RESEARCH ARTICLE

Assessment of Tree Productivity and Carbon sequestration of Sal Forests of Kumaun Region, Central Himalaya, India

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Abstract

This study was conducted to assess the various aspects of productivity and carbon in sal forests growing in Kumaun region. Sites were located in Sharda Forest range of Tanakpur in district Champawat of Uttarakhand. Sal forests of the region were categorized in three forest types i.e. Sal dense forest, Sal moderate forest & Sal open forest based on canopy densities. The vegetation composition of species was done by randomly placing 30 quadrats in each site. In sal dense forest, soil moisture, mass density, soil pH and soil organic carbon (SOC) across all the soil depths ranged from 10.4-32.0%, 0.4-0.5 gm/cm^3, 5.0-5.3 & 0.8-2.2% respectively. The soil moisture, soil bulk density, soil pH and SOC were 14.8-16.3%, 0.5-0.7gm/cm^3, 4.7-5.1 and 1.6-1.7% across the soil depths in sal moderate forest while in sal open forest, the soil moisture, bulk density, soil pH and SOC was 23.4-29.5%; 0.7-1.4 gm/cm^3; 4.7-5.1 and 0.6-1.2%, respectively. The C:N ratio varied between 4.6 to 7.7 across all three soil depths (0-30 cm). The Pearson correlation coefficient between different physical properties of soil significantly varied at 0.01 and 0.05 % significant level. The productivity of sal forests was 5.0, 11.0 and 17.5 t ha^{-1} yr^{-1} while carbon sequestration was 2.4, 5.2 and 8.3 t C ha^{-1} yr^{-1} in open, sal moderate and sal dense forest respectively. Sal dense forest had maximum productivity and carbon sequestration.Correlation revealed that the density, NPP, carbon sequestration varied significantly with forest sites. NPP of the forests positively correlated with carbon sequestration (p <0.05). In sal forest, density and canopy of trees were the major parameters for higher productivity and carbon sequestration. Therefore, conservation and management of sal trees are very imperative for improving the productivity and carbon accumulation in context of moderate and open sal forests for their sustainable management in the region.

Keywords: Canopy, sal, soil organic carbon, productivity, sequestration.

Highlights

- The productivity and carbon potential of dense sal forest is higher as compared to open canopy forest.
- The C:N ratio across different soil depths (0-30) cm is found higher in sal dense forest than other canopy forests.
- The productivity and carbon sequestration of present studied sal forests was on lower side in case of open sal forest and moderate sal forest. However, it was somewhat close to the values of dense sal forest.

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Introduction

In central Himalaya, there is a variation in composition of forest types which varied from tropical dry deciduous to temperate moist forests. As far as the growing stock and productivity of forest are concerned, it changes from one forest to another forest types with respect to the composition of tree species. Keeping in view, this investigation was done to determine the certain parameters of production and carbon content in sal forests of the region. The growing stock and productivity in sal forest depends on locality of growing sites and associated tree species composition along with applied management practices. In Sal (*Shorea robusta* Gaertn f.) dominated forests, a few under canopy tree species i.e. *Mallotus philippensis* (Lam.) Muell-Arg, *Terminalia bellerica* (Gaertn.) roxb., *T. chebula* Retz., *T. tomentosa* L., *Syzygium cumini* L.Skeels, *Lagerstroemia parviflora* Roxb., *Adina cardifolia* (Roxb.) Ridsdale and *Aegle marmolas* (L.) Correa are commonly associated in its growing areas particularly in Tarai and Shiwalik region upto 1500m elevations. A large tract of Sal forests in the region have been look after and managed by forest department, but due to paucity of the forest staff, lack of infrastructure and poor patrolling of forest sites consequently enhanced the anthropogenic pressure in sal forest sites. Thus, the sal forests are under pressure and disturbed by local people and villagers who are residing near to the forest sites. The people of nearby areas depend on the sal forests for timber, fuel wood, fodder and various other non-forest products. Besides this, women of the nearby villages also collect the forest soils and litter for their domestic uses. The expansion of roads and infrastructures are also causes depleting of the sal forest stands. The domestic animals of the nearby villages have impacted the regeneration of tree species in the sal forest. The damage of seeds, seedlings, foliage and timber parts was also brought by some insect- pests on sal forest (Gautam and Devoe, 2006). Such disturbances resulted in the decline of species composition and various aspects of dry matter production in sal forests, however, the present sal forests provide many commercial values, ecological

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services and social benefits to the stakeholders in the region. A few studies on the aspects on dry matter storage in Central Himalayan forests were reported by Chaturvedi and Singh, 1987; Rana *et al.,* 1989; Lodhiyal *et al.,* 2002; Pathak, 2006; Lodhiyal and Lodhiyal, 2012, Kaushal and Baishya, 2021. Therefore, the assessment of sal forest with regard to the regeneration, growth and biomass increment for sustainable forest management is very important for scientific understandings.

