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# Tree biomass and carbon sequestration in four short rotation tree plantations

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## Abstract

Biomass and carbon storage in four multipurpose tree plantation (*Acacia catechu, Dalbergia sissoo*, *Melia azedarach* and *Terminalia arjuna*) after ten years were evaluated on riverain soils. Data revealed that total and component (stem, branch, leaf, bark and root) biomass among four species differed significantly. The biomass in different tree species was in the order of *T. arjuna* > *A. catechu* > *D. sissoo* > *M. azedarach*. Over the study period, the dynamic pattern of biomass carbon sequestration potential of different tree species was proportional to that of total biomass production. The highest biomass carbon sequestration potential, 9.54 t C $ha^{-1}$ $yr^{-1}$ was recorded in *T. arjuna*, whereas, least in *M. azedarach* (3.44 t C $ha^{-1}$ $yr^{-1}$). Total soil organic carbon (SOC) in surface soil (0-15 cm) ranged between 8.10 to 14.88 Mg $ha^{-1}$. Total carbon sequestration in terrestrial system (biomass+ soil) was observed maximum in *T. arjuna* plantation with the rate of 11.03 t C $ha^{-1}$ $yr^{-1}$, which was 95 per cent more than tree-less area.

**Keywords**: Biomass, Carbon sequestration, Plantation, Short rotation trees

## Introduction

Land use change influences ecosystem processes that affect $CO_2$ fluxes between the atmosphere and ecosystems (Franzluebbers, 2005). Human activities are changing the natural rate of exchange of carbon between the atmosphere and the terrestrial biosphere through land use, land use change and forestry activities. Consequently, it is important to examine how the carbon stocks change in response to afforestation, reforestation and deforestation and other land use activities. The extent to which forests are altered by human activities (i.e., harvesting and conversion to other type of vegetation) has a substantial influence on the pattern in which carbon is cycled and stored at local, regional, national and global scales. Recent attention has been focused on balancing the fixation and release of carbon by trees and forest ecosystems, because the rising $CO_2$ concentration of the earth's atmosphere and projected change in global climate have the potential to alter the present day geographic distribution of forests and the rate at which they sequester carbon from the atmosphere (Chaturvedi *et al.,* 2016; Sharma *et al.,* 2016).

Carbon sequestration in tree biomass and thereafter locking in forest based products for a long time is considered as one of the viable option to reduce atmospheric carbon through fast growing tree species (Chauhan *et al.,* 2016). The rising $CO_2$ levels have severe implications on the global functioning of physical and biological system. In order to mitigate this problem, IPCC (1996) advocated an increase in the size of the carbon pools. Forest soils are an important component of the global carbon cycle as they store large amounts of organic carbon (OC). Soil carbon determines ecosystem functions, influencing soil fertility, water holding capacity and other soil parameters. Hence, it plays a significant role in the mitigation of atmospheric levels of greenhouse gases with special reference to the $CO_2$. It has a profound influence on chemical, physical, and biological soil properties, and its loss from cultivated soil is a widely used indicator of soil degradation.

Trees are known to maintain soil organic matter and nutrient cycling through the addition of litter and root residues into the soil (Chaturvedi and Das, 2002; Uthappa *et al.,* 2015). The availability of more wood biomass from plantations will facilitate in the exploitation of the potentials of using biofuels instead of fossil fuel in the future. The technology used to generate heat and power from biomass is fully developed and amount of energy obtained from wood is increasing in many developing countries including India. Plantations also play an important role in meeting the biomass needs of local communities and industries thus help in conserving the natural forest carbon pools in the traditional forests. A few attempts have been made to quantify the growth and biomass production (Panwar *et al.,* 2017; Sharma *et al.,* 2016; Chauhan *et al.,* 2015; Singh *et al.,* 2016) but information specifically for sandy soils is lacking. The present study was undertaken to achieve the objectives of biomass carbon assessment and soil carbon storage potential in sandy loam soil with four different tree species (leguminous and non-leguminous - two each) in comparison to non-planted area. All the four species are short rotation fast growing trees for small timber and fodder under scarcity.

