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# Biomass production and carbon sequestration of *Eucalyptus tereticornis* plantation in reclaimed sodic soils of north-west India

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ABSTRACT

*Eucalyptus tereticornis* is most preferred, adopted by farmers in Haryana as agroforestry species due to regular and assured income from expanding market of wood. Accurate and reliable predictive models are important tool to estimate biomass and C-stocks non-destructively in view of emerging carbon credit market mechanism. Allometric models (non-linear) were developed to estimate biomass and biomass carbon in different tree components. Adjusted $R^2$ for fitted functions varied from 0.911 to 0.995 for different components. Above ground biomass (AGB) = 0.493 × $(DBH)^{1.81}$ with adjusted $R^2$ value of 0.992 and below ground biomass (BGB) = 0.130 × $(DBH)^{1.89}$ with adjusted $R^2$ value of 0.987 were found best fit equations. Using models, the estimated total dry biomass was 225 mg/ha with biomass accumulation in decreasing order of bole>roots>twigs and leaves>fuelwood (branches). Mean C-concentration in different tree components varied from 43-46%. C-stocks ranged from 2.30 in fuel wood to 69.8 mg/ha in bole. Total C-stocks (AGB carbon+BGB carbon+soil carbon) were estimated to 122.6 mg/ha with $CO_2$ mitigation potential of 369.2 mg/ha in 6 year old *E. tereticornis* plantation. Carbon sequestration rate in plantations yielded 12.9 mg C/ha/year. C-storage in soil (0-30 cm) was estimated to 21.2-22.8 mg/ha in agri-silvicultre and recorded 44.4% gain over rice-wheat cropping system. Therefore, this study recommends *E. tereticornis* planting as a viable option for sustainable production and carbon mitigation.

**Key words**: Allometric, Biomass, Carbon sequestration, Carbon stocks, $CO_2$ assimilation, *Eucalyptus tereticornis*

Eucalyptus (*E. tereticornis*) has high economic value, as it is major source of plywood industry. It is the most adapted species under agroforestry plantations in India due to the assured market, high returns and supportive government policies. In Haryana, various tree plantation drives and agroforestry farms helped to bring out 45% of total outside forest area under eucalyptus (HSAPCC 2011). Among different species, *E. tereticornis* is most preferred by farmers as it is resistant to pests and termites, and have ability to come up on marginal and salt affected soils easily.

Worldwide quantification of biomass and C-stocks has become important and presently, is an important tool in implementation of emerging carbon credit market mechanism (Mugasha *et al.* 2013). Estimation of biomass is increasingly important in context of global carbon cycle to mitigate global climate change through an innovative mechanism such as Reducing Emissions from Deforestation and Forest Degradation ($REDD^+$) in developing countries (UNFCCC 2008). Recently, harvesting of fast growing species at very young age is increasing due to enhanced demand of wood in industries for manufacturing of match stick, plywood, furniture etc. As a result, there is need to develop models for estimation of biomass precisely without destructive sampling. Biomass studies are time consuming, expensive and tedious, applicable to localized conditions. Typically, biomass models comprise easily measureable tree variables such as DBH, height, canopy spread, etc. that are closely correlated to biomass (Chave *et al.* 2005). DBH is most important variable used for predicting biomass (Singh and Lodhiyal 2009, Rizvi *et al.* 2011, Mugasha *et al.* 2013). Few allometric models for biomass of *E. hybrid* have been previously developed (Dhanda and Singh 1990), *E. tereticornis* (Singh 2017), Eucalyptus clones for central India (Ajit *et al.* 2006), timber volume equation for *E. tereticornis* in alluvial plains of India (Dhanda *et al.* 2005), which however, have limited application on reclaimed salt affected soils of Haryana. Further, models predict AGB only and don't include BGB (roots). Therefore, present study

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was designed to develop biomass models for estimation of above- and belowground biomass and C-stocks in 6-year aged *E. tereticornis* plantations.

