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Carbon Sequestration Potential of *Populus deltoides* plantation under Social Forestry Scheme in Kurukshetra, Haryana in Northern India

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Abstract

The role of plantation forests as carbon reservoirs is considered crucial for improving predictions about the effects of land use and land cover changes on the global carbon cycle. Tree growth serves as an important means to sequester atmospheric carbon dioxide in vegetation, soils and biomass. Estimation of vegetation and soil carbon stock of *Populus deltoides* plantation under social forestry scheme in Kurukshetra, Haryana in Northern India was carried out over a period of one year. The study revealed that the plantation had a significant carbon sequestration potential with vegetation carbon stock of 88.45 Mg/ha in different tree components with a carbon flux of 4.6 Mg/ha/yr. The net primary productivity of the plantation in terms of biomass accumulation was 9.74 Mg/ha/yr assimilating 16.97 Mg/ha/yr of carbon dioxide. The total STC stock of the plantation was 76.97 Mg/ha up to one meter depth of soil. Highest contribution (61-70%) to the percent weight of whole soil was from micro-aggregates whereas maximum amount of organic carbon (0.06-0.63%) was found in macro-aggregates in all depths. The soil microbial biomass carbon was found to be declining down the depth, being higher in rainy season, (117 -355 $\mu g g^{-1}$ of soil) compared to winter and spring seasons.

Keywords: Carbon sequestration, Net Primary Productivity, Soil Organic Carbon, Microbial Biomass

1. Introduction

Evaluation of biospheric fluxes and stocks of carbon is of major importance in the context of increasing atmospheric CO_2 concentration and the related potential change in climate [1]. Above-ground biomass, below-ground biomass, dead wood, litter, and soil organic matter are the major carbon pools in any ecosystem [2-4] with a potential to absorb and store carbon dioxide (CO_2) from the atmosphere [5]. Carbon sequestration in growing forests is known to be a cost-effective option for mitigation of global warming and global climatic change [6].

Tropical ecosystems store 340 billion tons of C [7], corresponding to more than forty times total annual anthropogenic emissions from fossil fuels [8]. Therefore, increased focus on forestry and agroforestry systems as C sinks is necessary to achieve a significant long term reduction in atmospheric GHG levels, particularly from tropical areas [9, 10]. The CO_2 removal by India's forests and tree cover is enough to neutralize 11.25% of India's total GHG emissions at 1994 level [11]. Net C accumulation by forest ecosystems depends on forest age and natural disturbance regimes, and land-use practices play a key role in regulating C cycling and storage [12].

Biomass analysis is an important element in the carbon cycle and carbon sequestration [13]; being increasingly used to help quantify pools and fluxes of green house gases (GHG) from terrestrial biosphere [14]. Differences among species in growth characteristics may also explain the variations in estimates of carbon storage among trees of the same diameter [15-18]. Tree growth serves as an important means to capture and sequester atmospheric carbon dioxide in vegetation, soils and biomass products [19].

Forestry has been recognized as a sink measure for atmospheric greenhouse gases under the Clean Development Mechanism (CDM) of Kyoto Protocol in terms of afforestation and reforestation [20]. To be traded in the carbon market, it is necessary to know the potential CO_2 sequestration, and hence the net primary productivity (NPP) of the reforested/replanted species [21].

The National Commission on Agriculture, Government of India, first introduced the scheme of 'social forestry' in 1976. Massive afforestation programme have been undertaken by Forest Department, Haryana, on

Government Lands, Institutional Lands, Panchayat Lands, Common Lands and other waste lands in order to increase the forest and tree cover.

The recorded forest area of the state of Haryana is only 3.53% of its total geographical area out of which reserved forests constitute 15.97%, protected forest 74.28% and 9.75% is covered by unclassed forests [22]. Hence, Social forestry schemes can make considerable differences in overall forest cover in a short time. More land under tree cover ultimately can play a significant role in sequestering the atmospheric CO_2 in biomass and soil and thus contribute in mitigation of climate change.

