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Full Length Research Paper

Assessment of biomass carbon stock in an *Ailanthus excelsa* Roxb. plantation Uttarakhand, India

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The article presents biomass carbon stock for an *Ailanthus excelsa* plantation in Dehradun Forest Division, Uttarakhand, India. Destructive sampling was used to calculate the biomass of *A. excelsa* and undergrowth vegetation (shrubs and herbs); volumetric equations were used for estimating the biomass of associated tree species. The total biomass of *A. excelsa* was calculated as 126.07 t ha^{-1} with above ground biomass (AGB) 102.96 t ha^{-1} and below ground biomass (BGB) 23.11 t ha^{-1}. The total biomass of the two associated tree species was estimated as 43.91 t ha^{-1} (AGB 34.01 and BGB 9.9 t ha^{-1}). The total biomass of shrub and herb species was calculated as 1.62 and 0.98 t ha^{-1}, respectively. Litter biomass was calculated as 0.98 t ha^{-1}. The estimated total biomass of the whole ecosystem (173.56 t ha^{-1}) was obtained as the sum of these component biomass values. Carbon content of the main tree species, associated tree species, and understory vegetation (shrubs+herbs), was estimated in AGB pool (63.76 Mg ha^{-1}) and BGB pool (14.84 Mg ha^{-1}), and added to the litter carbon (0.35 Mg ha^{-1}) and soil organic carbon (SOC) (46.27 Mg ha^{-1}) to estimate the carbon stock in the whole ecosystem (125.22 Mg ha^{-1}). The SOC to AGB ratio was 0.72.

Key words: Biomass, carbon stock, litter, *Ailanthus excelsa* Roxb. plantation ecosystem, above ground biomass and below ground biomass.

INTRODUCTION

Forest ecosystems are deemed to be an important factor in climate change because they can be both sources and sinks of atmospheric CO2. They can assimilate CO2 via photosynthesis and store carbon in biomass and in soil (Trexler and Haugen, 1994; Brown et al., 1996; Watson et al., 2000). Plantations or naturally regenerated trees can protect watersheds against droughts, flash floods or landslides thought to be more prevalent due to climate change. Sustainable forestry practices can increase the ability of forests to sequester atmospheric carbon, while simultaneously enhancing other ecosystem services, such as improved soil and water quality. Carbon sequestration is also a good indicator of the health and functioning of ecosystems. Forests may help local communities to cope with climate change in a numerous ways (Robledo and Forner, 2005).

Ailanthus excelsa Roxb. commonly known as 'Ardu' or 'Mahanimb' is a fast growing tree and is extensively cultivated in many parts of India. Its wood is very light, soft and perishable. The timber is used for packing cases, fishing floats, boats, spear sheaths, sword handles, toys and drums. The bark is bitter, astringent, anthelmintic and it is used in diseases like dysentery, bronchitis, asthma, dyspepsia and ear ache. It is also used for environmental conservation as it is resistant to drought and soil conditions. It grows well on slopes. The pulp is obtained from debarked wood and is used in paper industry as a substitute for aspen, for printing papers, the leaves are rated as highly palatable and protein rich nutritious fodder for sheep and goats and are said to augment milk production