Keeping in view all the above scenarios, we have decide to investigate the actual scientific information of sal forests in the Himalayan region of Uttarakhand with special reference to the various dry matters and carbon content in sal forests. The analysis of stand structure of sal forest is very imperative to get the real time data of the above said attributes as stand structure of sal forests have great potential in controlling the various aspects of dry matter and carbon content in the region. The current study attempted for evaluation the soil characteristics, aspects of productivity and carbon sequestration of Sal forests in Sharada catchment of Kumaun region.

Material and Methods

Site Description

The studied forest sites were located between 29.07^0 N lat. and 80.10^0 E long at 250-358 m elevation in Sharda Forest range at Tanakpur of Champawat district in Kumaun region of Uttarakhand. The sal dominated forests of the region were divided into three categories, i.e., sal dense forest (62%), sal moderate (53%) forest and sal open forests (35%) on the basis of occurrence of forest and their canopy cover.

Sampling

In sal forest, tree analysis was done by using quadrat method (Misra, 1968; Saxena and Singh, 1982) in the duration of 2019 to 2021. A total 30 quadrats of size 10x10m were studied in each sal forest site. The soil sampling was carried out for each sal forest sites. From each sal forest site, soil samples were collected at three different depths i.e. 0-10 and 10-20 and 20-30 cm and brought in the laboratory for the analysis of physical and chemical properties. The soil moisture (MC), bulk density, texture and water holding capacity (WHC) were determined following Misra (1968) and Piper (1950). The soil pH was determined by using digital pH meter. Organic carbon was estimated by Walkely-Black method (Walky and Black,1934). Nitrogen of soil was determined by micro-Kjeldahl technique (Misra, 1968). For the estimation of biomass, the regression equations (y= a + b x, where, y= dry weight of component, x= circumference, a= intercept and b= slope or regression coefficient) were used (Rana *et al.,* 1989) and Jha (1995). The productivity for bole, branch, twig and leaves and roots components was calculated by subtracting initial year biomass (B_1) from second year biomass (B_2) (i.e. NPP = B_2 - B_1). The carbon stock of tree component was determined by biomass value multiply with a factor (0.475) (Magnussen and Reed, 2004). However, the rate of carbon sequestration of bole, branch, twig, leaf and root components was calculated by subtracting initial year carbon stock (C_1) from second year carbon stock (C_2) (i.e. CS = C_2 - C_1).

Statistical Analysis

The collected data of sal forests were compiled by M.S. Excel 2019. The statistical analysis was done by using SPSS, 2016.

Results

Physico-chemical properties of soil

The soil moisture content percentage varied from 16.26 ± 1.01-32.02 ± 1.25 in 0-10 cm depth**,** 14.95 ± 0.38-28.49 ± 1.0 in 10-20cm depth and 10.45 ± 0.14–23.41 ± 1.56 in 20-30 cm depth across all three studied forests. Moisture content of studied Sal forests which shows decreasing trend with an increase in depth of studied sal forests (Fig. 1). Sal dense forest shows high value (32.02 %) in 0-10 cm depth and lowest value (10.45%) of M.C. in 20-30cm depth. WHC in all three studied forests, ranged between 25.99 ± 0.12-31.90 ± 0.11 % in 0-10 cm, 24.58 ± 1.04-36.32 ± 1.03% in 10-20 cm and 25.59 ± 0.76-43.06 ± 0.12% in 20-30 cm soil depth (Fig. 1). The highest value of WHC was recorded 43.06 % in 20-30 depth of Sal open forest. In depth of 10-20 cm WHC was found low (24.58%) in sal moderate forest. Bulk density ranged between 0.41 ± 0.003 to 0.72 ± 0.03gcm^{-3} in 0-10 cm depth, 0.45 ± 0.002-1.20 ± 0.03 gcm^{-3} in 10-20cm depth and 0.49 ± 0.004 to 1.39 ± 0.05 gcm^{-3} in 20-30 cm depth across all three studied forests (Fig. 1). Sand, silt and clay percentage across all studied forests, ranged from 11.77 ± 0.36 to 21.18 ± 0.25, 46.87 ± 1.45 to 69.92 ± 0.94, and 18.31 ± 0.58 to 31.95 ± 0.7 in 0-10 cm depth, respectively. The percentage of sand, silt and clay in three studied forests varied 14.94 ± 0.03-22.59 ± 1.02, 45.48 ± 2.01-56.76 ± 0.03 and 28.30 ± 0.03-33.87 ± 6.54 in the depth 10-20 cm respectively. Sand, silt and clay ranged from 9.06 ± 0.52

Table 1: Pearson correlation of the soil physical parameters of studied Sal Forest sites

	Site	*Soil Depths*	*Soil Moisture*	*Sand*	*Clay*	*Silt*	*Water Holding Capacity*	*Bulk Density*
Site	1.00	0.00	0.23	0.52**	0.35	0.18	0.31	0.63**
Soil Depths		1.00	-0.38	-0.05	-0.03	-0.12	0.47*	0.21
Soil Moisture			1.00	-0.13	-0.15	0.34	0.21	0.30
Sand				1.00	0.23	-0.62**	-0.30	-0.20
Clay					1.00	0.19	0.03	0.30
Silt						1.00	0.57**	0.70**
Water Holding Capacity							1.00	844**
Bulk Density								1.00