**Materials and Methods**

***Experimental site***: The experimental site was 18 km from PAU main campus at the University Seed Farm, Ladhowal, Ludhiana, Punjab situated at an elevation of 731 ft above mean sea level and lies at 30°58' N and 75°45' E, which represents the central agro-climatic zone of the Punjab. The climate of the experimental site is subtropical with long dry spell from late September to early June and wet from July to mid-September. The area receives an average annual rainfall of 732 mm (80% is received during monsoon months). The topography of the site is plain and characterized inceptisol soils. Soils are deep, well drained sandy loam in texture with high humus content on the top layer and soil pH of 8.0. Four fast growing tree species, two leguminous (*Acacia catechu* and *Dalbergia sissoo)* and two non-leguminous (*Melia azedarach* and *Terminalia arjuna*) tree species were evaluated for growth and biomass parameters at rotation period of ten years.

***Data recording***: For growth parameters, five trees per replication were measured and for above/below ground biomass studies, three trees per species were harvested. Roots were physically excavated to record root parameters (main root, coarse root and roots <1 mm). The tree height was recorded with the help of multimeter and diameter with tree caliper. Crown spread was recorded with the help of measuring tape and farm factor was recorded as per the procedure suggested by Chaturvedi and Khanna (1994). Tree components were separated manually and measured for fresh weight in the field itself and dry weight of respective samples were recorded in the laboratory to calculate complete dry weight and carbon storage. Carbon values of respective components (Table 1) as reported by Chauhan *et al.* (2009) were used for making calculations for carbon content (respective C values were multiplied with the dry biomass value of the species). Soil organic carbon content (SOC %) was estimated by Walkley and Black (1934) rapid titration method and SOC pool (t ha$^{-1}$) in top 15 cm layer was calculated as per the procedure described by Kukal *et al.* (2009) *i.e*., SOC pool (top 15 cm layer) = (OC/100)*(BDx1500); where OC is organic carbon (%), BD= bulk density of 0-15 cm layer and 1500 is the volume (m$^3$) of 1 ha furrow slice (15 cm). Total of biomass and SOC was projected as potential under different tree species in comparison to open condition. The data generated was suitably analyzed for comparison among four species.

**Table 1.** Carbon (%) in different component of four tree species

| Species | Stem | Bark | Branch | Leaf | Root |
|---|---|---|---|---|---|
| *A. catechu* | 46.67 | 40.46 | 44.71 | 48.00 | 45.67 |
| *D. sissoo* | 47.91 | 44.12 | 47.24 | 45.86 | 45.08 |
| *M. azedarach* | 46.48 | 44.15 | 47.32 | 43.86 | 44.95 |
| *T. arjuna* | 46.71 | 40.23 | 44.25 | 45.51 | 45.48 |

**Results and Discussion**

Reasonable methods for estimating tree biomass and carbon stocks in commercial forest tree plantation are becoming increasingly important with given concerns of global climate change, increasing interest in bio-energy projects, and carbon sequestration protocols for the voluntary and regulated markets. The results of tree biomass production and carbon sequestration potential of four tree species were quantified in the present study. The growth (height, diameter and volume) of both the leguminous tree species was at par though significantly less to *T. arjuna* but more than *M. azedarach* (Table 2). However, crown spread was high in *M. azedarach* than other three species. Root spread was maximum in *A. catechu* and significantly more than other three species.

***Tree biomass:*** The maximum total above ground biomass at the age of ten years i.e., stem, branch, leaf and bark was recorded in *T. arjuna* (470.99 kg tree$^{-1}$ and 261.4 t ha$^{-1}$), which was significantly higher than three other species (Table 3). It is important to notice that biomass of *A. catechu*, *M. azedarach* and *D. sissoo* was at par statistically. Though numerically minimum total above ground biomass (AGB) was recorded in *M. azedarach*, both *D. sissoo* and *A. catechu* accumulated almost similar above ground biomass. Maximum above ground biomass attained by *T. arjuna* might be due to better access to essential nutrients due to presence of abundant tertiary roots and root hairs. Swamy *et al.* (2003) reported that in nutrient rich soil, more biomass was allocated to above ground parts. A similar trend was followed in mean annual increment for total AGB fresh as well as dry. Above ground components contributed