Therefore, the objective of this study was to determine carbon sequestration potential of *Populus deltoides* plantation through estimation of (i) NPP (Net Primary Productivity); (ii) vegetation carbon stocks and CO_2 assimilation rates; (iii) soil carbon stocks and (iv) carbon storage in soil aggregates and microbial biomass.

Study Site

The study sites were located in the campus of Kurukshetra University, Kurukshetra. The district of Kurukshetra with an area 1682.53 Sq.Kms, lies between latitude 29°-52' to 30°-12' and longitude 76°-26' to 77°-04' in the North Eastern part of Haryana State. The distance between the rows of trees and between trees in a row was 6.0 m and 3.5 m. The climate of the study area is of very pronounced character i.e. very hot in summer (up to 45ºC) and very cold in winter (about 3ºC). The maximum and minimum temperature ranged from 18.77 to 45.15ºC and 5.37 to 32.15ºC respectively from November, 2011 to December, 2012. The plantation of *Populus deltoides* was done in year 2001 by Forest Department of Haryana, under Social Forestry Scheme. The study was conducted in the year 2011-12.

2. Materials and Methods

2.1 Estimation of Plant Biomass, Net Primary Productivity and Carbon Pool

Direct tree harvest data are difficult to obtain so allometric equations were used for estimating the biomass of trees. 20 x 20 m experimental plots were demarcated within the *P. deltoides* plantation. Component wise (above and below ground) biomass of trees was estimated by dimension analysis of sample trees based on diameter at breast height (dbh) using linear regression equations developed by Lodhiyal et al. [23] for *Populus deltoides*. Total Net Primary Productivity was estimated as the sum of increment in biomass of tree components (above ground and below ground) over a period of one year. Carbon pool of various tree components was calculated by multiplying factor (0.475) with the estimated biomass values [24]. Estimated C stocks in tree components were converted to CO_2 equivalents (C x 3.67) for calculating CO_2 assimilation by biomass.

2.2 Soil Sampling and Analysis

The samples were collected down to one meter depth (0-15cm, 15-30cm, 30-45cm, 45-60cm and 60-100cm) using soil corer from within the sampling plots. Some samples were procured for measurement of bulk density and moisture content and others were air dried, ground and stored for further chemical analysis. Soil moisture was determined using Moisture meter (IR 60, Denver Instruments), bulk density by soil core method [25]. Soil pH was measured in 1:2 ratio with distilled water using Systronics µpH System 361. Soil aggregates were determined by wet sieve method [26]. Total carbon (%) in soil was determined following dry combustion method through CHNS analyzer (ElementR Vario Macro). Organic carbon (%) in soil samples and soil aggregates was analyzed by wet digestion method [27]. Soil Inorganic carbon (%) was determined as the difference between total soil carbon and soil organic carbon [28]. Soil Carbon stocks were estimated from bulk density, soil depth, and organic carbon concentration in soil of the respective soil depth. The microbial biomass was determined following the method of Nunan [29] from the soil samples collected seasonally.

2.3 Statistical analysis

The results of the study were analyzed statistically through correlation analysis between basal area and biomass of different tree components. The differences in soil parameters were analyzed through two-way ANOVA using MS Excel spreadsheets.

3. Results and Discussion

3.1 Plant biomass and primary productivity

The total basal area of the plantation was 21.77 m^2/ha in 2011 and 23.82 m^2/ha in 2012. The biomass in different tree components of *Populus deltoides* is given in Table 1. The percentage contribution to the total biomass was maximum from bole (52%) followed by stump root (13%) and branches (11%) and minimum was from fine roots (1%).

