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Growth and Carbon Storage Potential of Important Agroforestry Trees of North-West Himalaya

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A B S T R A C T

Growth, biomass, carbon storage and allometric relations for estimating stem volume and aboveground biomass on the basis of DBH and Height of tree and growth pattern curve, carbon storage and developed various allometric equations on selected Agroforestry trees. Total seven species including 210 trees were marked selected in the present study. The maximum adjust R^2 found in; *Albizia chinensis* where quadratic function showed the highest adj R^2 (0.993) on the basis of DBH and according to the height of tree (H), the best fit was also quadratic, which showed adj R^2 in the value of (0.695), on the other hand for six species trees, power function was the best significant equation which modified the highest adj R^2 for the following specieses, that are *Albizia lebbeck* (0.964), *Acacia mollissima* (0.992), *Melia composita* (0.990), *Dalbergia sissoo* (0.992), *Toona ciliata* (0.888) and *Ulmus villosa* (0.990) recorded on the basis of DBH, however, to the height of tree as an independent variable, the best equation was sigmoid which showed the adj R^2 value in *Albizia lebbeck* (0.480), *Acacia mollissima* (0.530), *Melia composita* (0.598), *Dalbergia sissoo* (0.551), *Toona ciliata* (0.645) and *Ulmus villosa* (0.597). The total biomass (AGB + BGB) was calculated using specific gravity and root-shoot ratio. Branch and leaves biomass of each species was estimated using biomass expansion factor (BEF) of trees as per the guidelines of IPCC (2003). All biomass values were converted to tree biomass carbon by multiplying factor of 0.5. However, in this research, equation selection was based on adjust R^2 and minimum standard error.

Introduction

Forestry play an important role in regional and global carbon (C) cycle because they store large quantities of C in vegetation and soil, exchange C with the atmosphere through photosynthesis and respiration and are source of atmospheric C when they are disturbed by human or natural causes, become atmospheric C sink during re-growth after disturbance, and can be managed to sequester or conserve significant quantities of C on the land (Brown *et al.*, 1996; Sharma *et al.*, 2011). This global importance of forest ecosystem emphasizes the need to accurately determine the amount of carbon stored in different forest ecosystem (Nizami, 2010). Forest ecosystems act as both source and sink of carbon and thus play a crucial role in global carbon cycles. Forests form an important aspect of active carbon pool as they account for 60 percent of terrestrial carbon storage (Wilson and Daff, 2003). Forest ecosystem is one of the most important carbon sinks of the terrestrial ecosystem. It uptakes the carbon dioxide by the process of photosynthesis and stores the carbon in the plant tissues, forest litter and soils. As more photosynthesis occurs, more CO_2 is converted into biomass, reducing carbon in the atmosphere and sequestering it in plant tissue above and below ground (Gorte, 2009; IPCC, 2003) resulting in growth of different parts (Chavan and Rasal, 2010).

Allometry, generally relates some non-easy to measure tree characteristics from easily collected data such as dbh (diameter at breast height), total height or tree age and provides relatively accurate estimates. Models for volume, biomass or nutrient content within the trees belong to the same class as methodologies for sampling trees and fitting and using the equations are similar. Despite their apparent simplicity, these models have to be built carefully, using the latest regression techniques.

Tree growth parameters varies considerably with species, site quality, location, climatic regimes, altitude etc. and therefore becomes necessary to obtain accurate and precise tree allometric estimates in order to improve understanding of the role of these carbon sinks in global carbon cycle. An unsuitable application of allometric equation may lead to considerable bias in carbon stocks estimations (Henry *et al.*, 2013).

Materials and Methods

Site description

The study was conducted in out in, Dr Y S Parmar University of Horticulture and Forestry, Nauni area, Solan Himachal Pradesh, India. The area lies about 13 kilometres from Solan between 30o 50 30 to 30o 52 0 N latitude and the longitude 77o8 30 and 77o11 30 E (Survey of India Toposheet No. 53F/1) with an elevation of about 900-1300 m above mean sea level. The minimum and maximum temperature varies from 3^oC during winter (January) to 33^oC during summer (June), whereas; mean annual temperature (MAT) is 19^oC.