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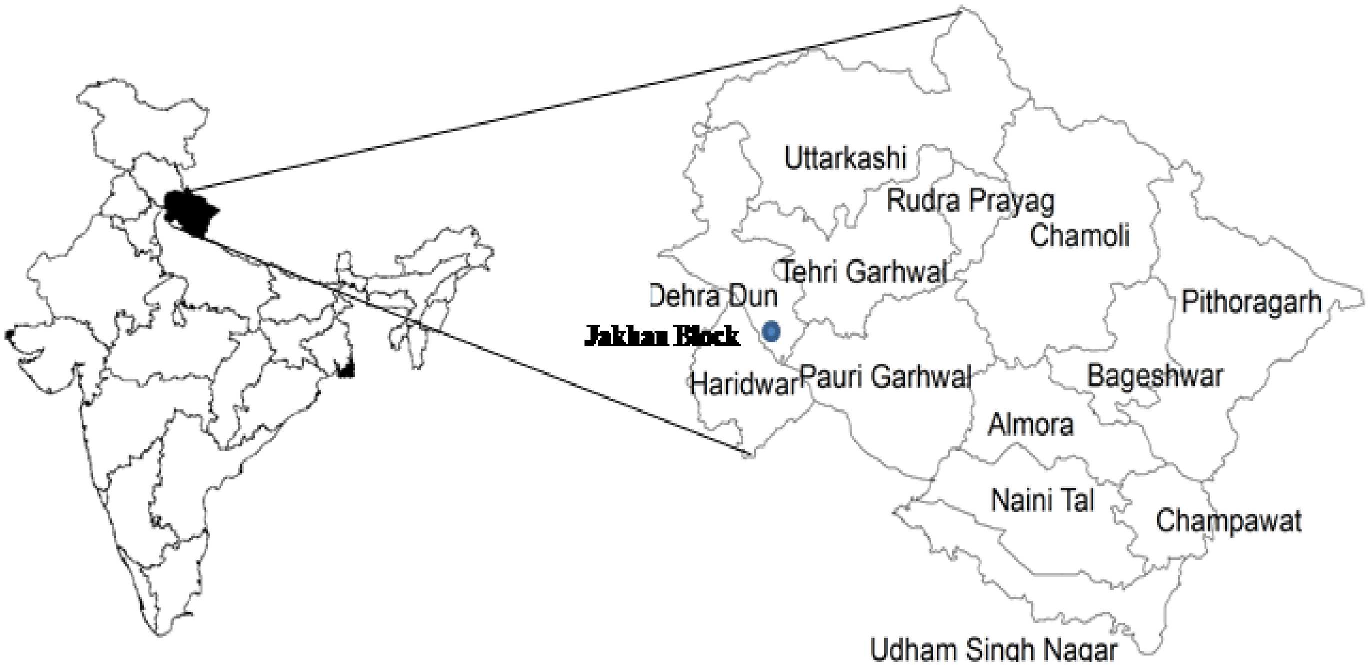

Map 1. Study site.

(Jat et al., 2011).

Above ground biomass (AGB) has been given the highest importance in carbon inventories and in most mitigation projects and is the most important pool for afforestation and reforestation CDM projects under the Kyoto Protocol. However, below ground biomass (BGB) has been shown to be an important carbon pool for many vegetation types and land-use systems and accounts for about 20% (Santantonio et al., 1997) to 26% (Cairns et al., 1997) of the total tree biomass. BGB accumulation is linked to the dynamics of AGB. The greatest proportion of root biomass occurs in the top 30 cm of the soil surface (Bohm, 1979; Jackson et al., 1996).

The carbon (C) sequestration potential of a forest ecosystem depends on initial soil organic carbon (SOC) content, stand growth rates, the biological carrying capacity of the stand and stand age. In particular, C sequestration and storage may be increased significantly, if forests are harvested and trees are converted into wood products (Skog and Nicholson, 1998). Some researchers suggest that sequestration of C in tree biomass and litter is a delaying tactic that only buys time for finding more permanent solutions for C sequestration (IPCC, 2000). Making an effort to maximize the productivity of the restored forest is also worthwhile because forest C pools can vary five-fold within a local edaphic gradient as a function of site quality (Burger and Zipper, 2002).

This article presents complete stand level (ecosystem level) estimates of biomass by component. This is the first report of C stock / C pool estimation of AGB, BGB of all existing vegetation and litter, as well as soil organic carbon (SOC) at the ecosystem level in India.

MATERIALS AND METHODS

Study area

This study was conducted in a 39 year old *A. excelsa* plantation in the Jakhan block, Barkot Range of Dehradun Forest Division, Uttarakhand, India (Map 1), nearly 25 km east of Haridwar and 30 km south east side of Dehradun city. The area lies in a subtropical region at an altitude of 449 m msl at 30°04'37.2''N and 78°12'11.1''E. It has a very gentle slope with a south aspect. The maximum, minimum and mean temperatures of the area (1980 to 2010) were 28.11 13.52 and 20.32°C, respectively. The mean annual rainfall during this period was 1901.03 mm when averaging monthly and approximately 80% of the rainfall occurred during the south-west monsoon period (June to September) (Figure 1).