Total net primary productivity in terms of biomass accumulation in tree components was calculated to be 9.74 Mg/ha/yr. However, the above ground components (Bole +Bark +Branch +Twig +Foliage) contributed 80% to the total tree biomass and net primary productivity. Positive and Significant correlation was observed between biomass of different tree components and the basal area of the tree ($r= 0.99$, $p<0.01$).

Total carbon pool in the *P. deltoides* plantation was 83.82 Mg/ha in 2011 and 88.45 Mg/ha in 2012, which accounted for a carbon flux of 4.63Mg/ha/yr (Table 2). Maximum amount of carbon was sequestered by tree bole in the above ground components and by stump roots in below ground components.

Table 1: Total biomass ($Mgha^{-1}$) and net primary productivity (NPP, $Mgha^{-1}yr^{-1}$) of different components of *Populus deltoides* plantation.

Component	Biomass (Mg/ha) in 2011	Biomass (Mg/ha) in 2012	NPP (Mg/ha/yr)
Bole	92.56	97.36	4.80
Bark	15.45	16.24	0.80
Branch	16.83	17.86	1.03
Twig	4.12	4.55	0.44
Foliage	11.87	12.53	0.66
Total AG	**140.82**	**148.54**	**7.72**
Stump root	22.80	24.05	1.25
Lateral root	11.22	11.89	0.67
Fine Root	1.63	1.73	0.11
Total BG	**35.65**	**37.67**	**2.02**
TOTAL	**176.47**	**186.21**	**9.74**

Table 2: Carbon pool (MgC/ha) and carbon flux (MgC/ha/yr) of different tree components of *P. deltoides* plantation

Component	Carbon pool (Mg/ha) in 2011	Carbon pool (Mg/ha) in 2012	Carbon Flux (Mg/ha/yr)
Bole wood	43.96	46.25	2.28
Bark	7.34	7.72	0.38
Branch	8.00	8.48	0.49
Twig	1.96	2.16	0.21
Foliage	5.64	5.95	0.31
AG	**66.89**	**70.56**	**3.67**
Stump root	10.83	11.42	0.59
Lateral root	5.33	5.65	0.32
Fine Root	0.77	0.82	0.05
BG	**16.93**	**17.89**	**0.96**
TOTAL	**83.82**	**88.45**	**4.63**

The percent contribution of tree components to total carbon storage was based on the biomass accumulation. Tree bole with a carbon flux of 2.28Mg/ha/yr contributed 52% to the total carbon storage while the fine roots with minimum biomass accumulation and a carbon flux rate of 0.05 Mg/ha/yr contributed only 1% to the carbon sequestration (Figure 1). Carbon stocks of different tree components were converted to their CO_2 equivalents. A total of 16.97Mg/ha CO_2 was assimilated by the Populus plantation over a period of one year (Figure 2).

3.2 Physico-chemical properties of soil

Soil samples collected seasonally (winter, spring and rainy season) from each site were analyzed for the physiochemical properties. The values for moisture content were maximum in the rainy season followed by winter and spring season. Moisture content of soil increased down the depth in winter and spring season, while a decreasing trend was observed in rainy season. In rainy season surface soil receives ample amount of rain water which seeps down the depth slowly accounting for higher moisture content in the upper horizons of the soil than that of deeper layers. However, increased temperature of spring and dryness of winter atmosphere makes the water of surface soil readily available for evaporation which lowers down the moisture content of surface soil while deeper layers retain their moisture. The pH for all soil samples was neutral or slightly alkaline. In general, the pH values increased down the depth. Significant differences ($p<0.01$, 0.05) were observed in pH values between seasons and depths. There was no observable trend in the values of Electrical conductivity of the soil sample down the depth and among the seasons. Also, the differences were only significant between depths at 5% level. Total and organic carbon content of the soil decreased down the depth in all the season.

