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ALLOMETRIC RELATIONSHIPS FOR PREDICTING THE BIOMASS IN *Dalbergia sissoo ROXB.* PLANTATION IN PUNJAB, PAKISTAN

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Allometric relationships for estimating the above and below ground biomass and its allocation at four different ages (viz-a-viz 6,11,16 and 20 years) of *Dalbergia sissoo* were investigated in monoculture irrigated plantation of Punjab Pakistan. Destructive sampling (including stump removal) of true representative trees was carried out in spring, summer and autumn seasons of the year 2010, 2011 and 2012. Results indicate that a linear relationship exists in general between age, diameter, height and volume of the tree. The total biomass of *D.sissoo* estimated at four age brackets showed a linear relationship, where it was minimum (144.83 kg tree^{-1}) at the age of 6 years, while the maximum weight (456.37 kg tree^{-1}) was observed at the age of 20 years. Maximum above ground biomass contribution was from stem (38%) followed by branches (32%), twigs (9%) and leaves (5%) respectively whereas, underground portion of the tree i.e root contributed 16% of the total biomass. The study also indicated that, right now the plantation compartments having trees of age 6, 11, 16 and 20 years are not equal in numbers/areas due to which sustained production is not available. The present study might be the first for *D.sissoo* in Pakistan as no significant literature is available for the estimation of biomass expansion or allocation in different tree components of the species. So the results of the study are helpful in determining the amount of carbon credits earned by plantations on area basis, which are requisite under the Kyoto Protocol and REDD policy.
Keywords: *Dalbergia sissoo*, biomass, irrigated plantation, allometric relationships

INTRODUCTION

D. sissoo grows naturally in sub Himalayan tract ascending up to the range of 1300 m. Geographically, it extends over a vast region throughout the Indo Gangetic Plains. In the sub Himalayan tract, it grows along streams. *D. sissoo* grows naturally under sub tropical climate. In its natural habitat, the absolute maximum temperature varies from about 39 to 49°C. It can tolerate occasional frost (Troup, 1921). Although in its natural range annual rainfall varies from 750 to 4500 mm, and most of it falls in June to September, the growth is poor in areas with annual rainfall less than about 1000 mm. *D. sissoo* can withstand 3-4 month drought (Hocking, 1993) however, under irrigated conditions, young plants are adversely affected if the supply of water is suddenly suspended for any length of time (Champion *et al*., 1965).

In the subject, the broadest definition of allometry is the linear or non-linear correlation between increase in tree dimension (Picard *et al*., 2012). Therefore, allometric equations can be used to link difficult variables, such as volume or biomass. These equations are of great importance for the estimation of tree volume and biomass, and then to estimate forest carbon stock and carbon stock changes. The quality of these equations is crucial for ensuring the accuracy of forest carbon estimates and is not only a matter of statistical tools. The errors made all along the process of building these equations should be considered, from the field work to the modeling and the prediction (Picard *et al*., 2012).

Statistical indicators can also be used for comparison and assessment of the goodness of fit. The models should be compared to generic models in terms of error, but the robustness of a model is also dependant of the number of trees sampled for the modeling. Picard *et al*. (2012) developed guidelines to support the development of tree allometric equations.

The recommended variables to be measured in order to assess the biomass are tree diameter at breast height, tree height and wood density. The use of diameter and height is easy to understand as they are used in the mathematical formulas for volume calculation. Wood Density (WD) is also very important as it differs a lot among tree genus and species (Chave *et al*., 2006). It is defined as the ratio of dry biomass by fresh volume without bark (IPCC, 2006). Allometric model selection with different alternative variables can also give different reliability (Chave *et al*., 2004). A research conducted in Panama showed that apart from Diameter at Breast Height (DBH) and height (H), the variable of Wood Density (WD) was necessary. Similarly, Basuki *et al*. (2009) pointed out the presence of wood density in the model resulted in high reliability for their research in lowland dipterocarp forests. Variables of Crown Density (CD) or Crown Area (CA) can improve the reliability and accuracy of the biomass estimates as described by Dietz *et al*. (2011), Henry *et al*. (2010) and Johannes *et al*. (2011).