Soil analysis

Texture

It is the proportion of particle size distribution (soil texture) into classified grades expressed as percentage of sand, silt and clay. After air drying of samples, big stones were removed and the soil was passed through 2 mm sieve. Part of the soil samples having particle size less than 2 mm were subjected for texture analysis by Hydrometric method (Black, 1965) and percentage of different fractions namely: sand, silt and clay was estimated in each sample and textural class was determined using the Triangular diagram by U.S.D.A (Black, 1965).

Soil moisture

Soil moisture percentage (%) was measured by means of moisture

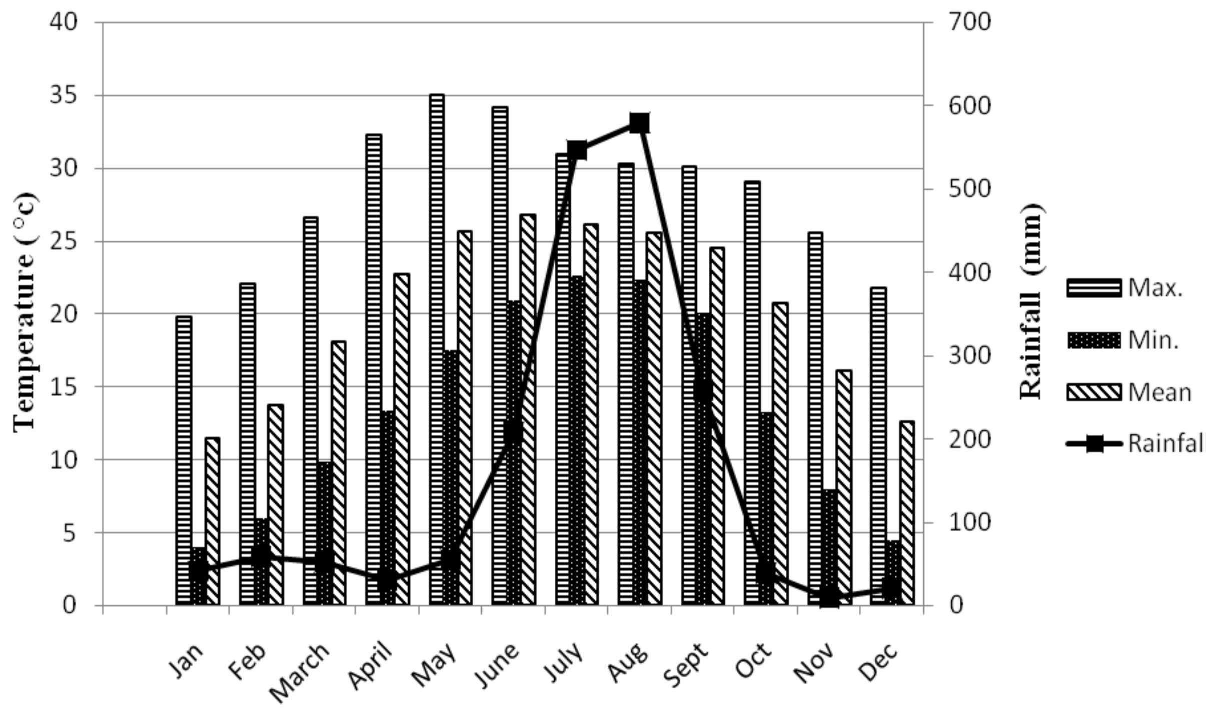

Figure 1. Ombrothermic graph of rainfall, mean, maximum and minimum temperature for 30 years (1980 to 2010).

meter.

Soil bulk density

A metal core cylinder (by core sampler) of known weight and volume was used to determine the soil bulk density (Wilde et al., 1985). Soil bulk density was determined by the following expression:

$$\text{Bulk density (g cm}^3\text{)} = \frac{W1 - W2}{V}$$

Where, W1= weight of cylinder + weight of soil, W2 = weight of empty cylinder, V= volume of cylinder

Biomass estimation of *Ailanthus excelsa*

The stratified tree technique method of Art and Marks (1971) was used to harvest the sample trees. Temporary sample plots (30 m × 30 m) were laid out in the plantation and the diameter at breast height (DBH at 1.3 m) of all the standing trees were recorded within the sample plots. The DBH range was divided into five different diameter classes that is, 10 to 20 cm, 20 to 30 cm, 30 to 40 cm, 40 to 50 cm and 50 to 60 cm from which 2 trees were harvested from 10 to 20 cm diametr class, 3 trees from 20 to 30 cm, 2 trees from 30 to 40 cm, 1 tree from 40 to 50 cm and 1 from 50 to 60 cm and in this way 9 representative sample trees were selected for the study.

