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Biomass Estimation and Carbon Sequestration in *Populus deltoides* Plantations in India

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ABSTRACT

Trees are known to sequester the atmospheric carbon into long lived wood biomass and soil pool. This study reports growth, biomass, carbon storage and carbon sequestration potential of *Populus deltoides* in different age plantation. Mean carbon concentration in aboveground components varied from 44.1% to 47.8%. Carbon stock in *Populus deltoides* increased from 9.15 to 74.3 Mg ha^{-1} from 1 to 7-year plantation age. Soil carbon stock increased with age (1-7 years) from 11.8 to 17.6 Mg ha^{-1} and decreased with soil depth. Total carbon (biomass+soil) increased from 20.95 Mg C ha^{-1} at 1-year of age to 91.93 Mg C ha^{-1} at 7-year of age, which was more than four times higher than 1-year plantation. Maximum carbon sequestration rate was recorded at plantation age of 4-year. *Populus deltoides* based plantation forestry was not only remunerative to the farmers but also substantially improved the soil health.

Keywords: Biomass, Carbon stock, CO_2 assimilation, Long lived carbon, *Populus deltoides,* Soil organic carbon

Introduction

Afforestation and reforestation sequester the atmospheric carbon into a long lived wood biomass, hence known as a biological tool to mitigate global warming and climate change. For India, net sequestration of 5 Tg C for the reference year 1986 (Ravindranath *et al.,* 1997) and 1.09 Tg C for year 2002 has been estimated (Kaul *et al.,* 2009). The mitigation potential of the forestry sector, based on a biomass-demand scenario, using short or long-term commercial forestry option has been estimated to 122 Tg C for the period 2000–2012 (Ravindranath *et al.,* 2001). The importance of plantation forestry as a greenhouse gas mitigation option, as well as the need to monitor, preserve and enhance terrestrial carbon stocks was studied by Updegraff *et al.* (2004). Xu *et al.* (2010) reported that most of the *Populus deltoides* plantations are still immature, and so retain a substantial capacity for carbon sequestration.

The greatest potential for above ground biomass and carbon storage in the forest ecosystem resides in the canopy tree layer, although the understory, litter and coarse woody debris can also make a considerable contribution. Species-specific carbon sequestration potential studies have provided entirely different estimates depending upon various factors like weather conditions, location and management activities (Singh, 2003). Monitoring of the accumulation of biomass by the canopy tree layer over the growth cycle as well as with stand age of *Populus deltoides* plantations has been documented (Lodhiyal *et al.,* 1995). Soil being a major contributor to the carbon mitigation technology but had various constrains such as soil salinity and sodicity (Kumar *et al.,* 2014; Felker *et al.,* 2009). Studies indicated that changes in some soil properties were influenced by tree species (Lemma, 2006; Chaudhari *et al.,* 2014), stand age (Zhang *et al.,* 2004), biological factors (Burgess *et al.,* 1993; Paul *et al.,* 2013), and intensity of forest

management (Zhang *et al.,* 2007). Besides these, tree species also varied widely in their inherent nutrient requirements and use (Cole and Rapp, 1981).

However, neither the means to assess their capacity to sequester biomass and carbon, nor a proper understanding of how this biomass and carbon storage is influenced by the plantation age are currently available. Information related to soil organic carbon (SOC) build up in different soil depths under different age of *Populus deltoides* for optimization of SOC stock in the soil are also meagre. Therefore, the present study was conducted with the following objectives (i) to estimate the biomass, carbon sequestration and its rate under different age of *Populus deltoides* plantation forestry, and (ii) to examine influences of plantation age and soil depth on SOC and its stocks under *Populus deltoides* plantation forestry.

Materials and Methods

Site description

The study was conducted for estimation of terrestrial carbon in *Populus deltoides* plantation at Hara Farm, Yamunanagar district of Haryana state of India (30°7'55"N, 77°22'34"E, 255 m above sea level). Yamunanagar has sub-tropical continental monsoon climate and experiences extreme conditions. May and June are the hottest months, and December and January are the coldest. The average annual rainfall of the district is 1107 mm. The soil of the research farm was sandy loam in texture. Chemical analysis of the soil (0-15 cm) showed neutral pH (7.73), low organic carbon content (0.35%) and low N (204.4 kg ha^{-1}), high P_{Olsen} (57.3 kg ha^{-1}) and medium K (234.3 kg ha^{-1}), medium DTPA extractable Zn (1.21 ppm), high DTPA extractable Mn (110.5 ppm) and Cu (1.27 ppm) with bulk density of 1.38 g m^{-3}.

Biomass, carbon stocks and sequestration

Growth parameters i.e. plant height and diameter at breast height (1.37 m) was recorded in March 2013.Estimation of biomass accumulation and carbon sequestration in block plantation of different age *Populus deltoides* was performed using allometric equation developed by Puri (2002): $W=25.21-6.50D+0.7D^2-0.006D^3$, where D is the diameter at breast height (DBH in cm) and W the dry stem-wood biomass (kg). Carbon concentrations of plant samples were determined by CHNS Analyzer (M/s Elementar Analysensysteme GmbH, Hanau, Germany). Carbon stock was calculated at a hectare basis by multiplying carbon in a tree with density of the tree. The estimated carbon stock was converted into CO_2 equivalents (quantity of C× 44/12) for calculating CO_2 assimilation.