Biomass sampling

Seven species (each species 30 trees) were measured for their diameter at breast height (DBH) and height with tree calliper and Ravi's altimeter, respectively. Biomass of the stem is determined by multiplying volume of stem with specific gravity. Local volume equation developed for specific tree species and region was used for calculating the volume of the forest trees, Branch and leaves biomass was estimated by multiplying the volume of trees of each species with their corresponding biomass expansion factors,

The total aboveground biomass of the tree comprised of the sum of stem biomass, branch biomass and leaf biomass, The below ground biomass (BGB) calculated by multiplying above ground biomass taking 0.26 as the root: shoot ratio and for total biomass were calculated sum of above ground biomass and belowground biomass.

Growth

To find the growth were calculated growth parameter (crown area, crown width, crown volume and height of the tree)

Crown area

Crown area will be assumed to be a circle, and it was calculated and used the formula given by Chaturvedi and Khanna (2000) and expressed in meter square. $CA=\pi \div 4D^2$.

Crown width

The crown width (m) was measured in two directions (North-south and East-west) and average was calculated as:

$$CW = \frac{D1 + D2}{2}$$

Crown volume

For calculated, used the following formula (Balehegn *et al.*, 2012):

CV=4ℼ÷3+(CW÷2+CD÷2)³.

Height of trees

It is the height from base to top of standing tree measured and used Ravi Millimeter and expressed in meters.

Carbon storage

Biomass of each tree component converted to biomass-carbon by multiplying biomass with conversion factor of 0.50.

Statistical procedure

All the species compared for their morphological characters by using standard statistical procedure.

The allometric relationships among different tree components of an individual tree like height, dbh, biomass and volume developed by using linear and non-linear functions.

Data processing and analysis

The best linear and nonlinear relationship between tree components determined by determination of (Adj.R^2) and standard residual error.

Adjusted R^2

Calculated as per following formula given by Gujrati, 1998.

$\bar{R}^2 = 1 - \left[\frac{(1-R^2)(n-1)}{n-k-1}\right]$ Where: R = sample R-square, N= number of observations and K= number of parameter.

Standard residual error: (Mbow *et al.*, 2013) σ

$$SRE = \frac{\sqrt{n}}{\bar{y}}$$

Where: y = the average of the observed parameter, **σ** = the standard deviation and n= is the number of sample.

Results and Discussion

Determination of allometric equation among the tree components

The result on various linear and non-linear functions for tree volume as the dependent variable and DBH (diameter at breast height) and tree Height separately as independent variable for *Albizia chinensis*, *Albizia lebbeck*, *Melia composita*, *Acacia mollissima*, *Toona ciliata*, *Dalbergia sissoo* and *Ulmus wallichiana* and are present in Table 1.

Albizia chinensis

The allometric relations for estimating stem volume with DBH and Height of tree , each taken independently , where quadratic Function showed highest $\bar{R}^2$ (0.98) stem volume with DBH. In case of tree Height sigmoid function showed highest adj $\bar{R}^2$ (0.69).

The allometric relationship of tree stem biomass with DBH and tree Height , each taken independently, where quadratic function showed $\bar{R}^2$ (0.99) for tree stem biomass with DBH. In case of Height of tree sigmoid function showed the highest adj $\bar{R}^2$ (0.69).

Albizia chinensis showed significant allometric relationship for estimating of branch and leaves biomass (BB) with DBH as well as tree Height when used independently. The results revealed that quadratic function was strong with adj $\bar{R}^2$ (0.98). Similarly, stronger relationships were found for tree Height variable with maximum $\bar{R}^2$ values by sigmoid function (0.69).

The allometric relationships of tree above ground biomass (AGB) with DBH and Height of tree , each taken independently , where quadratic Function showed $\bar{R}^2$ (0.99) and In case of tree Height sigmoid function showed $\bar{R}^2$ (0.69).

Albizia lebbeck

Albizia lebbeck were significant for DBH. The power function showed highest $\bar{R}^2$ (0.96) for volume with DBH and in case of Height of tree power function showed highest $\bar{R}^2$ (0.47).

The allometric relations for estimating stem biomass with DBH and Height of tree , each taken independently , where power Function showed highest $\bar{R}^2$ (0.96) stem biomass with DBH and In case of tree Height power function showed highest adj $\bar{R}^2$ (0.47).