The tree components (leaves, twigs, branches, bark, bole and roots) were separated immediately after felling and their fresh weights recorded. Samples of all tree components (100 g of each component) were selected for oven dry weight estimation and chemical analysis for C content.

The bole of each sample trees was cut into 2 m long sections (billets) for convenience of weighing.

Biomass estimation for the associated tree species

Biomass of the associated tree species (*Acacia catechu* and *Eucalyptus* hybrid) was estimated using the volumetric equations of the Forest Survey of India (FSI, 1996). Estimated volumes were multiplied by the density of the corresponding wood following the methods of Chaturvedi and Khanna (1982) to get the dry weight stem biomass. The biomass of branches and leaves were estimated using 45 and 11% of the stem biomass, respectively, as per Sharma (2003). BGB was estimated using the root-shoot ratios (R:S) of these species (FAO, 2000); Table 1). Total biomass per tree was obtained by summing AGB and BGB for each sample tree and averaging over the sample. The total biomass per ha for each of these species was esyimated by multiplying the average biomass per tree by the trees per ha for each of the species (80 trees ha^{-1} for Acacia Catechu and 40s tree ha^{-1} for *Eucalyptus* hybrid). C was estimated as 43% of the total biomass (Negi et al., 2003).

Biomass estimation of understory vegetation

Ten quadrats of 3 m × 3 m and 1 m × 1 m were laid out for shrubs and herbs, respectively. Complete harvesting of all shrub and herb species present in all quadrats was done; the plant materials were separated into above and below ground portions. Fresh and dry weights were measured for biomass and C was estimated according to the methodology given earlier. Biomass values were then multiplied by an expansion factor to sclae them to a one hectare area.

Estimation of litter biomass

Litter biomass was estimated by laying out ten 5 m × 5 m sample plots in the plantation. Litter samples were collected on these sam-

Table 1. Volumetric equations and root shoot ratio (R:S) used for estimation of biomass of associated tree species.

Tree specie	Volumetric equations (FSI, 1996)	R:S (FAO, 2000)
Eucalyptus hybrid	$V = 0.02894 - 0.89284\,D + 8.72416\,D^2$	0.30
Acacia catechu	$V = 0.048535 - 0.183567\sqrt{D} + 3.78725D^2$	0.25

V = volume, D = diameter.

Table 2. Moisture, Bulk density and Texture of soil at different depths under *A. excelsa* plantation.

A. excelsa plantation (cm)	Moisture (%)	BD (g cm^{-3})	Texture (Sandy loam)		
			Sand (%)	Silt (%)	Clay (%)
0-30	5.990± 0.198	1.223± 0.004	51.23 ± 0.470	26.83 ± 0.536	21.93 ± 0.133
30-60	7.075± 0.363	1.267± 0.003	51.67 ± 0.636	25.80 ± 0.851	22.53 ± 0.606
60-90	8.848± 0.203	1.283± 0.003	52.80 ± 0.208	25.37 ± 1.538	22.50 ± 0.589

ple plots and a fresh and an oven dry weight at 80°C (until a constant weight was achieved) were obtained. The litter was ground for chemical analysis to estimate C content.

Estimation of carbon in A. excelsa trees, shrubs, herbs, litter and soil organic carbon (SOC)

Samples of all three parts of *A. excelsa* trees, shrubs, herbs and litter soil were analyzed for C content using Wakley and Black's titration method (Jackson, 1967). For estimation of SOC, soil samples were taken from the surface to 90 cm depth (in three depth classes of 0 to 30 cm, 30 to 60 cm and 60 to 90 cm) from randomly selected points in the plantation area. Three replicates from each point were collected.

RESULTS AND DISCUSSION

Floristic struture

In the plantation, *A. excelsa* showed the maximum density (350 ha^{-1}) followed by *A. catechu* (80 ha^{-1}) and *Eucalyptus* hybrid (40 ha^{-1}).