In India, economic rotation of 4–7 years is followed for harvesting *Populus deltoides* to cater to the needs of plywood industries. Therefore, carbon sequestration rate (CSR) was calculated for plantations of >4 years. The exact lifetime of wood products is poorly known, but a reasonable assumption is that wood product lifetime is at least equal to rotation length. The proportion of stem wood used as long-lived wood products was taken as 42% (Wang and Feng, 1995). Long-lived carbon storage and carbon storage from coal combustion was estimated (Wang and Feng, 1995).

Soil organic carbon and stock

Soil samples were randomly collected at 3 different places at 7 depths (0–15, 15-30, 30-45, 45-60, 60-75, 75-90 and 90–105 cm) in each plantation. At each sampling point, samples were collected below the tree canopy and outside the tree canopy in 4 cardinal directions around the tree. The samples were mixed to obtain a composite sample for each depth. In total, 147 samples (7 ages × 7 depths × 3 replicates) were collected. Soil samples were analysed for SOC by the Walkley and Black (1934) method. Bulk density was determined using metal core samplers of 4.0 cm in height and 5.0 cm in internal diameter at all the depths studied. Samples were then oven-dried separately at 105 °C for 48 h. The oven-dried weight of the sample divided by the volume of core sampler gave the bulk density of soil (Yaduvanshi *et al.,* 2009). The amount of carbon stored per hectare was obtained by multiplying the values of soil depth (cm), bulk density (g/cm^3), and the percentage of SOC content.

Fig. 1: DBH and height with stand age of *Populus deltoides*

Table 1: Total carbon stocks (plant+ soil) under different age of *Populus deltoides* plantation

Plantation age (years)	Carbon stock (Mg C/ha)				
	Plant			Soil	Total
	Above ground	Below ground	Total		
1	7.90	1.25	9.15	11.8	20.95
2	24.08	3.79	27.87	12.8	40.67
3	47.34	7.46	54.80	14.3	69.10
4	50.94	8.03	58.97	16.4	75.37
5	53.21	8.38	61.59	16.5	78.09
6	58.51	9.22	67.73	17.1	84.83
7	64.21	10.12	74.33	17.6	91.93

Statistical analyses

Data were analyzed using the one-way analysis of variance (ANOVA) procedures of the CROPSTAT 7.2 statistical software program (IRRI, Philippines). Least square difference (LSD) tests were performed to separate means when ANOVA results indicated the presence of significant differences at $P \leq 0.05$.

Results and Discussion

Tree growth, biomass and carbon storage

Mean DBH and height were found to be 8.90 cm and 8.59 m, respectively at the age of 1-year, which reached up to 21.60 cm and 23.1 m, respectively, at the age of 7-year (Fig. 1). The estimated biomass (above and below ground) was 162.3 Mg ha^{-1}at the rotation period of 7-year, which was about 8 times higher than 1-year plantation.Similarly CO_2 assimilation increased from 33.6 to 272.8 Mg C ha^{-1} when plantation age increased from 1 to 7 year (Fig. 2). Assumption of 50 % of tree biomass as carbon content by IPCC was deviated in the present study. The literature also revealed that carbon content in different tree parts has been generally assumed to be 45%–50% of the dry weight (Wang and Feng, 1995; Rizvi *et al.,* 2011). In the present study carbon concentration in aboveground components varied from 44.1- 46.6% with an average of 46.1% (data not shown). Carbon stock in *Populus deltoides* increased from 9.15 t/ha at 1-year to 74.33 Mg ha^{-1} at 7-year plantation (Table 1). These observed values were comparable to the estimates of Chauhan *et al.* (2010) for *Populus deltoides* (62.5 Mg ha^{-1}). The above ground carbon stocks were higher comparable to the findings of Rizvi *et al.* (2011) for *Populus deltoides* at a 7-year rotation (65.62 and 52.11 Mg ha^{-1} at 2 different locations).

Estimated carbon storage and sequestration rate by *Populus deltoides* are presented in Table 2. Long-lived carbon storage increased from 21.4 Mg C ha^{-1} in the 4-year to 27.0 Mg C ha^{-1} in the 7-year *Populus* plantation. Maximum CSR was recorded when plantation age was 4-year (11.5 Mg C ha^{-1} yr^{-1}), however, decline started with the increase in