**Table 2.** Growth performance of four tree species (ten years)

| Species | DBH (cm) | Height (m) | Crown spread ($m^2$) | Root spread ($m^2$) | Root depth (m) | Form | Volume ($m^3$) |
|---|---|---|---|---|---|---|---|
| *A. catechu* | 20.59 (2.06) | 10.37 (1.04) | 56.53 | 34.77 | 3.8 | 0.40 | 0.14 (0.01) |
| *D. sissoo* | 20.70 (2.07) | 9.20 (0.92) | 54.09 | 24.91 | 3.0 | 0.38 | 0.12 (0.01) |
| *M. azedarach* | 17.52 (1.75) | 9.30 (0.93) | 95.2 | 18.48 | 4.1 | 0.37 | 0.08 (0.01) |
| *T. arjuna* | 28.56 (2.86) | 11.37 (1.14) | 80.68 | 26.4 | 3.5 | 0.35 | 0.25 (0.03) |
| LSD (P=0.05) | 3.71 (0.37) | 1.64 (0.16) | 12.65 | 1.88 | NS | NS | 0.02 |

*Mean annual increment (DBH, height and volume) in parentheses

**Table 3.** Tree biomass partitioning* (kg tree$^{-1}$) in four tree species

| Species | Stem | Branch | Leaf | Bark | Root | Above ground biomass | Total biomass | Above ground biomass (t ha$^{-1}$) | Total biomass (t ha$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| *A. catechu* | 150.67 (94.92) | 20.67 (11.37) | 23.20 (6.22) | 20.00 (11.28) | 97.00 (59.78) | 214.54 (123.79) | 311.54 (183.57) | 114.07 | 172.90 |
| *D. sissoo* | 114.00 (78.66) | 41.67 (22.50) | 26.67 (7.00) | 22.00 (12.41) | 76.33 (49.49) | 204.34 (120.57) | 280.67 (170.06) | 113.41 | 155.77 |
| *M. azedarach* | 109.67 (70.18) | 24.67 (11.10) | 21.67 (6.20) | 18.00 (10.15) | 69.00 (37.81) | 174.01 (97.63) | 243.01 (135.44) | 96.58 | 134.87 |
| *T. arjuna* | 304.00 (209.76) | 109.33 (48.11) | 31.33 (8.61) | 26.33 (14.85) | 148.67 (82.87) | 470.99 (281.33) | 619.67 (364.20) | 261.40 | 343.92 |
| CD (P=0.05) | 59.10 (41.05) | 20.57 (9.87) | 4.67 (1.53) | 2.17 (1.78) | 4.86 (4.16) | 66.46 (5.90) | 69.06 (16.64) | 21.46 | 37.42 |

*Dry biomass in parenthesis

76.28% and below ground components contributed only 23.78%. Values of above ground biomass in present study were comparable with those obtained by Lodhiyal *et al.* (1995) for *Populus deltoides* and Pandey *et al.* (1987) for *Eucalyptus* species. Raizada and Srivastava (1989) obtained 44.5 t above ground biomass/ha in 14 years old *Populus deltoides* plantation. In general, branches and twigs usually accumulate less fraction of total biomass (Fig 1). Singh (1998) reported that stem wood alone constituted 55% of tree biomass, branch/twig, root and leaves accounted about 22, 17 and 6-8%, respectively.

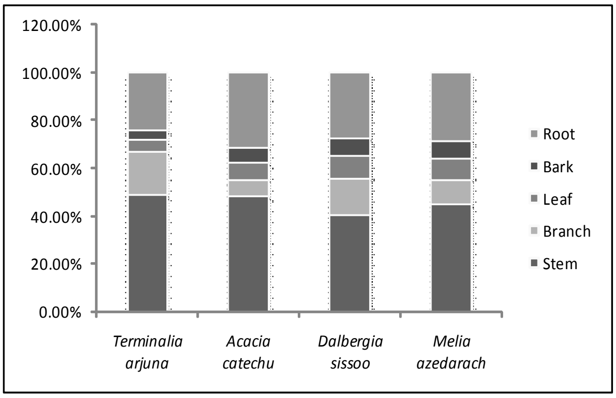


**Fig 1.** Biomass partitioning (on fresh weight basis) of four tree species

Root biomass of different species was also recorded (Table 3). It was apparent from data that significant differences existed among species (Plate 1). After stem biomass, the second rank in biomass accumulation was accounted in below ground component. Maximum weight among root systems was observed in tap root system followed by the coarse root and secondary roots (Fig 2). Variation of root biomass among different tree species might be due to genetic nature and growth habit of the species under specific available conditions of tree growing. Chandran *et al.* (2009) recorded interspecies variation in below ground biomass. Mclaughlin *et al.* (1987) also observed that the root biomass to be 18 per cent of total tree leafless biomass after three growing seasons, which also justified the present findings. Similar results regarding root studies were reported by Vance and Nadkarni (1990), where below-ground total root biomass in the soil of tropical montane forest ranged from 1600 g $m^{-2}$ to 7200 g $m^{-2}$ and biomass of fine roots (< 2 mm dia.) ranged from 300 g $m^{-2}$ to 1300 g $m^{-2}$.