Furthermore, biomass estimates can be used to determine the carbon stocks in the trees, findings of the study would be helpful to determine carbon stocks of plantations. This attempt might be the first for *D. sissoo* in Pakistan as no significant literature is available for the estimation of biomass expansion or allocation in different tree component of the species. So the results of the study are helpful in determining the amount of carbon credits earned by plantations on area basis, which are requisite under the Kyoto Protocol and REDD policy. The specific objective of the study is to determine the variation in biomass yield of *D. sissoo* at four different ages (6, 11, 16 and 20 years) and preparation of Biomass Expansion Factor (BEF) of *D. sissoo* for estimating the contribution of tree components in total tree biomass.

MATERIALS AND METHODS

***Study area*:** Current study was carried out in the Daphar irrigated plantation, Phalia Tehsil of Mandi Bahuddin district, Pakistan, situated at intersection latitude 32^{o}26` N and longitude 73$^o$ 11` E. The ground generally slopes down from East to West and varies from place to place. The soil of the plantation is alluvium with varying proportions of clay and sand. Ecologically area lies in semi- arid climatic zone. The elevation of Daphar plantation is 203 m. The mean annual maximum and minimum temperature is 31^{o}C and 17^{o}C respectively, and the average annual rainfall is 380mm.

***Research design*:** The destructive felling technique was adapted for this study and number of trees to be felled were finalized after review of literature of similar studies in the region (Abbas *et al*., 2011; Peichl and Arain, 2006). The sample size of 5, 8 ,6 and 4 trees for 6, 11, 16 and 20 years old trees of *D. sissoo* growing in the daphar plantation was selected respectively. Trees were selected randomly from entire compartments of the plantation according to the sample size. The selected trees were felled, and diameter and length were measured in the field. This procedure was repeated in each season for three years (2010-2012). Length of the tree was measured by using measuring tape and diameter was measured by using tree calliper. For calculating volume of each tree, Huber`s formula was used i.e.,

Volume (m^3) = Middle Cross Sectional Area (m^2) x Length (m) x Form Factor

Cross-sectional area (πr^2), where r^2 is radius, was taken from measuring middle trunk diameter. After calculating volume of main stem, branches, leaves and twigs were separated from the main stem of each tree to calculate volume of each component separately. Volume of main stem and all branches were used for biomass determination. This was carried out by multiplying stem and branches volume (m^3) separately with a generic wood density of *D. sissoo* in kg m^{-3} (Nizami *et al.*, 2009; Nizami, 2012). Generic wood density has been taken from literature as 750-800 kg m^{-3} (Tanvir, 1995).

Biomass (kg) = Volume (m^3) x Basic Wood Density (Kg m^{-3})

Separated leaves and twigs from branches were weighed with the help of spring balance right at the place of plantation to estimate the fresh weight. Afterwards leaves and twigs were brought into laboratory and dried weight of leaves and twigs was determined by placing in oven at 72^{o}C for 48 hours. By summing up the biomass of stem, branches, leaves and twigs, 20% of the total was taken as the biomass of roots (Montagu *et al*., 2002; Jenkinson, 1990). Finally, Biomass Expansion Factors (BEF) of the individual tree stating contribution of each component was prepared for each age bracket.

RESULTS AND DISCUSSION

The total biomass of the tree, including the contribution of each tree component was analyzed using Sigma plot version 12. The total mean biomass (kg tree^{-1}) including all components was 144.839$\pm$33.93, 220.39$\pm$33.31, 312.94$\pm$41.71 and 456.37$\pm$92.87 for 6, 11, 16 and 20 years old *D. sissoo* tree, respectively (Fig. 1; R^2= 0.99). The co-efficient of variance (CV) in the biomass at the chronosequence was 23%, 15%, 13% and 20% at 6, 11, 16 and 20 years old *D. sissoo* tree respectively.

