	0.67	01.00	04.23	20.00	00.57	24.79
	Malloutus phillippinsis	30.00	01.00	03.00	12.68	30.00	04.06	46.74
	Adina cordifolia	10.00	0.67	01.00	04.23	20.00	00.62	24.84
Bhawala	*Shorea robusta*	196.66	01.00	19.66	92.91	60.00	98.66	251.57
	Malloutus phillippinsis	15.00	0.67	01.50	07.09	40.00	01.37	48.43
Manduwala	*Shorea robusta*	226.66	01.00	22.66	91.89	75.00	99.35	266.24
	Malloutus phillippinsis	20.00	0.33	02.00	08.11	25.00	00.65	33.76
Shuduwala	*Shorea robusta*	193.33	01.00	19.33	66.67	23.08	90.44	180.19
	Terminalia arjuna	20.00	0.33	02.00	06.90	07.69	06.48	21.07
	Malloutus phillippinsis	15.00	0.67	01.50	05.17	15.38	00.54	21.10
	Adina cordifolia	15.00	0.67	01.50	05.17	15.38	00.49	21.04
	Syzygium cumini	10.00	0.67	01.00	03.45	15.38	01.21	20.05
	Diploknena butyracea	37.00	01.00	03.67	12.64	23.08	00.84	36.56

F%= Frequency %, Ab= Abundance, RD= Relative density, RF= Relative Frequency, Rd. = Relative dominance, IVI= Important value index

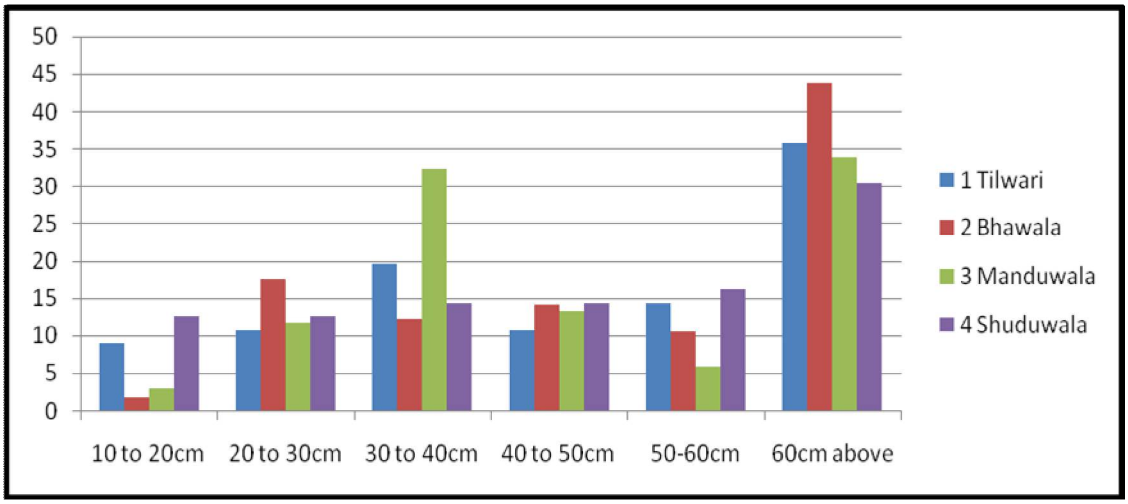

Figure 2: Population structure of various diameters classes at different sites of study

Table 4: Species richness (Margalef's index of richness) of trees in different sites of study area

Site	Name of specie	Species richness	Total species richness
Tilwari	*Shorea robusta*	0.75	9.18
	Zizphus jujuba	2.73	
	Malloutus phillippinsis	1.37	
	Adina cordifolia	4.33	
Bhawala	*Shorea robusta*	0.25	1.16
	Malloutus phillippinsis	0.91	
Manduwala	*Shorea robusta*	0.24	1.15
	Malloutus phillippinsis	0.91	
Shuduwala	*Shorea robusta*	0.99	22.56
	Terminalia arjuna	4.33	
	Malloutus phillippinsis	3.64	
	Adina cordifolia	5.77	
	Syzygium cumini	5.77	
	Diploknena butyracea	2.06	