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

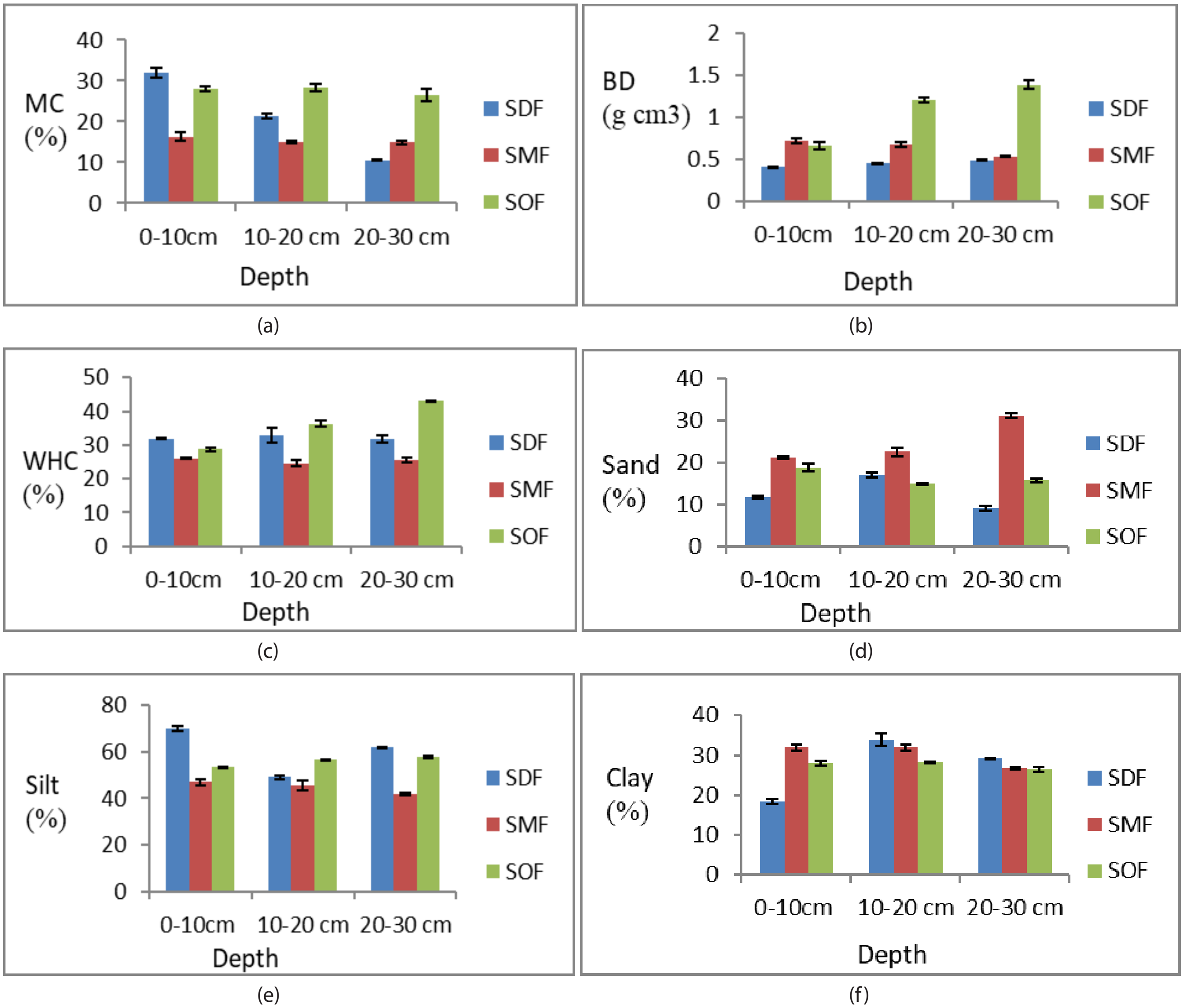

Fig. 1: Depth wise soil physical properties of all studied Sal forests. (a) moisture content, (b) bulk density, (c) water holding capacity, (d) sand percentage, (e) silt percentage, (f) clay percentage. SDF: Sal dense forest; SMF: Sal moderate forest; SOF: Sal open forest

Table 2: ANNOVA for different physical properties of soil of studied Sal Forest

Dependent	*Source of variation*	*Type III sum of squares*	*DF*	*Mean square*	*F-value*
	Moisture	624.34	2	312.17	3.85*
	Sand	548.52	2	274.26	30.48*
	Clay	121.83	2	60.92	1.74NS
	Silt	2547.13	2	1273.57	26.11*
	WHC	413.99	2	206.99	22.96*
Site	BD	1.71	2	0.86	93.07*
	Moisture	423.956	2	211.98	2.09NS
	Sand	3.144	2	1.57	0.066NS
	Clay	56.996	2	28.50	0.87NS
	Silt	292.270	2	146.14	1.01NS
	WHC	173.991	2	87.00	3.66*
Depths	BD	0.088	2	0.04	0.90NS

to 31.17 ± 0.64, 42.01 ± 0.51 to 61.71 ± 0.37 and 26.46 ± 0.75 to 29.17 ± 0.16% at depth 20-30 cm soil depth respectively (Fig. 1).