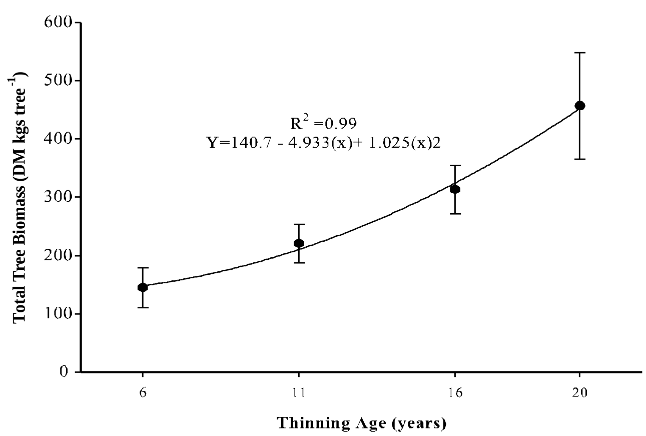

Figure 1. Total biomass (DM kg tree^{-1}) of *D. sissoo* at four different thinning ages.

Contribution by weight (kg tree^{-1}) of each component at each age in total biomass is presented in Fig. 2, which indicates that among the tree components, stem contributed 38%, branches 32%, roots 16%, twigs 9% and leaves 5% biomass on an average for entire rotation age. The maximum contribution value (38%) in total tree biomass was exhibited by the stem while leaves had the minimum contribution value (5%) to the total tree biomass (Fig. 3).

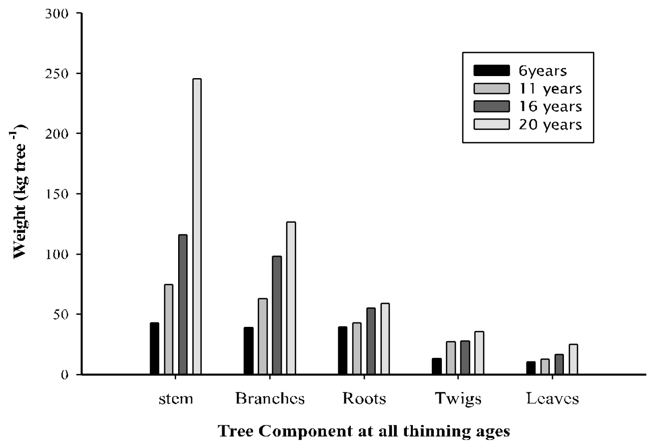

Figure 2. Weight wise contribution of each tree component of *D. sissoo* at four different ages of plantation.

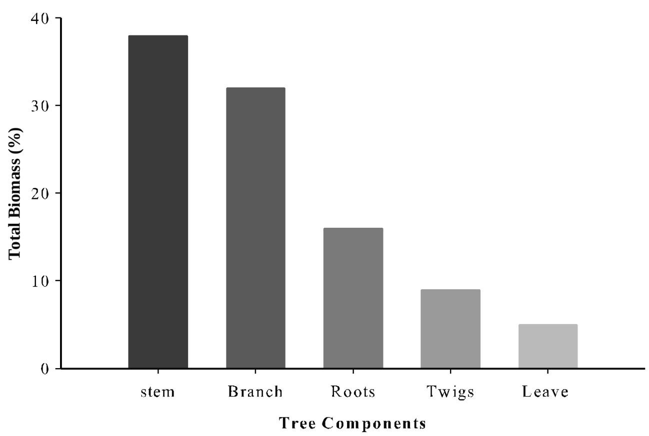

Figure 3. Contribution of each tree component in total biomass of *D. sissoo*.

In a similar study Neelu and Lodhiyal (2003) found that stem contributed 57.4%, branch 13.3%, leaves 5.3%, reproductive parts 1.1%, coarse roots 16.1% and fine roots 6.1% in total tree biomass in Bhabar Shisham (*D. sissoo*) at Central Himalaya forest, India. Hunter (2001) also reported that in *D. sissoo* dry biomass of wood, bark, branches and leaves is equal to 3.3, 0.7, 3.2 and 0.4 t ha^{-1} respectively, in 3 years old plantation of Southern India.