Population structure, regeneration and carbon sequestration

The tree population of *S. robusta* was recorded higher as compared to seedling and sapling in all the sites (Figure 2). However, seedling of *S. robusta* was recorded higher in number as compared to the sapling in all the study sites. Similar to present study, [22] reported less number of saplings as compared to seedlings in their study area and observed that most of the saplings turn into young trees, this may be due to that seedlings transiting into the saplings by facing intense competition. Similarly, [23] observed that *S. robusta* exhibited higher proportion of seedling but low density of sapling and tree population in Banke National Park, Nepal. Thus, the dominant tree species differed greatly by proportion of density of seedling, sapling and trees. In the Kumaun region of central Himalaya reported the seedlings were found higher in Sal forest but their transition was low because they were unable to grow up to adult stage due to disturbance created by frequent fire, soil and water erosion, over grazing by animals, cutting of under canopy plants by villager for fuels and fodders [24]. In present study the population of sal trees was recorded higher in 60 cm and above girth classes. Similarly, while working in Sal moist forest of West Bengal, [25] recorded the higher population of sal trees in 60 cm and above girth classes. The regeneration of *S. robusta* was recorded fair in the study sites (table 5). Regarding the regeneration in Tarai-Bhabhar forest, [26] reported that good quality timber species were not regenerating, with the exception of *S. robusta*. Similarly, in the present study among all the sites number of trees were higher as compared to seedlings and saplings and almost all the trees of *S. robusta* were well mature and in good conditions. The volume of trees of *S. robusta* under all the study sites ranged from 30.66 m^3/0.1 ha to 39.48 m^3/0.1ha. However, [27] while working in Kharagpur Forest Range, reported the 651.00 m^3/0.1ha average volume of pure Sal forest and 30.56 m^3/0.1ha average volume of Sal mixed forest. The difference of volume in different study sites may be owing to the number of trees as well as different GBH classes of trees present in study area which may lead variation in volume. The growing stock in all the study sites ranged from 306.6 m^3 ha^{-1} to 394.8 m^3 ha^{-1} (table 6). Similarly, [28] from Tkauli Forest, Nepal, reported that the average growing stock of Sal dense forest was 588.7 m^3/ha, Sal medium forest was 390.09 m^3 ha^{-1}, Sal low dense forest was 318.34m^3ha^{-1} and the average growing stock of Sal mixed forest was 180.30 m^3ha^{-1} which was lowest among all other types of forest. On comparing this study with our investigation the growing stocks comes under medium Sal forest in the study sites which might be due to the fair regenerations of Sal trees in present study areas. In Sal plantations the standing biomass increases with increase in age [29]. In present study, total carbon density ranged from 189.29 Mg ha^{-1} to 244.78 Mg ha^{-1} (table 7). The carbon stock in Sal forests of Sivalik Hills of Dehradun ranged from 57.5 to 291 Mg ha^{-1} [30] while in another study carbon stock in Sal dominated moist deciduous forest of Doon valley of western Himalaya, India ranged from 169.2 to 219.1 Mg ha^{-1} with an average of 199.8 Mg ha^{-1} [31].

Table 5: Regeneration status of *Shorea robusta* forest under different sites

Site No.	Name of Sites	Density ha^{-1} of seedling	Density ha^{-1} of sapling	Density ha^{-1} of tree
1	Tilwari	70	46.7	186.7
2	Bhawala	53.3	36.7	196.7
3	Manduwala	53.3	36.7	226.7
4	Shuduwala	93.3	60	193.3

Table 6: Stand structure, volume and growing stock of *Shorea robusta* on different sites

S.No.	Name of site	DBH (m)	Height (m)	Avg. Volume (m^3/0.1ha)	Growing stock (m^3/ha)
1	Tilwari	0.47 (±0.18)	21.48 (±1.51)	37.48 (±1.43)	374.8
2	Bhawala	0.50 (±0.16)	21.49 (±1.25)	39.8 (±1.34)	398.0
3	Manduwala	0.45 (±0.17)	21.43 (±1.59)	38.39 (±1.33)	383.9
4	Shuduwala	0.47 (±0.17)	21.56 (±1.32)	30.66 (±1.23)	306.6

Table 7: Biomass and carbon stock values in different sites of Sal (*Shorea robusta*) forest

Sl. No.	Site	AGBD (Mg/ha)	BGBD (Mg/ha)	TBD(Mg/ha)	TCD(Mg/ha)
1	**Tilwari**	374.80	86.82	461.63	230.81
2	**Bhawala**	398.00	91.56	489.56	244.78
3	**Manduwala**	383.90	88.69	472.59	236.29
4	**Shuduwala**	306.60	72.58	378.58	189.29

AGBD: Aboveground biomass density**; BGBD:** Belowground biomass density**; TBD:** Total biomass density **TCD:** Total carbon density

Table 8: Physical properties of soil at 0-15 cm and 16-30 cm depth

Name of sites	0-15 cm depth			16-30 cm depth		
	BD g/cc Mean±SD	PD g/cc Mean±SD	Moisture% Mean±SD	BD g/cc Mean±SD	PD g/cc Mean±SD	Moisture% Mean±SD
Tilwari	1.29±0.127^{ab}	2.40±0.39	13.70±1.50^{b}	1.37±0.36^{ab}	2.44±0.39	17.58±0.90^{d}
Bhawala	1.43±0.09^{b}	2.40±0.48	13.52±0.47^{b}	1.50±0.75^{b}	2.46±0.44	8.10±1.71^{b}
Manduwala	1.23±0.12^{a}	2.33±0.29	12.73±2.76^{ab}	1.35±0.09^{ab}	2.37±0.26	13.85±1.59^{c}
Shuduwala	1.21±0.61^{a}	2.07±0.70	9.71±1.50^{a}	1.30±0.60^{a}	2.20±0.53	3.90±0.70^{a}