The soil was sandy loam in the sal dense forest. In the sal moderate forest soil was sandy loam and sandy clay loam in upper and lower soil depths respectively. The soil was sandy loam at 0-10 and 10-20 cm soil depth while sandy clay loam at 20-30 cm soil depths in the sal open forest. Overall soil was loamy sand of sal dense forest, sandy clay loam of sal moderate

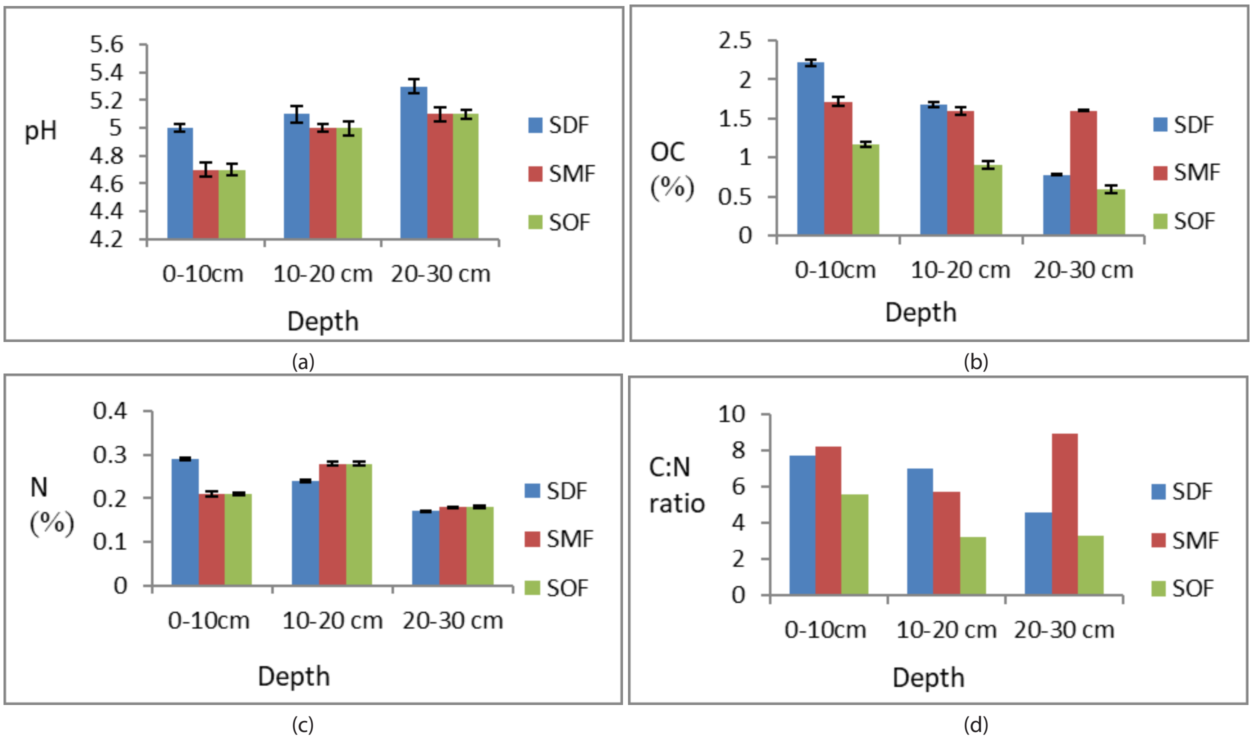

Fig. 2: Depth wise soil chemical properties of all studied Sal forests. (a) soil pH, (b) organic carbon, (c) available nitrogen, (d) C:N ratio. SDF: Sal dense forest; SMF: Sal moderate forest; SOF: Sal open forest

Table 3: Net primary productivity of Sal forests in Kumaun region of Champawat district