Results of the present study also indicated that a strong relation exists between the age of the tree and the biomass of stem, branches, leaves, twigs and roots (see Figs. 4-8, Table 1). Further, figure 2 explains that total biomass of the tree and the biomass of individual tree components increased with the increasing age. It was found that mean value of stem biomass was 42.7, 74.8, 116.22 and 245.27 kg tree^{-1} at the age of 6, 11, 16 and 20 years, respectively (Fig. 2) and the biomass value of the stem in total also increased with the increase in age (Fig. 3, R^2=0. 97). Likewise, biomass of the branches, roots, leaves and twigs recapitulated with increasing age showing different regression models (Table 1, Figs. 4-8). Comparison with forests of almost similar age indicates that present estimates of biomass conspicuously higher than the value 103 t ha^{-1} reported for 8 years *D. sissoo* forest and plane area (a rich nutrient site with high water table) (Pacholi, 1997). However, it was lower than 186 t ha^{-1} reported for 24 years old *D. sissoo* forest (Sharma *et al*., 1988), 193 t ha^{-1} for *Tectona grandis* forests (Negi *et al*., 1995), 144 t ha^{-1} for 30 years old *T. grandis* plantation (Jha, 1995), 121 t ha^{-1} for Eucalyptus hybrid deltoids (Kaul and Sharma, 1983), 200-719 t ha^{-1} reported for more than 100 years old *Shorea robusta* (Rana and Singh, 1989) and 112-300 t ha^{-1} for *E. grandis* (Tandon *et al*., 1988). Khan and Faruque (2010) also reported non linear regression allometric equation for stem volume as function of Diameter at Breast Height (DBH) for *D. sissoo* plantation in Bangladesh.

The deviation in the contribution of each component in total biomass of the present study is may be due to irrigation treatment which was given each year in the plantation from 1st October to 31st March. The biomass of branches is different because treatments were applied to the D. sissoo in irrigated plantation for the production of more branches to fulfill the demand of fuel wood in the local areas. The results of the present study are supported both by Toky and Bisht (1993) and Singh *et al*. (2011) with respect to stem, leaves and twigs biomass where Toky and Bisht (1993) stated that in 6 years old *D. sissoo* tree grown in arid climates, each component showed the contribution in total biomass as 45.23% was by stem, 17.04% by branches, 3.91% by leaves and 33.80% was from roots. Similarly, Singh *et al*. (2011) also documented an increase in biomass by each component of 4 years old D. sissoo tree, that included stem (40%),

Table 1. Correlation coefficient (R^2) and regression models for biomass of each component of *D. sissoo*.

Component	Model	Relationship Type	R^2
Stem	$Y= 116.6-19.01(x)+1.255(x)^2$	Polynomial	0.97
Branch	Y=8.82+5.14(X)	Linear	0.97
Roots	Y= 29.33+1.84(X)	Linear	0.99
Twigs	Y= -10.52+14.37In(x)	Logarithmic	0.89
Leaves	Y= 0.509+5.808In(X)	Logarithmic	0.94

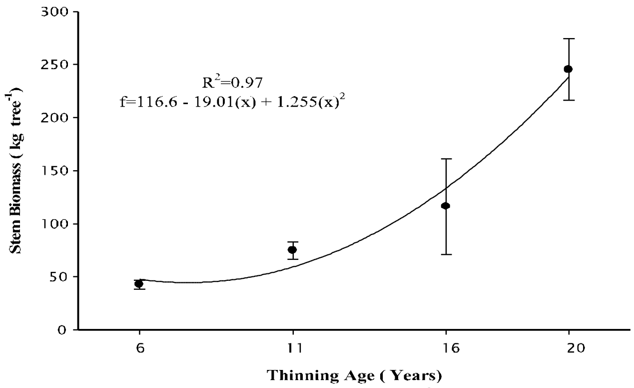

Figure 4. Correlation coefficient (R^2) and regression models for stem biomass of *D. sissoo* at four different ages.