## MATERIALS AND METHODS

*Study site:* The present study was carried out in 2013-14 under block plantation of *E. tereticornis* on reclaimed sodic soil at Raina Farm, Kurukshetra (29° 57' N, 76° 59' E, 257 m a.s.l.), Haryana, India. Kurukshetra district has tropical monsoon climate with 800 mm annual rainfall; year is divisible into three seasons i.e. warm-wet rainy season (June to September), a cool dry winter season (October to February) and a hot dry summer (March to May). Surface soil (0-15 cm) of research farm was calcareous loam with 8.31 pH, 0.28% organic C, 180.3 kg/ha alkaline $KMnO_4$-N, 21.6 kg/ha P, 338.1 kg/ha K and 1.47 mg/m$^3$ bulk density.

*Estimation of growth and biomass:* AGB, BGB and carbon content of *E. tereticornis* (6-year) plantation was assessed by following the mean-tree technique. It involves destructive sampling of trees, represents the mean size of a plantation and used the number of trees in the plantation to expand mean-tree values to an area basis. Selection of sample tree was based on average height, DBH and crown cover. Total ten trees of *E. tereticornis* (6-year) with a spacing of 3.6 m × 3.0 m (plant density of 925 trees/ha) were harvested. Felled trees were separated into three components viz. stem, branches and foliage. Stem was cut into 2.0 m logs, and stem samples (stem wood + stem bark) were obtained from disks cut from the center of each log. Fresh weight of tree components was determined in the field and sub-samples were oven dried at 60 ºC until constant weight to determine moisture content. Using dry/fresh weight conversion factor, dry weight was estimated for different tree components. Total AGB (bole, branchwood and foliage) was obtained by adding values of all logs of each sample tree. Root biomass was studied by excavating roots of five sampled trees using JCB machine. After excavating, roots were separated into tap roots and lateral roots. Tree height was measured using Ravi Altimeter (Rizvi *et al.* 2011).

*Model fitting and validation:* Allometric growth model was fitted to establish relationship between AGB and BGB (kg/plant) and DBH (cm) of trees. To get an idea of shape of function to be fitted on the data, a scatter plot of total biomass vs DBH and total biomass vs height was initially drawn. It was clear from scatter plot that the candidate functions usually adopted for modeling total biomass-DBH curves will fit in observed dataset. For validation, original dataset of 10 trees was randomly split into two datasets; 8 for model estimation and remaining trees for 'testing' models. The best fitted model (allometric) was used for estimation of biomass in different tree components, i.e., $Y=a \times D^b$ where, Y is dry weight of component (kg/tree) or biomass carbon (kg), D is predictor variable i.e. DBH (cm) and *a* and *b* are model coefficients.

*Estimation of biomass and C-stocks:* The developed allometric model was used to determine biomass of 6 year (density 925 trees/ha) aged *E. tereticornis*. DBH of each tree was used in the developed model to estimate biomass for different tree components and respective biomass values in different components were multiplied by tree density to obtain total biomass (mg/ha).

C-concentration of oven dried plant samples was determined by CHNS Analyzer (M/s Elementar Analysen systeme GmbH, Hanau, Germany). Dried samples were ground with wiley mill grinder and passed through a 0.15 mm sieve for carbon (C) analysis. The mass of C stored in individual tree was estimated by multiplying their measured mass by C concentration. C-stocks were expanded on area basis and tree-components summed to obtain total C-storage. The estimated C-stocks were converted into $CO_2$ equivalents (quantity of C × 44/12) for calculating $CO_2$ assimilation.

After harvesting, C can be sequestered by using wood for furniture, plywood, fiberboard packaging, etc. The proportion of stemwood used for long-lived products is estimated to be 42% as per formulae proposed by Wang and Feng (1995). Therefore, C-sequestration rate was calculated as:

Long-lived C-storage = carbon mass in stemwood × 42 %.