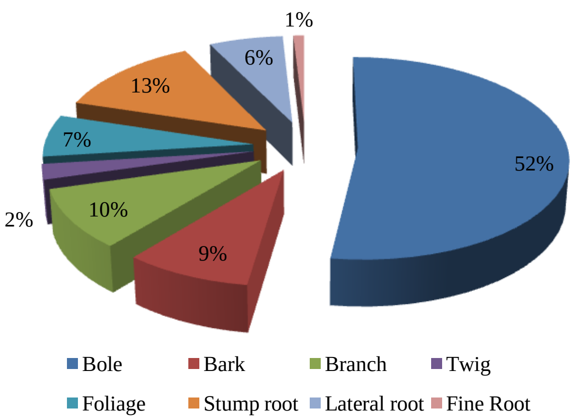

Fig 1: Percent contribution of tree components to carbon storage

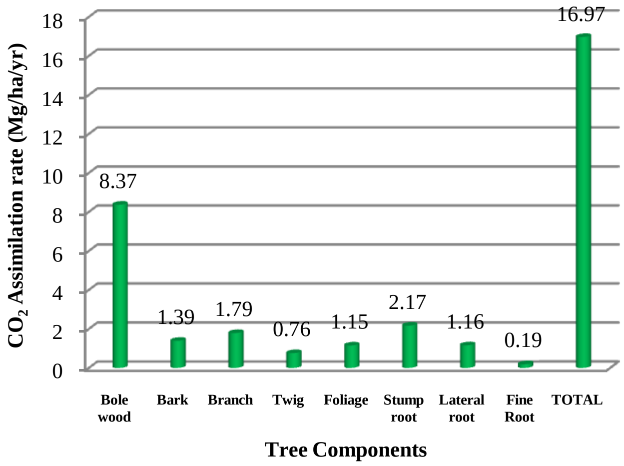

Fig 2: CO_2 Assimilation rate (Mg/ha/yr) of different tree components of *P. deltoides* plantation

A continuous increase was observed in the carbon content of the soil from winter 2011 to rainy season of 2012 except the above 30 cm soil samples of spring season. This decrease can be attributed to man-made fire in that season to burn off all the herbaceous vegetation (Table 3).

Table 3: Seasonal variations in physiochemical properties of soil samples from different depths.

Season	Soil Depth (cm)	Moisture content (%)	pH (1 : 2 ratio)	EC (µS) (1 : 2 ratio)	Soil Total Carbon (%)	Soil Organic Carbon (%)	Soil Inorganic Carbon (%)
Winter, 2011	0-15	8.00±0.48	7.22±0.02	183.73±4.72	0.99	0.88±0.01	0.02
	15-30	8.98±0.34	7.35±0.02	149.27±3.81	0.63	0.60±0.01	0.03
	30-45	9.87±0.34	7.48±0.01	159.80±4.75	0.62	0.55±0.01	0.08
	45-60	10.50±0.26	7.61±0.01	108.23±2.72	0.59	0.49±0.01	0.10
	60-100	11.10±0.31	7.74±0.02	97.07±3.43	0.41	0.42±0.01	0.13
Spring, 2012	0-15	2.96±0.24	7.37±0.02	187.20±3.74	0.86	0.84±0.01	0.02
	15-30	4.02±0.44	7.65±0.02	148.14±3.42	0.61	0.58±0.01	0.03
	30-45	4.82±0.32	7.75±0.02	123.51±2.87	0.65	0.57±0.01	0.08
	45-60	5.48±0.29	7.84±0.02	134.00±3.42	0.63	0.52±0.01	0.11
	60-100	6.56±0.22	7.96±0.02	105.81±2.91	0.44	0.46±0.01	0.14
Rainy, 2012	0-15	14.37±0.29	7.36±0.02	134.04±3.58	0.99	0.99±0.01	0.01
	15-30	13.08±0.29	7.68±0.02	117.44±3.15	0.69	0.68±0.01	0.01
	30-45	12.26±0.17	7.84±0.01	126.29±3.84	0.68	0.59±0.01	0.09
	45-60	11.44±0.19	7.92±0.02	114.95±2.90	0.64	0.53±0.01	0.11
	60-100	10.63±0.16	8.04±0.02	104.75±2.90	0.46	0.48±0.01	0.15