Table 9: Chemical properties of soil at 0-15 cm and 16-30 cm depth

Name of sites	0-15 cm depth					16-30 cm depth				
	pH Mean±SD	O.C Mean±SD	N Kg/ha Mean±SD	P Kg/ha Mean±SD	S ppm Mean±SD	pH Mean±SD	O.C Mean±SD	N Kg/ha Mean±SD	P Kg/ha Mean±SD	S ppm Mean±SD
Tilwari	5.60 ±0.51^{ab}	1.07 ±0.52^{ab}	212.61 ±13.31^{a}	24.88 ±5.05^{b}	14.85 ±1.41^{a}	5.93 ±0.89^{ab}	1.02 ±0.13^{b}	196.12 ±7.61^{b}	18.56 ±2.89^{a}	13.10 ±2.32^{a}
Bhawala	5.65 ±0.47^{ab}	1.77 ±0.92^{bc}	232.48 ±13.14^{ab}	26.32 ±5.11^{b}	19.26 ±2.72^{b}	5.37 ±0.43^{a}	1.26 ±0.16^{b}	224.34 ±12.60^{c}	16.73 ±1.94^{a}	15.05 ±2.38^{a}
Manduwala	5.40 ±0.17^{a}	0.75 ±0.12^{a}	204.77 ±5.42^{a}	14.55 ±1.04^{a}	13.04 ±1.43^{a}	5.95 ±0.10^{ab}	0.60 ±0.11^{a}	147.31 ±10.85^{a}	18.11 ±4.56^{a}	12.88 ±0.49^{a}
Shuduwala	6.18 ±0.07^{b}	2.06 ±0.85^{c}	291.45 ±62.94^{b}	34.92 ±5.43^{c}	24.39 ±2.44^{c}	6.71 ±0.27^{b}	1.24 ±0.16^{b}	220.16 ±13.73^{c}	29.80 ±2.15^{b}	18.42 ±0.89^{b}

Table 10: Pearson correlation coefficient between soil (at 0-15 cm depth) and vegetation parameters

	BD	PD	Moisture %	pH	SOC	N	P	S	Tree Density	BA	GSD	TBD	TCD
BD	1.000												
PD	.655	1.000											
Moisture %	.638	.999**	1.000										
pH	-.276	-.858	-.852	1.000									
SOC	.210	-.586	-.595	.868	1.000								
N	-.262	-.888	-.890	.984*	.888	1.000							
P	.007	-.630	-.621	.939	.912	.891	1.000						
S	-.025	-.759	-.765	.951*	.972*	.971*	.925	1.000					
Tree Density	-.290	.080	.057	-.549	-.577	-.421	-.784	-.508	1.000				
BA	.548	.858	.839	-.922	-.619	-.862	-.830	-.758	.532	1.000			
GSD	.674	.956*	.944	-.896	-.567	-.874	-.722	-.739	.301	.966*	1.000		
TBD	.670	.957*	.945	-.898	-.572	-.876	-.725	-.743	.302	.966*	1.000**	1.000	
TCD	.673	.957*	.944	-.897	-.568	-.875	-.723	-.740	.301	.966*	1.000**	1.000**	1.000

BD=Bulk density; PD= Particle density; SOC= Soil organic carbon; BA= Basal area; GSD = Growing stock density; TBD= Total biomass density; TCD= Total carbon density; N=Available Nitrogen (Kg/ha); P=Available Phosphorus (Kg/ha); S=Available Sulphur (ppm)