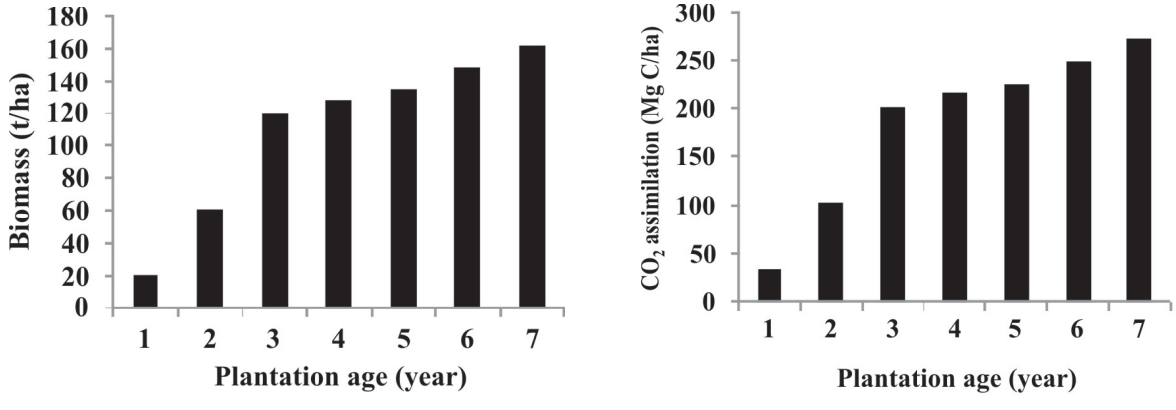

Fig. 2: Total biomass and CO_2 assimilation under different plantation age of *Populus deltoides*

Table 2: Estimated carbon storage and sequestration rate in different age of *Populus deltoides* plantation

Age (years)	Long-lived C storage (Mg C ha^{-1})	Carbon storage from coal substitution (Mg C ha^{-1})	Carbon sequestration (Mg C ha^{-1})	Carbon sequestration rate (Mg C ha^{-1} yr^{-1})
4	21.40	24.70	46.10	11.50
5	22.30	25.80	48.20	9.63
6	24.60	28.40	53.00	8.83
7	27.00	31.20	58.10	8.30

plantation age. The estimates of CSR in the present study are comparable than that reported by Kaul *et al.* (2010) for *Populus deltoides* (8 Mg C ha^{-1} yr^{-1}) but higher than that of moderate growing teak forests (2 Mg C ha^{-1} yr^{-1}) and slow growing long-rotation sal forests (1 Mg C ha^{-1} yr^{-1}).

Depth wise soil carbon stock in Populus plantation

A large fraction of the terrestrial aboveground biomass finds its way to the soil surface in the form of litter fall. Soil carbon stock decreased with soil depth across the plantation age (Fig.3). Across soil depths, soil carbon stock was 11.8 Mg C ha^{-1} under 1-year *Populus* plantation and reached up to 17.6 Mg C ha^{-1} at the age of 7-year, which was 49.2 % higher than 1-year plantation (Table 1). The increased carbon in subsoil (up to 45 cm) could be due to addition of organic matter through fine and coarse roots and their fast turn over. The increase in soil carbon stocks at the surface soil layer is attributed to greater carbon input from litter fall, dead roots, and root exudates (Kaushal *et al.,* 2012). Total carbon stock (biomass carbon + soil carbon) was only considered up to the 30 cm soil depth. Total carbon (biomass and soil) increased from 20.95 Mg C ha^{-1} at 1-year of age to 91.93 Mg C ha^{-1} at 7-year of age, which was more than four times higher than 1-year of plantation (Table 1).

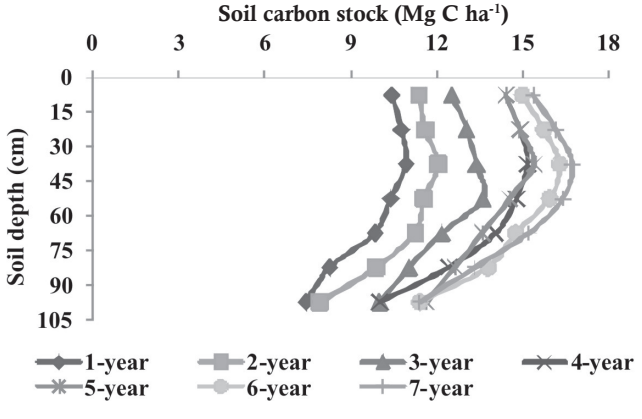

Fig. 3: Depth wise soil carbon stock under different age of *Populus deltoides*

Conclusions

- Maximum carbon sequestration rate was recorded when *Populus deltoides* age was 4-year (11.5 Mg C ha^{-1} yr^{-1}), but decline started with the increase in age.
- The root zones are hot spots of organic matter in the soil under plantations. With increase in plantation age, carbon stock was maximum (17.6 Mg C ha^{-1}) under 7-year plantation in the 0-30 cm soil layer.
- Total carbon (biomass and soil) increased from 20.95 Mg C/ha at 1-year of age to 91.93 Mg C ha^{-1} at 7-year of age of plantation.
- CO_2 assimilation was 272.7 Mg ha^{-1} by 7-year *Populus deltoides* which helps to reduce carbon emission, hence promising option for mitigating climate change.

Populus deltoids based plantation and agroforestry in Trans-Gangetic plains has substantial contribution towards enhancing farmer's income as well as improving soil health. Thus, this study recommends planting of *Populus deltoides* as a viable option for sustainable production and climate change mitigation option.

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