It is assumed that short-lived biomass (top portion of bole, branches, and roots) is used as a fuel to replace fossil fuels by industries. Since the heat released per unit weight of biomass is taken as $18 \times 10^9$ J/mg, therefore,

Heat from biomass combustion = [biomass – (stemwood weight × 0.42)] × $18 \times 10^9$.

The thermal efficiency of biomass combustion is only 60% of that achieved with fossil fuels. If the heat released from combustion of unit weight of coal is taken as $25 \times 10^9$ J/mg and carbon content of coal is 70%, then,

C-storage from coal combustion= (heat of biomass combustion × 0.60 × 0.70)/($25 \times 10^9$).

The total amount of carbon sequestered in agroforestry systems is the sum of long-lived carbon storage in wood products and C-storage due to substituting biomass for coal.

Soil samples were collected from soil depth (0-30 cm). SOC and bulk density were determined as per protocols given by Walkley and Black (1934) and Blake and Hartge (1986) respectively. An amount of C-stored/ha was obtained considering soil depth (cm), bulk density (g/cm$^3$) and SOC (%). Data on biomass were analyzed after following one way analysis of variance (ANOVA). Significant differences were tested at $p \leq 0.05$ using least significant difference test.

## RESULTS AND DISCUSSION

Allometric models developed between AGB, BGB and DBH resulted in $R^2$ values > 0.91. The present study included only one independent variable i.e. DBH for predicting biomass in model and adjusted $R^2$ of different component were presented along with respective fitted functions (Table 1). When DBH was used as independent factor for predicting biomass of tree, the non-linear equation for bole biomass = $0.522 \times (DBH)^{1.766}$ with maximum adjusted $R^2$ value

Table 1 Allometric relationship between DBH (cm) with biomass/ dry weight (kg/tree)

| Component | Diameter at breast height (DBH) vs biomass | | |
|---|---|---|---|
| | Parameter estimate | | $R^2$ |
| | a | b | |
| Bole | 0.522 | 1.766 | 0.995** |
| Fuel wood | 0.003 | 2.135 | 0.921** |
| Twigs and leaves | 0.185 | 1.890 | 0.911** |
| Total aboveground biomass (AGB) | 0.493 | 1.810 | 0.992** |
| Root (BGB) | 0.130 | 1.890 | 0.987** |

Equation used: Y= a × $D^b$; where, Y is the dry weight of the component (kg/tree) or biomasscarbon (kg), D is the predictor variable *i.e.* diameter at breast height (cm) and *a* and *b* are model coefficients.** Significant at p =0.01

Table 2 Biomass and C sequestered of 6-year aged *E. tereticornis* plantation

| Tree component | Dry biomass (mg/ha) | C concentration (g/kg) | Carbon-Stock (mg C /ha) | $CO_2$ Assimilation (mg/ha) |
|---|---|---|---|---|
| Bole | 155 ± 14.2 | 446 ± 22.1 | 69.8 ± 6.28 | 256.2 ± 23.04 |
| Fuel wood (Branches) | 5.12 ± 0.66 | 455 ± 19.6 | 2.30 ± 0.19 | 8.44 ± 0.69 |
| Twigs and leaves | 8.12 ± 0.95 | 430 ± 21.5 | 3.49 ±0.39 | 12.8 ± 1.43 |
| Roots | 56.8 ± 6.7 | 435 ± 20.1 | 25.0 ± 2.8 | 91.8 ± 10.3 |
| Grand Total | 225 ± 21.3 | - | 100.6 ± 11.4 | 369.2 ± 41.8 |

± Standard deviation of mean

of 0.995, total above ground biomass (TAGB) = 0.493 × $(DBH)^{1.81}$ with adjusted $R^2$ value of 0.992 and below ground biomass (BGB) = 0.130 × $(DBH)^{1.89}$ with adj. $R^2$ value of 0.987 were found best fit equations.