** Correlation is significant at the 0.01 level *Correlation is significant at the 0.05 level

Soil properties

The data related to soil physical and chemical properties is presented in table 8 and 9, respectively. The soil bulk density increased with increase in depth in all the sites. [32] reported that in Sal plantation of Bangladesh, the bulk density of soil of Sal ranged from 1.28 g/cm^3 to 1.63 g/cm^3 which were found almost similar to the present study sites. The sites of Bhawala were recorded with highest bulk density which could be due to more sand fraction in the soil as the texture for this site was recorded as loamy sand. In the present study the value of soil moisture percentage at 0-15 cm ranged from 9.71% to 13.70% and at 16-30 cm, ranged from 3.90% to 17.56% which was almost same as the values reported by [33] which were 7.53% for disturbed and 12.3 % for undisturbed sites of Sal in Shivalik region. These values were found higher than the values (7.2 to 9.5 %) reported by [34] in *S. robusta* forest of Jharkhand. In case of chemical properties of soil, the soil reaction influences the soil physical and biological properties and nutrient availability of plants [35]. Similar to present study, [36] reported that pH of Sal forest in Royal Chitwan National Park ranged from 5.90 to 6.42. [37] reported that pH of Sal in the Terai Bhabhar of Sohagibarwa Wildlife Sanctuary, was 6.8 in planted forest and 7.2 was in natural forest. [38] had also reported that slightly acidic forest soil has better balance of nutrient supply. Soil organic carbon is the main terrestrial carbon pool which increases the ion exchange capacity, water holding capacity and availability of nutrients. It decreased along with the increasing soil depth [39]. [40] observed that soil organic carbon % of Sal in the Terai Bhabhar of Sohagibarwa Wildlife Sanctuary was 1.5 in planted forest and 2.2 in natural forest. All these values were near to the values of present study. Comparatively low values of the organic carbon in Manduwala could be associated with less accumulation of organic matter or possible anthropogenic interference may have resulted in this condition in the site. The higher value of Nitrogen at Shuduwala and Bhawala sites were owing to the higher amount of organic carbon present at the sites. Similarly, [41] recorded the soil available Nitrogen of tropical Sal forest ecosystem ranging from 111.2 kg ha^{-1} to 197.5 kg ha^{-1}. These values are similar to the values of available nitrogen recorded in our study at different sites. Phosphorus availability influences the nitrogen fixation rate and carbon: nitrogen ratio in the litter which affects its decomposition rate and net nitrogen mineralization [42]. The values of Phosphorus recorded in all the sites were in higher range which could be associated with more production of soluble phospho-humic substances present in soil due to higher humus content in forest environment. [43] were of the opinion that availability of phosphorous increases near neutral soil and decreases as the soil become more acidic or alkaline. Similar trend is observed in the values of present study site where higher amount of P was recorded in Shuduwala site where the pH at both the depth is approaching toward near neutral value. The higher availability of sulphur in Shuduwala site may be associated with higher amount of organic matter which is the chief source of plant available sulphur in soil owing to the mineralization of organic forms of sulphur into soluble inorganic forms.

Pearson correlation coefficient between soil (at 0-15 cm depth) and vegetation parameters

The Pearson correlation coefficient between soil properties and vegetation parameters is presented in table 10. The particle density showed significantly positive correlation with growing stock density (0.956), total biomass density (0.957) and total carbon density (0.957). The growing stock density, total biomass density and total carbon density can be associated with more root volume below ground which resulted in compactness of surrounded soil hence increased the particle density. Soil pH showed significantly positive correlation with available nitrogen (0.984). [44] reported that nitrogen availability was more in pH range 6.5 to 8. Higher activity of microorganisms near neutral pH possibly increased the rate of mineralization and available nitrogen in soil. It also shows significantly positive correlation with available sulphur (0.972). [45] reported that with increase soil pH, available sulphur increases progressively and vice-versa. In the present study, available sulphur increases when increase in soil organic carbon. The release of sulphur from organic complexes as well as acidulating action of soil organic carbon may be attributed to the increase in availability of sulphur through organic matter in soil thus increasing the weathering of minerals containing sulphur. Similar results were reported by [46] and [47]. Available nitrogen showed significantly positive correlation with available sulphur (0.971). The availability of nitrogen increases with increase in sulphur in soil [48], [49]. Basal area showed significantly positive correlation with growing stock (0.966), total biomass (0.966) and total carbon density (0.966). Basal area gives an idea of the stocking of trees in a stand [50]. The GSD showed significantly positive and perfect correlation with total biomass density (1.000) and total carbon density (1.000) as the values of total biomass density and total carbon density are directly proportional to GSD. The volume (per ha) can be converted to biomass density (t/ha) by using a variety of formula [51], [52], [53]. The total biomass density showed significantly positive correlation with total carbon density (1.000). [54] reported that basal area in one of the most convenient variable to estimate the volume and above ground biomass of trees. So, from total biomass density it can be converted into total carbon density by using [55] default value of 0.05 fractions.

Present study concluded that Sal forests were older in almost all the sites and healthy growth of Sal stand was observed in Bhawala site. Due to the presence of higher number of fully mature trees, Bhawala site was observed with maximum volume and growing stock as well as total carbon density. Manduwala site showed maximum percentage of population than all the other sites in middle diameter classes, which indicated comparatively younger forest than other sites and it also exhibited potential to sequester carbon in future. In terms of soil physico-chemical properties, soils were having good fertility status in the sites. However; the nutrient content was comparatively higher in Shuduwala Sal forests along with more associated tree species than other sites indicating the future potential of this area in terms of supporting healthy vegetation and sequestration of carbon in plant/tree biomass.

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