Physical attributes of soil

Soil texture was observed to be sandy loam in nature, soil moisture was higher (8.848%) in the deepest layer that is, 60 to 90 cm depth, lower (5.990%) in uppermost layer that is, 0 to 30 cm depth. The trend of bulk density in soil depths was in the order 60 to 90 cm > 30 to 60 cm > 0 to 30 cm (Table 2).

Biomass of *A. excelsa* species

The DBH and heights of the nine sample trees varied from 15.5 cm to 55.09 cm and 8.85 m to 20.20 m, respectively. This variation in the total tree biomass which ranged from 75.04 to 759.56 kg tree^{-1}. The other tree components ranged from: bole, 40.21 to 551.48 kg; leaves, 0.32 to 12.71 kg; twigs, 0.43 to 5.10 kg; branches, 6.71 to 52.63 kg; bark, 5.84 to 18.28 kg; and roots 21.27 to 119.36 kg.

The total biomass of *A. excelsa* trees was estimated at 126.07 t ha^{-1}, of which the AGB comprised 102.96 t ha^{-1} and the BGB comprised 23.11 t ha^{-1}. The highest percentage of total biomass was found in boles (66.94%), followed by roots (18.33%), branches (9.07%), bark (3.36%), leaves (1.59%) and twigs (0.71%). The percentage contribution to the total biomass varied among dbh classes: 10 to 20 cm, 4.52%; 21 to 30 cm, 17.93%; 31 to 40 cm, 27.98%; 41 to 50 cm, 26.79%; and 51 to 60 cm, 22.76%. More than 77% of the *A. excelsa* trees have a dbh between 31 to 60 cm.

Biomass of associate tree species

The biomass values of *Acacia catechu* and the *Eucalyptus* hybrid were estimated as product of wood density (kg/m^3) and volumes using volumetric of FSI (1996). The biomass estimated for the *Eucalyptus* hybrid was 36.15 t ha^{-1} and for *Acacia catechu* was 7.76 t ha^{-1}.

Understory biomass

The shrub species present in the plantation ecosystem were *Lantana camara, Justicia adhatoda, Murraya koenigii, Eucalyptus* hybrid saplings, *Syzigium cumini, Lemonia acidissima* and *Cassia tora.* Herb species were *Ageratum conyzoides, Sida cuta, Oxalis corniculata, Aerva scandens, Rundia pectinata, Cyperus esculentus, Oplismenus compositus, Parthenium hysterophorus, Cynodon dactylon, Murraya koenigii* seedlings and *Achyranthes aspera*. The AGB of shrubs was 1.027 t ha^{-1} and the BGB was 0.591 t ha^{-1}. The total shrub biomass was 1.618 t ha^{-1}. The herb biomass was 0.983 t ha^{-1} (AGB 0.705 t ha^{-1} and BGB 0.278 t ha^{-1}). The total understory biomass (shrub and herb) was estimated at 2.60 t ha^{-1}. Total litter biomass estimated as 0.98 t ha^{-1}.

Table 3. Total Biomass distribution (t ha^{-1}) among different components of *A. excelsa* plantation ecosystem.

Level	Vegetational components				Total
	Main tree species	Associated tree species	Shrubs	Herbs	
Above ground	102.96	34.01	1.027	0.705	138.702
Below ground	23.11	9.90	0.591	0.278	33.88
Total	**126.07**	**43.91**	**1.618**	**0.983**	**172.58**