As allometric model (Y = a × $DBH^b$) provided best goodness-of-fit, therefore, different tree components were also fitted to allometric model using DBH as explanatory variable (Table 1). Results indicated that adjusted $R^2$ value for fitted functions varied between 0.911 and 0.995. Highest adjusted $R^2$ value was found for timber (0.995) followed by root (0.987) whereas, the minimum value was found to be 0.911 for twigs and leaves. Allometric models are widely used for relating measurable tree variables with biomass. Chave *et al.* (2005), Ajit *et al.* (2011), Mugasha *et al.* (2013) documented that allometric models performed better for different tropical and sub-tropical tree species. The linear model is generally not used for estimating biomass as it suffers from the problem of negative estimation of size i.e. predicted value of biomass comes out to be negative for lower values of explanatory variable (Ajit *et al.* 2011). Verma *et al.* (2014) selected allometric model (non-linear) for predicting biomass in different tree components in *Grewia optiva* due to higher adjusted $R^2$ and lower Akaike information criteria (AIC) value in model fitting. Predictive models using one independent variable (DBH) are simple and don't require additional height measurement for its application, hence less time consuming and cost effective. Numerous studies also indicated that biomass and C-stocks estimated from DBH without harvesting of trees is reliable (Singh and Lodhiyal 2009, Rizvi *et al.* 2011, Mugasha *et al.* 2013). Further, it has been reported that there are no significant differences in the biomass estimated with $(DBH)^2H$ or with DBH as independent variable (Ajit *et al.* 2011).

The estimated biomass obtained ranged from 5.12 mg/ha in fuelwood to 155 mg/ha in bole. At the time of harvesting, percentage contribution of different component to AGB were in order of timber > fuel wood > twigs/leaves (Table 2). The above- and belowground breakup of total biomass was 74.8% and 25.2% respectively, which was slightly higher than the values (79% and 21%) reported by Bargali *et al.* (1992) for eucalyptus. In present study, root biomass was 33.8% of AGB and contributed about 25.2% to the total biomass production. Average BGB/AGB ratio was 0.34 for 6-year old plantation (Table 2). Barton and Montagu (2006) also reported similar BGB/AGB ratio for 10 years old *E. camaldulensis* plantation under irrigated conditions. Biomass distribution among different components of woody perennial and variations in tree biomass may be attributed to numerous factors like plant architecture and morphology, site quality, age, density, structure, climatic, edaphic factors and management practices (Kanime *et al.* 2013, Goswami *et al.* 2014).

It is documented in literature that C-content in different tree components is assumed or recorded between 45 and 50 % of dry weight (Rizvi *et al.* 2011). Moreover, C-content in *E. grandis* tree parts has been generally assumed to be 44.9 % of the dry weight (Onrizal *et al.* 2009). In current study, mean carbon content in above ground components varied from 43% to 45.5% (Fig.1). The maximum C concentration observed in fuel wood (455 g/kg), followed by timber (446 g/kg), roots (435 g/kg) and twigs and leaves (430 g/kg).

C-stocks ranged from 2.30 in fuelwood to 69.8 mg/ha in bole. $CO_2$ assimilation computed from destructive

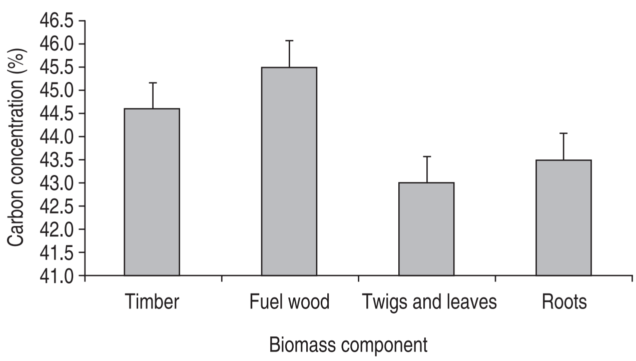


Fig 1. Carbon concentration in different components of *E. tereticornis.*

Table 3 Carbon storage in soils (0–30 cm) in 6-year aged *E. tereticornis* plantations

| Age (yrs) | SOC (%) | BD (g/cm$^3$) | *Carbon stored (mg/ha) | % increase over control |
|---|---|---|---|---|
| Control# | 0.40 ± 0.01 | 1.27 ± 0.01 | 15.2 ± 0.45 | - |
| *E. tereticornis* | 0.59 ± 0.02 | 1.21 ± 0.01 | 22.0 ± 0.78 | 44.4 |