Species	*Sal dense canopy forest*			*Sal moderate canopy forest*			*Sal open canopy forest*		
Component	AG	BG	Total	AG	BG	Total	AG	BG	Total
A.excelsa	-	-		0.39 (88.63)	0.05 (11.36)	0.44 (100)	-	-	
A. lebbeck	0.23 (79.31)	0.06 (20.68)	0.29 (100)	-	-		-	-	
B. ceiba	-	-		0.25 (78.13)	0.07 (21.87)	0.32 (100)	-	-	
C. fistula	-	-		0.27 (81.81)	0.06 (18.18)	0.33 (100)	-	-	
F. hispida	-	-		0.28 (82.35)	0.06 (17.64)	0.34 (100)	-	-	
A.cordifolia	0.34 (77.27)	0.10 (22.72)	0.44 (100)	-	-		-	-	
L. parviflora	0.34 (80.95)	0.08 (19.04)	0.42 (100)	-	-		-	-	
L. coromendelica	0.27 (79.41)	0.07 (20.59)	0.34 (100)	-	-		-	-	
M. philippensis	2.09 (97.66)	0.05 (2.34)	2.14 (100)	0.28 (87.5)	0.04 (12.5)	0.32 (100)	-	-	
Shorea robusta	8.78 (72.80)	3.28 (27.19)	12.06 (100)	4.68 (59.31)	3.21 (40.68)	7.89 (100)	3.77 (79.53)	0.97 (20.46)	4.74 (100)
S. cumini	0.65 (75.58)	0.21 (24.41)	0.86 (100)	0.73 (63.48)	0.42 (36.52)	1.15 (100)	-	-	
T. grandis	-	-		-	-		0.20 (95.23)	0.01 (4.76)	0.21 (100)
T. bellerica	0.44 (67.69)	0.21 (32.30)	0.65 (100)	-	-		-	-	
T. tomentosa	0.28 (80.0)	0.07 (20.0)	0.35 (100)	-	-		-	-	
T. nudiflora	-	-		0.11 (64.70)	0.06 (35.29)	0.17 (100)	-	-	
Total	13.42 (76.47)	4.13 (23.53)	17.55 (100)	6.99 (63.77)	3.97 (36.22)	10.96 (100)	3.97 (80.20)	0.98 (19.79)	4.95 (100)

* AG= Above ground; BG= Below ground

and sal open forests in texture. The pH of soil was slightly acidic in sal dense forest while sal moderate and sal open forest was acidic in nature. Soil organic carbon percentage ranged 0.78 ± 0.01 to 2.22 ± 0.04, 1.60 ± 0.01 to 1.72 ± 0.05 and 0.59 ± 0.05 to 1.17 ± 0.03 across all three depth layers (0-30 cm) of sal dense, sal moderate and sal open forest, respectively (Fig. 2).

The C:N ratio varied between 4.59 to 7.66 across different soil depths (0-30 cm), it was maximum (7.66) at top soil layer (0-10 cm) and minimum (4.59) at bottom soil depths layer (20-30 cm) in sal dense forest. In sal moderate forest, C:N ratio ranged from 5.71-8.89 in three soil depth (0-30 cm). The maximum value of C:N ratio was 8.89 found in 20-30cm while minimum value (5.71) at 10-20 cm. However, sal open forest shows 3.21-5.57 C: N ratio, it was maximum (5.57) in 0-10 cm and minimum (3.21) in 10-20 cm soil depth (Fig. 2).

The correlation between different physical properties of soil significantly varied at 0.01 and 0.05 % significant level. The sand particle and bulk density of soil varied significantly with studied sites at 0.01% significant level. The water holding capacity of soil varied significantly with soil depth at 0.05% significant level. The bulk density of soil significantly varied with silt particle and water holding capacity of soil at 0.01 % significant level (Table 1).

Annova showed that the soil moisture content, sand particle and bulk density of soil varied significantly with study sites at 0.05% significant level but not with the soil depth. There was significant change (0.05% significant level) in WHC with site and depth of the soil. (Table 2).

Biomass

In sal forest, total tree biomass was 473.3-787.2 t ha^{-1}. (Fig. 3). The aboveground and belowground part shared 77.9 - 79.5 % and 20.5 - 22.1 % respectively. Of this, *S. robusta* trees accounted for 471.9 to 691.0 t ha^{-1} (Siddiqui *et al.,* 2023).

Net Primary Productivity (NPP)

The NPP of sal forests ranged 4.95-17.55 t ha^{-1} yr^{-1}. Of which, above and below ground was 63.77 to 80.20% and 19.79 to 36.22% respectively. Of the total NPP, sal trees accounted for 4.74 to 12.06 t ha^{-1} yr^{-1}. The above and below ground parts accounted for 59.31-79.53 % and 20.46 to 40.68% of sal trees (Table 3). The NPP of associated tree species of sal forest was in order: *Shorea robusta>Mallotus philippensis>Syzygium cumini>Terminalia bellerica> Adina cordifolia>Alianthus excelsa>Terminalia tomentosa >Lannea corromendelica>Ficus hispida> Cassia fistula>Bombax ceiba>*Albizzia. *lebbeck> Tectona grandis > Trewia nudiflora.*

The productivity of sal dense forest was 17.55 t ha^{-1}yr^{-1}. Of this, aboveground and belowground parts accounted for 76.5 and 23.5% respectively (Table 3). In sal dense forest, *S. robusta* contributed 12.06 t ha^{-1}yr^{-}, *M. philippensis* 2.14 t ha^{-1}yr^{-1} whereas *A. lebbeck* contributed minimum 0.29 t ha^{-1}yr^{-1}. In sal moderate forest, the productivity was 10.96 t ha^{-1}yr^{-1}. Of this, aboveground and belowground tree components accounted for 63.8 and 36.2 % respectively (Table 3). *S. robusta* contributed 7.89 t