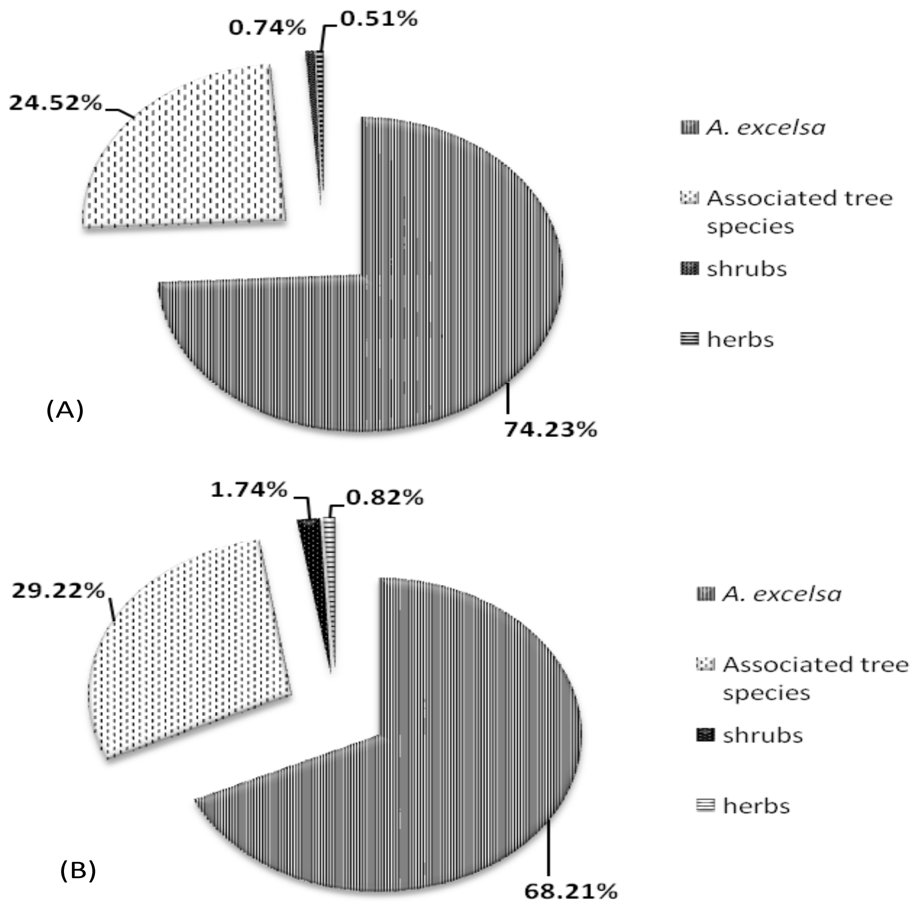

Figure 2. (a) AGB (%) contribution of different components of the ecosystem. (b) BGB (%) contribution of different components of the ecosystem.

Total biomass estimation

Total biomass of the whole ecosystem was estimated at 173.56 t ha^{-1} , which is the sum of the biomass of main tree species that is, *A. excelsa*, the biomass of associated tree species, shrub, herb biomass and litter biomass (Table 3).

The biomass contribution of the main tree species, associated tree species, shrubs and herbs to the total AGB and BGB was 72.64% for *A. excelsa* trees, 25.3% for associated tree species, 0.93% for shrubs, and 0.57% for herbs. Figure 2 (a) and (b) depicts the AGB and BGB contribution (%) sepaprately for these components.

Carbon content / carbon pool

A. excelsa tree species

The total C content (t ha^{-1}) in the different *A. excelsa* tree components were: 40.27 (boles), 10.22 (roots), 5.36 (branches), 1.61 (bark), 0.73 (leaves), and 0.33 (twigs). The amount of C content contributed by *A. excelsa* trees was 58.52 t ha^{-1}.

Associated tree species

Total C content in associated tree species was 18.88 t ha^{-1}, of which 14.62 t ha^{-1} (77.44%) was contributed by

Table 4. Carbon stock (t ha^{-1}) in different pools of *A. excelsa* plantation ecosystem.

Parameter	Carbon Pools				Total C
	AGB C	BGB C	Litter C	SOC	
Main tree species					
Ailanthus excelsa	48.3	10.22			**58.52**
Associate species					
(1) *Acacia catechu*	2.67	0.67			3.34
(2) *Eucalyptus* hybrid	11.95	3.59			15.54
					18.88
Understory vegetation					
(1) Shrubs	0.5	0.24			0.74
(2) Herbs	0.34	0.12			0.46
					1.20
			0.35		**0.35**
				46.27	**46.27**
Grand total	**63.76**	**14.84**	**0.35**	**46.27**	**125.22**

AGB and 4.26 t ha^{-1} (22.56%) by BGB.

Understory vegetation

Understory vegetation (shrubs+herbs) contributed 1.20 t ha^{-1} to the C pool. For shrubs 67.56% of the C was in the above ground material and 32.43% was in the below ground material. For the herb layer 73.91% of the C was in the above ground material and 26.09% was in the below ground material. Litter contains 0.35 t ha^{-1} of total C content (Table 4).