The most intuitive change soils experience during burning is the loss of organic matter [30], thus fire has the potential to decrease the amount of carbon stored in the soils [31]. The differences in the percentage of soil total carbon were significant between depths and between seasons ($p<0.01$, 0.05). However, the differences in the percent organic carbon content were significant between the depths at $p<0.01$ and 0.05 and were significant between seasons only at $p<0.05$. The inorganic carbon content increased down the depth. No observable trend in percentage of soil inorganic carbon was observed among the seasons. Also, the variations in percentage of soil inorganic carbon were significant only between different depths ($p<0.01$, 0.05) Values of bulk density of soil samples increased down the depth ranging from 1.09 g/cm3 from 1.32 g/cm^3 (Figure. 3).

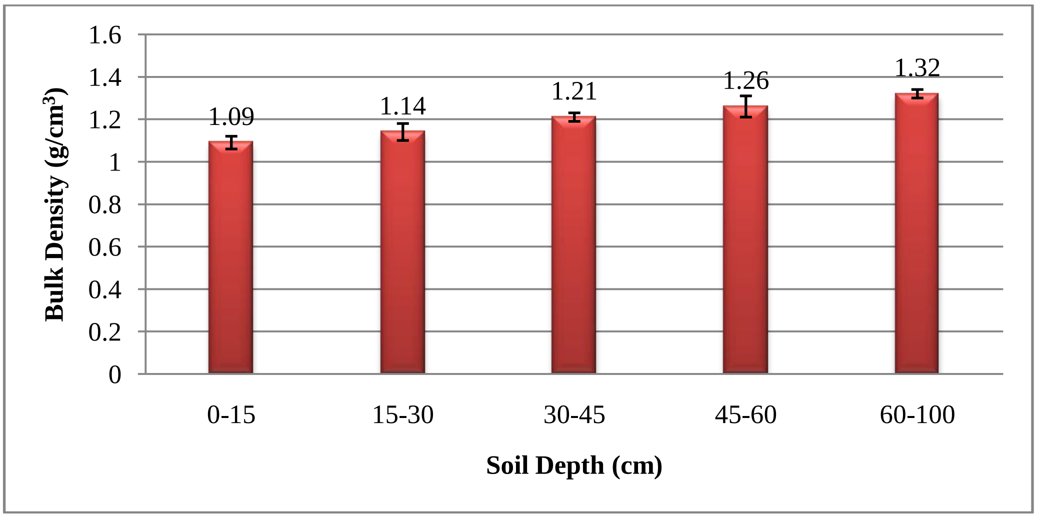

Figure 3: Bulk density of soil samples at different depths

The total carbon stocks (STC) and organic carbon stocks (SOC) of soil in *P.deltoides* plantation generally declined with increasing depth. However, in the 60-100 cm depths, the total stocks were higher than the upper layers (due to larger depth size of 40cm sampled) though the percentage of organic carbon was lower in that depth. The total STC stocks increased from 69.87Mg/ha in winter 2011 to 76.97Mg/ha in rainy season of 2012 and total SOC stocks increased from 58.87 Mg/ha in winter 2011 to 65.07Mg/ha in rainy season of 2012 (Figure 4a, b). The inorganic carbon stocks (SIC) of soil generally increased down the depth and an increase of only 0.89Mg/ha in SIC stock across all depths was observed during the study period.