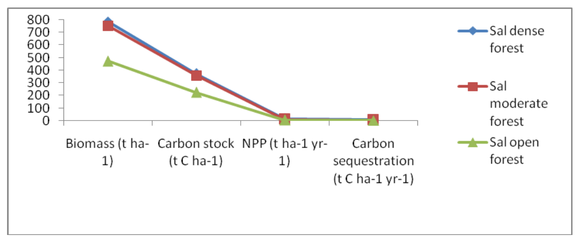

Fig. 3: Biomass, carbon stock, NPP and carbon sequestration of all studied Sal forests

Table 4: Carbon sequesration of Sal forests in Kumaun region of Champawat district

Species	*Sal dense canopy forest*			*Sal moderate canopy forest*			*Sal open canopy forest*		
Component	*AG*	*BG*	*Total*	*AG*	*BG*	*Total*	*AG*	*BG*	*Total*
A.excelsa	-	-	-	0.19 (90.48)	0.02 (9.52)	0.21 (100)	-	-	-
A. lebbeck	0.11 (78.57)	0.03 (21.42)	0.14 (100)	-	-	-	-	-	-
B. ceiba	-	-	-	0.12 (80.0)	0.03 (20.0)	0.15 (100)	-	-	-
C. fistula	-	-	-	0.13 (81.25)	0.03 (18.75)	0.16 (100)	-	-	-
F. hispida	-	-	-	0.13 (81.25)	0.03 (18.75)	0.16 (100)	-	-	-
A.cordifolia	0.16 (76.19)	0.05 (23.80)	0.21 (100)	-	-	-	-	-	-
L. parviflora	0.16 (80.0)	0.04 (20.0)	0.20(100)	-	-	-	-	-	-
L.coromendelica	0.13 (81.25)	0.03 (18.75)	0.16 (100)	-	-	-	-	-	-
M. philippensis	0.99 (98.01)	0.02 (1.98)	1.01 (100)	0.13 (86.66)	0.02 (13.33)	0.15 (100)	-	-	-
S. robusta	4.17 (72.8)	1.56 (27.2)	5.73 (100)	2.22 (59.2)	1.53 (40.8)	3.75 (100)	1.79 (79.55)	0.46 (20.44)	2.25 (100)
S. cumini	0.31 (75.61)	0.10 (24.39)	0.41 (100)	0.34 (62.96)	0.20 (37.03)	0.54 (100)	-	-	-
T. grandis	-	-	-	-	-	-	0.10 (90.90)	0.01 (9.09)	0.11 (100)
T. bellerica	0.21 (67.74)	0.10 (32.25)	0.31 (100)	-	-	-	-	-	-
T. tomentosa	0.13 (81.25)	0.03 (18.75)	0.16 (100)	-	-	-	-	-	-
T. nudiflora	-	-	-	0.05 (62.5)	0.03 (37.5)	0.08 (100)	-	-	-
Total	6.37 (76.47)	1.96 (23.53)	8.33 (100)	3.31 (63.65)	1.89 (36.35)	5.20 (100)	1.89 (80.08)	0.47 (19.91)	2.36 (100)

* TAG=total above ground; BG= below ground

Table 5: Correlation between different vegetational and growing stock parameters through Pearson's correlation

	Forest	*Density*	*Biomass*	*Carbon stock*	*NPP*	*CS*
Forest	1.00	-0.99*	-0.91	-0.91	-1.00*	-1.00*
Density		1.00	0.93	0.93	0.99	0.99
Biomass			1.00	1.00**	0.89	0.89
Carbon stock				1.00	0.89	0.89
NPP					1.00	1.00*
CS						1

NPP= Net primary productivity, CS= Carbon sequestration *Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed)

Table 6: Comparative study of different parameters of sal forests in India and elsewhere