Various allometric relationships used for DBH as well as tree Height for branch and leaves estimating of *Albizia lebbeck*. Trees were significant for DBH. The power function showed highest $\bar{R}^2$ (0.96) for branch and leaves with DBH and case of Height of tree power function showed highest $\bar{R}^2$ (0.48).

Albizia lebbeck showed significant allometric relations for estimating aboveground biomass (ABG) based on DBH as well as tree Height when used independently. The results revealed that power function was strong with adj $\bar{R}^2$ (0.95) and similarly, stronger relationships were found for tree Height variable with maximum $\bar{R}^2$ values by power function (0.47).

Acacia mollissima

Among based on DBH, the allometric relations were significant, where power function reported highest $\bar{R}^2$ (0.99) and for tree Height variable, the significant relationships were stronger with maximum value of $\bar{R}^2$ (0.52) for sigmoid.

Allometric relations for estimating stem biomass with DBH as well as tree Height separately for *Acacia mollissima*. The power function reported highest $\bar{R}^2$ (0.98) on the basis of DBH and for tree Height variable, the significant relationships were stronger with maximum value of $\bar{R}^2$ for sigmoid (0.51).

Various linear and non-linear relationships used for DBH as well as tree Height for branch and leaves estimation of *Acacia mollissima*. Trees were significant for DBH. The power function showed highest $\bar{R}^2$ (0.96) for branch and leaves with DBH and however, in case of Height of tree sigmoid function showed highest $\bar{R}^2$ (0.45).

Various linear and non-linear relationships used DBH as well as tree Height for stem volume estimation of *Acacia mollissima*. Trees were more significant for DBH. The power function showed highest $\bar{R}^2$ (0.97) and in case of Height of tree sigmoid function showed highest $\bar{R}^2$ (0.53).

Toona ciliata

Toona ciliata showed significant allometric relations for various linear and non-linear functions used for stem volume estimation with DBH as well as height when used independently. The results revealed that power function was strong with $\bar{R}^2$ (0.88) on the basis of DBH and similarly stronger relationships were found for tree Height variable with maximum value of $\bar{R}^2$ by sigmoid function (0.64).

The allometric relations for estimating stem biomass with DBH, where power function was strong with $\bar{R}^2$ (0.87) and similarly stronger relationships were found for tree Height variable with maximum value of $\bar{R}^2$ by sigmoid function (0.64).

Various linear and non linear relationships used for DBH as well as tree Height for branch and leaves estimation, trees were significant for DBH. The power function showed highest $\bar{R}^2$ (0.88) for branch and leaves with DBH and in case of Height of tree sigmoid function showed highest $\bar{R}^2$ (0.64).

Allometric relations for estimating aboveground biomass (AGB) based on DBH. The results revealed that power function was strong with adj $\bar{R}^2$ (0.87) and also, stronger relationships were found for tree Height variable with maximum $\bar{R}^2$ values by sigmoid function (0.63).

Dalbergia sissoo

Various linear and non-linear equations used to find out stem volume of this tree with DBH as well as height independently were significant. The power function showed highest $\bar{R}^2$ (0.99) value based on DBH and In case of height of tree sigmoid function is the best fitted and highest $\bar{R}^2$ (0.54) value.

Allometric relations for estimating stem biomass of *Dalbergia sissoo* trees with DBH showed The power function is best with highest $\bar{R}^2$ (0.98) value and In case of height of tree, sigmoid function is the best fitted and highest $\bar{R}^2$ (0.54) value. Various linear and non linear relationships for branch and leaves estimated based on DBH the power function showed highest $\bar{R}^2$ (0.98) and However, in case of Height of tree sigmoid function showed highest $\bar{R}^2$ (0.55).

Table.1 Calculation of Aboveground biomass (AGB), belowground biomass (BGB), Total biomass (TB), aboveground carbon (AGC) and Total carbon storage TC of selected trees

TREE SPECIES	Biomass (kg / Tree)			Carbon (kg/tree)	
	Aboveground (AGB)	**Belowground (BGB)**	**Total biomass TB**	**Aboveground (AGC)**	**Total carbon TC**
Albizia chinensis	572	154	726±25	286	363
Albizia lebbeck	800	220	1020±12	400	510
Acacia mollissima	560	120	680±23	280	340
Melia composita	950	260	1210±29	475	605
Toona ciliata	1030	280	1310±32	515	655
Ulmus villosa	650	180	830±14	325	415
Dalbergia sissoo	770	160	930±08	385	465