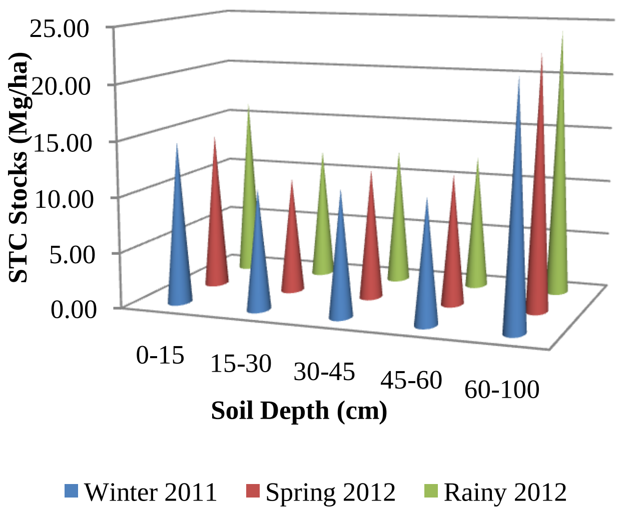

Fig. 4a: Seasonal variations in Soil Organic Carbon Stock (SOC) at different soil depths

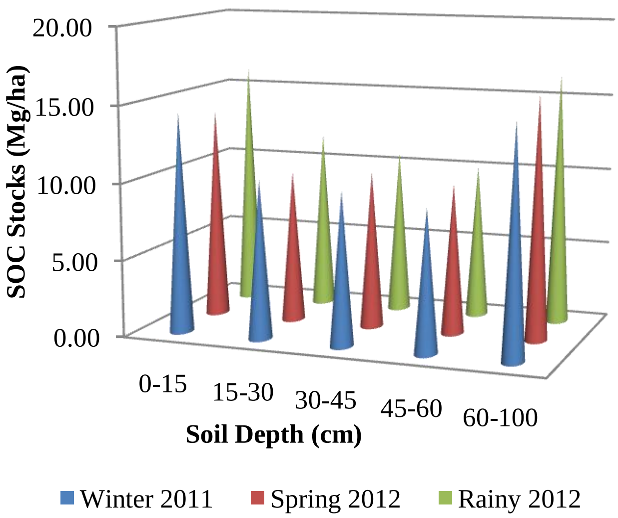

Fig. 4b: Seasonal variations in Soil Organic Carbon Stock (SOC) at different soil depths

The aggregate size fractions in the soil from different soil depths are given in Table 4. The maximum contribution in weight was observed to be from the microaggregates (250µm-53µm) followed by silt and clay associated fraction (<53µm) and macroaggregates (2mm-250µm) at all the depths. The differences in percent weight distribution among the three classes were observed to be significant ($p<0.01, 0.05$).
The extent of C retention in soils depends on the nature of soil aggregation [32, 33], which are affected by land use and land cover management [34, 35]. Macroaggregates play important role in storing carbon. In general the total carbon concentration declined with decreasing size of aggregates. It was maximum in macroaggregates (2mm-250µm), followed by microaggregates (250µm-53µm) and then by silt and clay associated soil fraction (<53µm) along all depths (Figure 5). Differences in distribution of organic carbon content among different size classes and depths were found to be significant ($p<0.01, 0.05$).

Table 4: Soil weight (%) distribution in aggregate size classes at different depths.

Soil Depth (cm)	2mm-250µm	250µm-53µm	<53µm
0-15	14.32±0.87	67.96±1.28	16.75±0.38
15-30	17.44±0.45	61.22±0.76	17.86±0.29
30-45	9.42±0.36	68.99±0.83	16.70±0.67
45-60	11.29±1.21	66.92±0.46	20.30±0.35
60-100	6.73±0.24	70.41±0.38	20.92±0.37