Forest Types	*Biomass ($t\ ha^{-1}$)*	*Carbon stock ($t\ C\ ha^{-1}$)*	*NPP ($t\ ha^{-1}\ yr^{-1}$)*	*Carbon sequestration ($t\ C\ ha^{-1}\ yr^{-1}$)*	*References*
Sal forest	455-710	216.1-337.3	15.5-18.8	7.4-8.9	Rana et al., 1989
Sub-tropical sal forest	362	171.9	17.8	8.4	Sundriyal et al., 1994
Mixed forests	90-192	42.8-91.2	-	-	Negi et al., 1995
Moist tropical plateau Sal	-	-	22.1	10.5	Mandal, 1999
Deciduous and Evergreen Forests	251.7- 307.3	125.8-153.7	-	-	Ramachandran et al., 2007
Sal mixed forest	380-815	181-387	33.1	15.7	Pathak, 2008
Sal mixed Forest, Chhattisgarh, India	66.5	33.3	-	-	Bijalwan et al., 2010
Sal forests	162-346.5	159.4	-	-	Sharma et al., 2010
Pure Sal foresst	392.1-579.6	186.2-275.3	-	-	Mandal and Joshi, 2014
W. Amazonia, forest, Peru	-	-	14.2-15.1	6.7-7.2	Malhi et al., 2014
Moist deciduous forest Doon valley India	338.4-438.2	169.2-219.1	-	-	Sahid and Joshi, 2015
Sal mixed forest	230.5-269.5	109.5-128.0	9.0-20.7	4.3-9.8	Kapkoti et al., 2016
Moist tropical forests	-	-	14.9-26.6	7.1-12.6	Gautam and Mandal, 2016
Central Himalayan Forest, India	1280.79	577.77	-	-	Kaushal and Baishya, 2021
Subtropical and temperate forest, Central Himalaya, India	577.16	274.15	-	4.63	Joshi et al.,2021
Sal dense forest	787.2	373.9	17.5	8.3	Present study
Sal moderate forest	754.8	358.6	11.0	5.2	Present study
Sal open forest	473.3	224.8	5.0	2.4	Present study

$ha^{-1}yr^{-1}$ followed by *S. cumini* 1.15 t $ha^{-1}yr^{-1}$ whereas *T. nudiflora* contributed minimum 0.17 t $ha^{-1}yr^{-1}$. Net primary productivity of sal open forest was 4.95 t $ha^{-1}yr^{-1}$. Of which, aboveground and belowground components accounted for 80.2 and 19.8 % respectively (Table 3). *S. robusta* contributed 4.74 t $ha^{-1}yr^{-1}$ whereas *T. grandis* 0.21 t $ha^{-1}yr^{-1}$ in total NPP (Table 3).

Carbon Stock

The carbon stock ranged from 373.9 to 224.8 t C ha^{-1} in sal forests (Fig. 3). Of this, aboveground and belowground parts accounted for 77.9 to 79.5 % and 20.5 to 22.1 % carbon respectively. Of the total carbon stock, sal trees accounted for 224.2-328.3 t C ha^{-1} (Siddiqui *et al.,* 2023).

Carbon sequestration

Carbon sequestration varied 2.36-8.33 t $ha^{-1}yr^{-1}$ in sal forests. Of this, above ground and below ground was 63.6 to 80.1% and 19.9 to 36.4% respectively. Of the total carbon sequestration, sal trees accounted for 2.25 to 5.73 t $ha^{-1}\ yr^{-1}$. The above and below ground parts accounted for 59.2 to 79.5 and 20.4 to 40.8% of sal trees (Table 4). The NPP of associated tree species of sal forest was in order: *Shorea robusta>Mallotus philippensis>Syzygium cumini>Terminalia bellerica> Adina cordifolia>Alianthus excelsa>Terminalia tomentosa>Lannea corromendelica>Ficus hispida> Cassia fistula>Bombax ceiba>*Albizzia*. lebbeck> Tectona grandis > Trewia nudiflora.*

In sal dense forest, carbon sequestration was 8.33 t $ha^{-1}\ yr^{-1}$. Of this, aboveground and belowground part accounted for 76.5 and 23.5% respectively (Table 4). *S. robusta* contributed 5.73 t $ha^{-1}yr^{-1}$ followed by *M. philippensis* 1.01 t $ha^{-1}yr^{-1}$ whereas *A. lebbeck* sequester minimum carbon 0.29 t $ha^{-1}yr^{-1}$ in sal dense forest.

Carbon sequestration of sal moderate forest was 5.20 t $ha^{-1}yr^{-1}$. Of which, aboveground and belowground components accounted for 63.6 and 36.4% respectively (Table 4). *S. robusta* contributed 3.75 t $ha^{-1}yr^{-1}$ followed by *S. cumini* 0.54 t $ha^{-1}yr^{-1}$ whereas *T. nudiflora* contributed minimum value 0.08 t $ha^{-1}yr^{-1}$.

In sal open forest, carbon sequestration was 2.36 t $ha^{-1}yr^{-1}$. Of this, aboveground and belowground tree components accounted for 80.1 and 19.2 % respectively. *S. robusta* contributed 2.25 t $ha^{-1}yr^{-1}$ followed by *T. grandis* 0.11 t $ha^{-1}yr^{-1}$ in carbon sequestration. The maximum carbon sequestration was found in *Shorea robusta* in all three selected forests (Table 4).

The correlation between different variables showed that the density, NPP, carbon sequestration varied significantly with forest sites. Biomass varied significantly with carbon stock ($p<0.01$) (Siddiqui *et al.,*2023). NPP varied significantly with carbon sequestration ($p<0.05$) (Table 5).

Discussion

Forests provide many goods and services such as timber, fuelwood, fodder fruits, fibres and environmental regulating services. Apart from these, they also benefit to the society through employment and income. Consequently, these provisioning and regulating services not only improve the livelihood of the people but also improve the environment of the site. According to Lodhiyal *et al.* (2016) the growing population pressure on forest has depleted the species composition and also led to impoverished soil fertility and productivity.