***Biomass carbon:*** There were significant differences in total biomass carbon in different parts of tree (stem, branch, leaves, bark and roots; Table 3). Mean total carbon content ranged between 62.29 to 170.38 kg tree$^{-1}$. Carbon sequestration potential of four tree species ranged from

3.44 to 9.54 t biomass carbon $ha^{-1}$ $yr^{-1}$. Maximum total carbon storage was accumulated by *T. arjuna* (170.38 kg $tree^{-1}$), which was significantly higher than other three species. All tree- components of *T. arjuna* accumulated maximum carbon content. Other three species, *A. catechu, D. sissoo* and *M. azedarach* were at par with each other but numerically in decreasing order. Much lesser carbon storage took place in *M. azedarach* (62.29 kg $tree^{-1}$). These results were in accordance with the findings reported earlier by Jha (2005) and Chauhan *et al.* (2009). Swamy and Puri (2005) recorded 66.6%, 19.7%, 10% and 3.7% biomass contribution in stem, root, branches and leaves, respectively in *Gmelina arborea*. Singh and Lodhiyal (2009) reported 78.68 and 21.32% carbon allocation in above and below ground components in poplar. Biomass allocation pattern reflects that more carbon was allocated to above ground components in plantation than below ground.

***Soil organic carbon*:** Input of litter and their decomposition were the main factors determining the OC content of soils. The quantity of litter and quality influenced the SOC content, which varied over time with species, age and geometry of planting. There were significant differences of OC content in soil under different tree species including tree less area. SOC (t $ha^{-1}$) was also been worked out, which indicated significant variation under different species *i.e.*, 8.10 to 14.88 Mg $ha^{-1}$ (Table 4). OC content in the present study at 0-15 cm soil depth ranged between 0.38 to 0.64 per cent. The SOC was 65.32 per cent more in site under *T. arjuna* than control, which might be due to higher litter fall addition in last ten years and also a good amount of leaf, twig and bark added in comparison to other species. Due to dense canopy behaviour of plantation, the sunlight was not able to penetrate completely on soil surface, which might have facilitated better microbial activity for decomposition. The leaf biomass was also recorded highest in *T. arjuna* (31.33 kg) plantation than other three species (Table 3). Singh and Sharma (2007) reported that on account of recycling of organic matter, higher OC% was observed in the soil under plantations. The higher amount of OC under plantations might be due to roots and addition of aboveground litter. Soil under trees is a major store house of OC in comparison to other land use systems. The higher buildup of organic carbon on surface layer of soils under different tree species might be attributed to the regular accumulation of litter fall and fine root turnover. The subsequent decomposition of litter fall and its incorporation into soil with time might have raised the organic matter status of soil. Swamy *et al.* (2003) observed increase in SOC from 8.46 to 14.02 t $ha^{-1}$, which was similar with present study. Kaul *et al.* (2011) also recorded increased organic carbon under *T. arjuna* over *D. sissoo*.