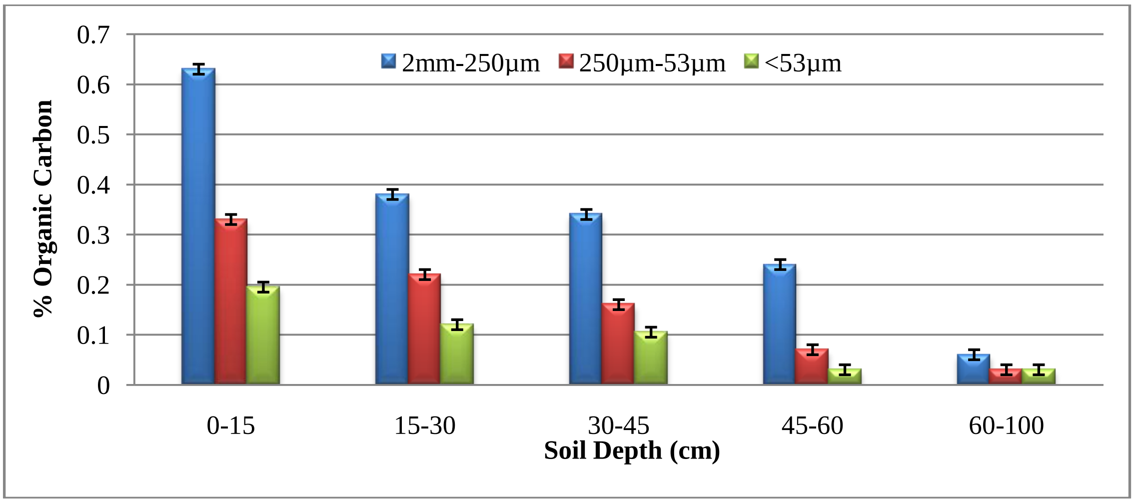

Figure 5: Organic carbon (%) distribution in aggregate size classes at different soil depths

Microbial biomass is the most active fraction of soil and its measurement can give an early indication of changes in total soil organic matter. The soil microbial biomass carbon decreased down the depth (Table 5). It may be due to the presence of decomposable organic matter content in upper layers of soil added by leaf litter, plant residues and rhizospheric roots triggering the microbial activity.

Table 5: Seasonal variations in Microbial Biomass Carbon (µg C g^{-1} of soil) at different depths**.**

Depth (cm)	Winter season, 2011	Summer season, 2012	Rainy season, 2012
0-5	101±0.03	86±0.11	355±0.09
5-15	89±0.07	53±0.08	286±0.11
15-30	63±0.01	25±0.11	117±0.14

The rainy season provides sufficient amount of moisture and optimum temperature conditions necessary for microbial growth, thus accounting for highest amount of microbial biomass carbon.

Conclusion

Forests are capable of effective sequestration of atmospheric carbon in above-ground and below-ground biomass through the processes of photosynthesis and tree growth. Plantations may be an important element in increasing adaptive capacity in the sense of adapting to climate change [36]. Establishing forest plantations on presently non-forested land provides an energy-conscious world with a clean and efficient means of absorbing atmospheric CO_2 [37].

Soil organic matter physically and chemically binds the primary particles in the aggregates increasing their stability. The trends indicated by soil aggregates (% weight distribution) and % organic carbon in aggregate size class in the present study were comparable to other studies [38-40].

Soil microbial communities play a significant role in ecosystem processes, such as carbon cycling and nutrient turnover. The soil microbial biomass carbon also represents a potential stock of carbon. The seasonal variations of soil microbial biomass reflect the degree of immobilization and mineralization of soil carbon.

A goal to have 20% of forest and tree cover in the state of Haryana by its Forest Department can only be achieved when major thrust is given to afforestation on the lands outside the notified forest areas. The present study reveals that the plantation of *Populus deltoides* had a significant role in sequestering carbon and assimilating 53.63Mg/ha CO_2 over a period of one year in different tree components. Also, soil total carbon stocks of 76.97Mg/ha represent a large carbon pool, making it an efficient storehouse of atmospheric carbon. In this regard, plantations like *Populus deltoides* under social forestry schemes can play a substantial role in increasing the forest cover in addition to their significant contribution in sequestering carbon as a strategy to mitigate climate change.

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