Soil organic carbon (SOC)

Soil Organic Carbon was estimated at 46.27 t ha^{-1}.

Total carbon stock

The total C stock was determined to be 125.22 t ha^{-1} of which 46.73% was contributed by *A. excelsa* trees, 15.08% by associated tree species, 0.59% by shrubs, 0.37% by herbs, 0.28% by litter and 36.95% contibuted by soil (Table 3).

Pande et al. (1988) also the estimated biomass of *A. excelsa* of different ages in Uttar Pradesh. They have reported that contribution of bole to AGB was just over 50%, bark contributed 19.9 to 23.3%, branches contributed 9.68 to 14.5% and roots 18.1 to 25%. This study has showed a similar order of contribution of different tree components to AGB. The percent contribution of AGB to total biomass was estimated as 81.67% in the present study, which is similar to overstory biomass contribution of 81.9 and 81% reported by Nascimento and Laurance (2002) and Henry et al. (2009), respectively. However, it is less than the 92.7 to 94% of overstory contribution reported by Clark and Clark (2000).

Rana and Singh (1990) showed that the understory (shrubs+herbs) accounted for 1.5% of the total forest biomass (432.8 t ha^{-1}) in a *Pinus roxburghii* plantation located in Kumaun Himalaya of Uttarakhand. Mac Lean and Wein (1977a) found that understory biomass in *Pinus banksiana* ranged from 1 to 6% of the ecosystem biomass in old stands. The per-cent contribution of the understory to the total biomass in this study was 1.50%. Negi (1984) reported 2.3 and 0.9% understory biomass contribution to the total stand tree biomass in *Shorea robusta* (sal) forest and *Eucalyptus* hybrid plantation ecosystems, respectively.

The maximum concentration of C was found in the bole (47.2%) and the minimum concentration was in the leaves (36.08%). Similar findings have been reported by Kraenzel et al. (2003) and Negi et al. (2003) in teak plantations of Panama and India, respectively.

Conclusion

Long rotation forests have larger long term C storage in the forest biomass and product pool. Biotic interferences and changes in land use cause significant exchanges of carbon between the land and the atmosphere. The phytomass carbon pool estimates are associated with significant uncertainties due to deficiency of data, volume biomass conversion approach and the extent of the human activity on ecosystem and environment, because many ecological processes depend on the carbon cycle.

In the tropical forest the carbon in the soil is roughly equivalent to or less than the AGB due to degradation (cited from Ramachandran et al. 2007). Ravindranath et al. (1997) reported that the ratio of SOC and biomass carbon was 1.25. Kaul (2010) has given the range of this ratio between 0.7 to 2. She indicates that in the plantations, the carbon content in the soil was double the biomass carbon but not 2.5 to 3 times the biomass carbon as recorded earlier. The fact she gives that the sequestered SOC came from the original vegetation in the past before exploitation. The SOC and AGB ratio of the present study comes to be 0.72.

Biomass and productivity of *A. excelsa* plantation of 16 and 21 years at Mohand range of Shiwalik forest division of Uttarakhand have been estimated by Pande et al. (1988) and they have reported 37.62 t ha^{-1} biomass of 16 years and 31.78 t ha^{-1} of 21 years plantations. The productivity of both the plantations was 1.95 and 1.45 t ha^{-1} yr^{-1}, respectively. 126.07 t ha^{-1} biomass of the present study of *A. excelsa* species with 3.23 t ha^{-1} yr^{-1} of productivity showed a high value when compared to the study of Pande et al. (1988), which may be because of high density of *A. excelsa* trees and associate species, and more age (39 years old) of the species, which would have supported more biomass in the present study site and signifies that at this age the species shows high productivity and better C stock.

Stand level estimates of biomass according to tree components are needed when biomass productivity and litter fall by biomass components of different quality are modeled and linked to soil as Liski et al. (2002) model describes the decomposition of dead organic matter also. For these purposes it is important to be able to observe the dynamics of C stock in different tree components, such as foliage, branches, bark, stem, stump and roots according to stand age (Lehtonen et al. 2004).

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