The forest productivity and carbon content depends on density and growing stock of a tree species and different locality factors such as climatic, edaphic, topographic and disturbances brought by human and grazing animals. Thus, it is very important to assess the real picture of the sal forest with regard to productivity and carbon at different sites in the region. However, a broad study is needed for assessing the carbon potential of the sal forests growing nearby the human habitation. We need to develop other tools, equations and techniques which help in estimating the actual productivity and carbon potential without destructing the forest stands. In this study, we have focused on the various aspects of NPP and carbon of sal forests located in Sharda catchment forest area in Kumaun of Central Himalayan region of Uttarakhand. The present investigation aims to assess the real picture of sal forest with regard to net primary productivity and carbon in sal forests growing at different forest sites in the region. In this context, present findings of net primary productivity of sal forests was 5.0 to 17.5 t ha^{-1} yr^{-1}, which lower side in case of open and moderate sal forests while dense forest had shown somewhat close to value of NPP as reported 14.2-18.8 t ha^{-1} yr^{-1} for Sal forest of central Himalaya (Rana *et al.,*1989), 9.0-20.7 t ha^{-1} yr^{-1} (Kapkoti *et al.,* 2016) and 22.1-33.1 t ha^{-1} yr^{-1} (Mandal, 1999; Pathak, 2008; Gautam and Mandal, 2016).

As far as carbon is concerned, it is vital component of growing stock/biomass of forest, which plays a significant role in climate change mitigation. Higher the biomass and productivity of forest means more accumulation of carbon stock and sequestration in the forest. The tropical forest sequesters more carbon than other type of forests; however, the rate of carbon sequestration and its potential depends on forests types, age and size class of the forest trees (Terakunpisut *et al.,* 2007). The carbon sequestration findings of sal forests was 2.36- 8.33 t C ha^{-1} yr^{-1}, which was lower side for open and moderate forests but it was close for dense sal forest to the values (7.4 - 8.9 t C ha^{-1} yr^{-1} , 8.4 t C ha^{-1} yr^{-1} , 10.5 t C ha^{-1} yr^{-1} , 15.7 t C ha^{-1} yr^{-1} ; 6.7-7.2 t C ha^{-1} yr^{-1}, 4.3-9.8 t C ha^{-1} $yr^{-1}$and 7.1-12.6 t C ha^{-1} yr^{-1}) reported for sal forests of the region (Rana *et al.* 1989; Sundriyal *et al.* 1994; ; Mandal, 1999; Pathak, 2008; Malhi *et al.,* 2014 ;Kapkoti *et al.,* 2016; Gautam and Mandal, 2016) respectively (Table 6).

The present findings had highlighted the potential of sal forests in relation to biomass, productivity and carbon storage. In this context, the assessed sal forests had indicated that biomass production and carbon content influenced with the changes of tree density and canopy cover of forests. Apart from this, the variation in soil characteristics has also played significant role. Hence, those sal forests which have dense canopy should be conserved through proper management and scientific inputs. Proper fencing and patrolling by the forest staff should be done so that dense sal forest could be protected from further degradation. As well as in open sal forest, restoration programme like plantation and regeneration of associated tree species should be implemented by minimizing human disturbance i.e. encroachment, illegal felling, fire and grazing.

Conclusion

In the present scenario of climate change and wood products demands have gained a significant importance for sustainability of development and natural resources in every part of the world but the growing population pressure had degraded the natural resources particularly in the forests. Consequently, the production and productivity of forest had declined in different parts in the region. Thus, it is very essential to monitor and protect the existing forest with suitable management techniques; however, the forest composition is varied from one region to another. As far as the climate change mitigation is concerned, they mitigate the carbon from atmosphere and gained significant importance in relation to the recent year disputation (Shahid and Joshi, 2015).

The variations in canopy status, growing stock and carbon potential of sal forests had been brought by various anthropogenic pressures. However, the dense sal forest of present study had showed the higher values of NPP and carbon sequestration. Thus, it is concluded that the sal dense forests need to be protected from various anthropogenic pressures by proper monitoring, management strategies, making policies to avert the encroachment and strict regulations so that they do not turn in to open forest in the future. However, they have also played an important role in mitigation of atmospheric carbon. So, it is very imperative for forest management authorities to provide the resources to the field staff so they can identify and categorize forest according the growing stock status. Consequently, sal forest of the region needs more scientific inputs for their better growing stock with reference to the production and carbon mitigation, therefore degradation and encroachment in sal forests could be reduced through appropriate management strategies such as regeneration of associated tree species, controlled forest fire and grazing as well as proper supervision of regeneration status of tree species and other intervention of local people.

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Authors Contribution

Author 1: Conceptualization, Methodology, Data collection, Data analysis, writing original draft, Editing and Finalized. Author 2: Conceptualization, Methodology, Supervision, Review and Finalized.

Author 3and 4: Editing and Finalized etc**.**

Conflict of Interest

The authors report there is no conflict of interests in this manuscript.

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