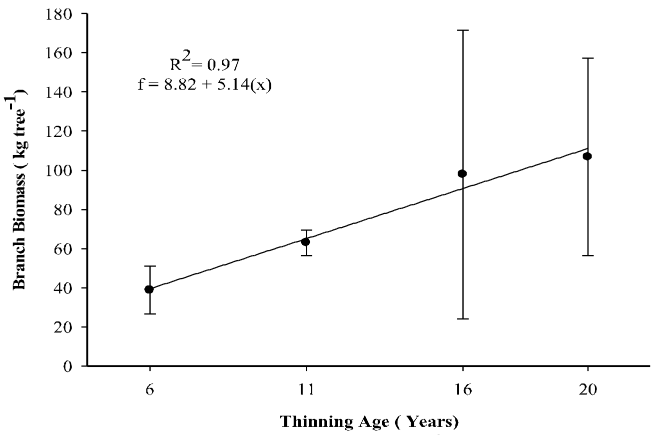

Figure 5. Correlation coefficient (R^2) and regression models for branches biomass of *D. sissoo* at four different ages.

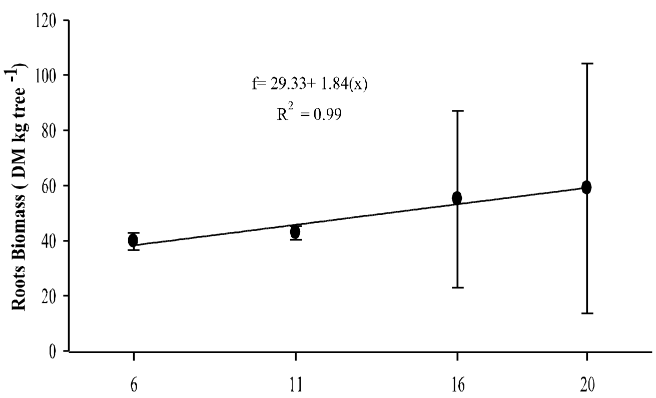

Figure 6. Correlation coefficient (R^2) and regression models for roots biomass of *D. sissoo* at four different ages.

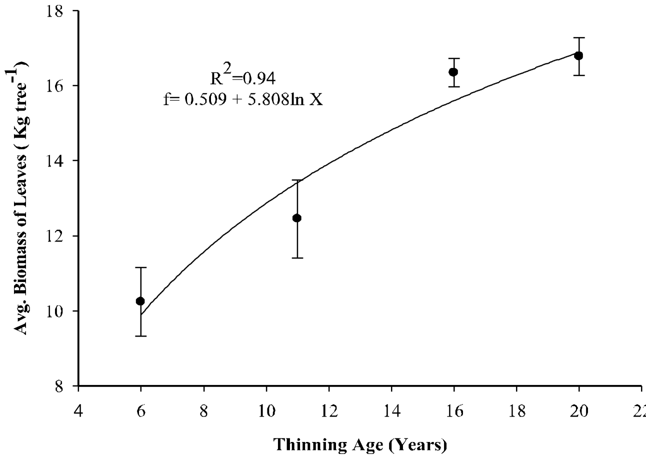

Figure 7. Correlation coefficient (R^2) and regression models for leaves biomass of *D. sissoo* at four different ages.

branches (17.8%), leaves (10%), twigs (7.32%) and root (25%).

***Conclusion*:** The findings of this study indicate that there is a variation in the contribution of each tree component in the total tree biomass of *D. sisso* grown in Daphar irrigated plantation. However, a polynomial, relationship existed between age of the plant and stem biomass, while the linear relationship exists among age, branches and roots. Logarithmic relationship existed among age, leaves and twigs. Use of independent variables (age) in allometric equations for estimating the biomass in each tree component of *D. sissoo* proved to be appropriate. The allometric relationships described in this paper may not be appropriate in mixed or open forest stands, because the present study was carried out under monospecific and closed canopy conditions. These allometric equations could be used for further estimations of biomass and C stocks in light of reducing emissions from deforestation and forest degradation (REDD+).

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