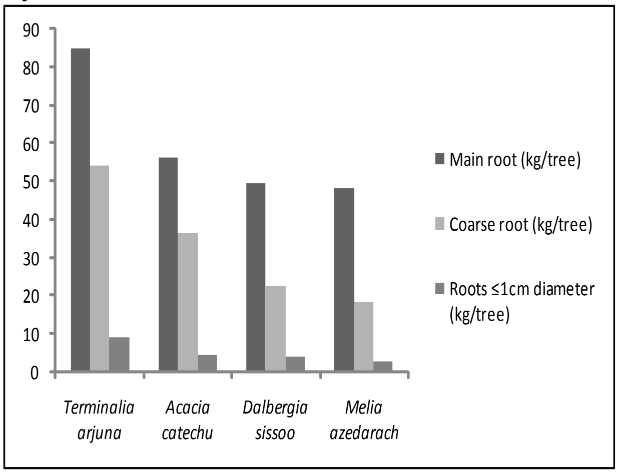


**Fig 2.** Weight (kg per tree) of root parts of four tree species

**Table 4.** Carbon stock (kg $tree^{-1}$)*in tree components and soil underneath

| Species | Stem | Branch | Leaf | Bark | Root | Total | Bulk density | Soil OC (%)** |
|---|---|---|---|---|---|---|---|---|
| *A. catechu* | 44.61 | 5.12 | 2.98 | 6.55 | 27.50 | 86.84 | 1.32 | 0.46 |
| | (2.48) | (0.28) | (0.17) | (0.32) | (1.53) | (4.78) | | (9.14) |
| *D. sissoo* | 37.76 | 10.57 | 3.22 | 8.26 | 22.27 | 82.08 | 1.39 | 0.42 |
| | (2.10) | (0.59) | (0.18) | (0.43) | (1.24) | (4.54) | | (8.81) |
| *M. azedarach* | 32.99 | 5.22 | 2.73 | 4.35 | 17.02 | 62.29 | 1.34 | 0.38 |
| | (1.83) | (0.29) | (0.15) | (0.22) | (0.95) | (3.44) | | (8.10) |
| *T. arjuna* | 98.58 | 21.17 | 3.88 | 9.46 | 37.29 | 170.38 | 1.53 | 0.64 |
| | (5.48) | (1.18) | (0.22) | (0.59) | (2.07) | (9.54) | | (14.88) |
| *Tree-less plot* | - | - | - | - | - | - | 1.46 | 0.23 |
| CD (P=0.05) | 19.31 | 4.50 | 0.68 | NS | 1.89 | 21.95 | NS | (5.16) |
| | (1.07) | (0.25) | (0.04) | (0.23) | (0.10) | (1.22) | | 0.08 |

*Carbon sequestration potential (t C $ha^{-1}$ $yr^{-1}$) in parentheses; ** SOC pool (t $ha^{-1}$) in top 15 cm layer

***Dalbergia sissoo*** ***Terminalia arjuna***

***Acacia catechu*** ***Melia azedarach***

**Plate 1.** Root systems of four tree species

**Table 5.**Total carbon sequestration rate (t C ha$^{-1}$ yr$^{-1}$) in terrestrial system

| Species | Soil organic carbon | Biomass carbon sequestration | Total carbon storage in terrestrial system |
|---|---|---|---|
| *A. catechu* | 0.91 | 4.78 | 5.69 |
| *D. sissoo* | 0.88 | 4.54 | 5.42 |
| *M. azedarach* | 0.81 | 3.44 | 4.25 |
| *T. arjuna* | 1.49 | 9.54 | 11.03 |
| Control | 0.52 | — | 0.52 |

***Total carbon sequestration rate in terrestrial system (biomass + soil)*:** The sum of carbon sequestration by tree biomass and soil underneath was also worked out (Table 5). Maximum rate of carbon sequestration was observed in *T. arjuna* plantation i.e., 11.03 t C ha$^{-1}$ yr$^{-1}$. The other three species also sequestrated good amount of carbon (5.79, 5.42 & 4.25 t C ha$^{-1}$ yr $^{-1}$ in *A. catechu*, *D. sissoo* and *M. azedarach* plantations, respectively) as compared with the site without vegetation (0.52 t C ha$^{-1}$ yr$^{-1}$) but substantially less than *T. arjuna*. Therefore, the carbon sequestration through plantations has become relevant to exert significant impact as a global carbon sink.

**Conclusion**

The area under short rotation tree species is increasing to meet the domestic and industrial requirements, and these studied species (*Acacia catechu, Dalbergia sissoo*, *Melia azedarach* and *Terminalia arjuna*) were observed to sequester relatively large quantities of carbon in biomass as well as in soil underneath and need to be exploited with respect to climate change. However, among these species, the highest biomass carbon sequestration potential of 9.54 t C ha$^{-1}$ yr$^{-1}$ was recorded in *T. arjuna*, whereas it was least in *M. azedarach* (3.44 t C ha$^{-1}$ yr$^{-1}$). Total carbon sequestration in terrestrial system (biomass + soil) was also observed maximum in *T. arjuna* plantation with the rate of 11.03 t C ha$^{-1}$ yr$^{-1}$, which was 95 per cent more than tree-less area.

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