* The amount of carbon stored per hectare was obtained considering soil depth (cm), bulk density (g cm$^{-3}$) and soil organic carbon (SOC); #rice-wheat cropping system

sampling of 6-year *E. tereticornis* in AGB was 277.4 mg C/ha, however, total $CO_2$ assimilation was 369.2 mg C/ha. Major portion of the C assimilated was fixed in stem (69.4%) followed by roots (25.8%) and remaining 4.8% in leaves, twigs and fuel wood. In general, C-stocks pertain to absolute quantity of C held at the time of inventory, whereas, C sequestration rate refers to the process of expelling carbon from atmosphere and storing it in a reservoir (Takimoto *et al.* 2008). Large C-stocks doesn't necessarily mean a large C sequestration potential. Therefore, estimated C-storage and sequestration rate (CSR) in 6-year aged *E. tereticornis* plantation were computed as per formulae proposed by Wang and Feng (1995). Long-lived carbon storage of the plantation was 29.3 mg/ha while total carbon sequestration was recorded as 77.7 mg/ha. CSR was yielded 12.9 mg C/ha/year in *Eucalyptus* plantation. The estimates of CSR in the present study are higher than that reported for fast growing short-rotation poplar (8 mg C/ha/yr) and Eucalyptus (6 mg C/ha/yr) by Kaul *et al.* (2010) and for 7–11 years matured polar plantation (CSR varied from 5.8 to 6.6 mg C/ha/year) by Arora *et al.* (2014) due to only consideration of AGB for calculation of CSR and neglected BGB like roots. Thus, allometric equation based on the DBH could predict 91-99% variability in biomass production, C-assimilation and C-sequestration in *E. tereticornis* plantations.

Total C stock (biomass C + soil C) was only considered up to the 30 cm soil depth, as per the guidelines of the Intergovernmental Panel on Climate Change (IPCC). Total C-stocks (AGB carbon + BGB carbon + soil carbon) was estimated to 122.6 mg/ha under 6-year aged Eucalyptus plantation while, C-storage in soil (0-30 cm) varied from 21.2 to 22.8 mg/ha (Table 3). Soil C-storage under plantation was 44.4% higher than rice-wheat cropping system prevalent in this region. Results are further in agreement with the findings of Chaudhari *et al.* (2015) who reported that *Eucalyptus* (4 year) + wheat had 29.3 % higher soil C-stocks as compared to sole wheat crop. The enhanced soil carbon under plantations could be due to addition of organic matter through fine and coarse roots and their fast turn over. Soil organic C stock in agroforestry system was 65-88% higher than rice-wheat system (Benbi *et al.* 2012), even high microbial biomass (MB-C) carbon was reported in poplar based agroforestry system than rice-wheat rotation. The increased MB-C may be due to carbon available for microorganisms derived from rhizodeposition and from the high quality litter Chaudhari *et al.* (2015).

In present study, developed models are only valid within DBH range of 6-year old *E. tereticornis* plantations considered during sampling because they don't include other sources of variation. A tree components-biomass model is useful to farmers in estimation of standing biomass, C-stocks and additional revenue via. carbon credit by simply measuring the diameter. *E. tereticornis* plantations can be helpful in reducing pressure on forests by fulfilling the demand of woods, plywood industries/other use besides providing C-storage benefits in long term to mitigate climate change. Therefore, this study recommends *E. tereticornis* planting as a viable option for sustainable production and carbon mitigation.

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