Fig.1 Scatter diagrams from carbon storage of total biomass of *Albizia chinensis* (A), *Albizia lebbeck* (B), *Melia composita* (C), *Acacia mollissima* (D), *Toona ciliata* (E), *Ulmus villosa* (F) and *Dalbergia sissoo* (G)

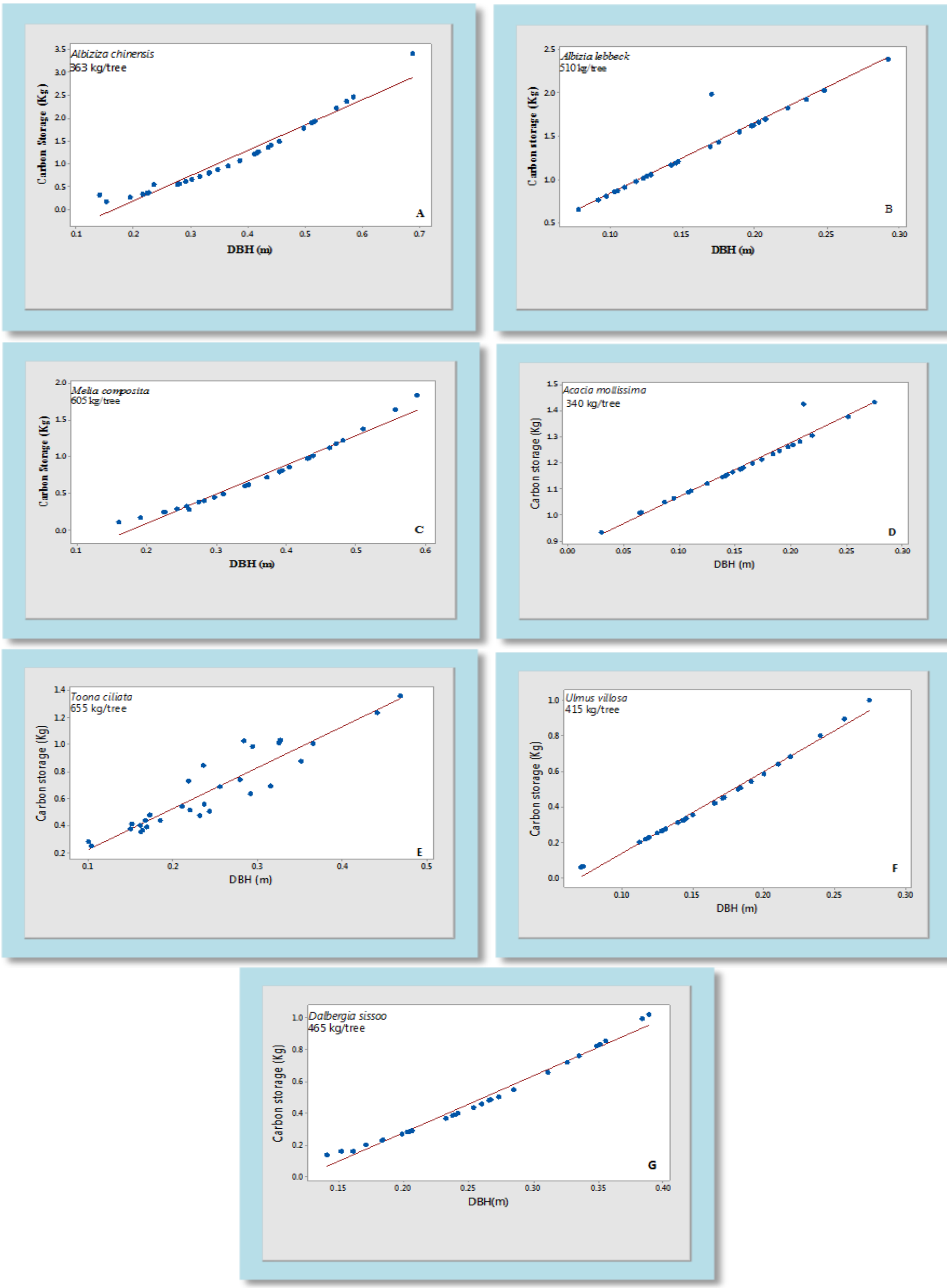
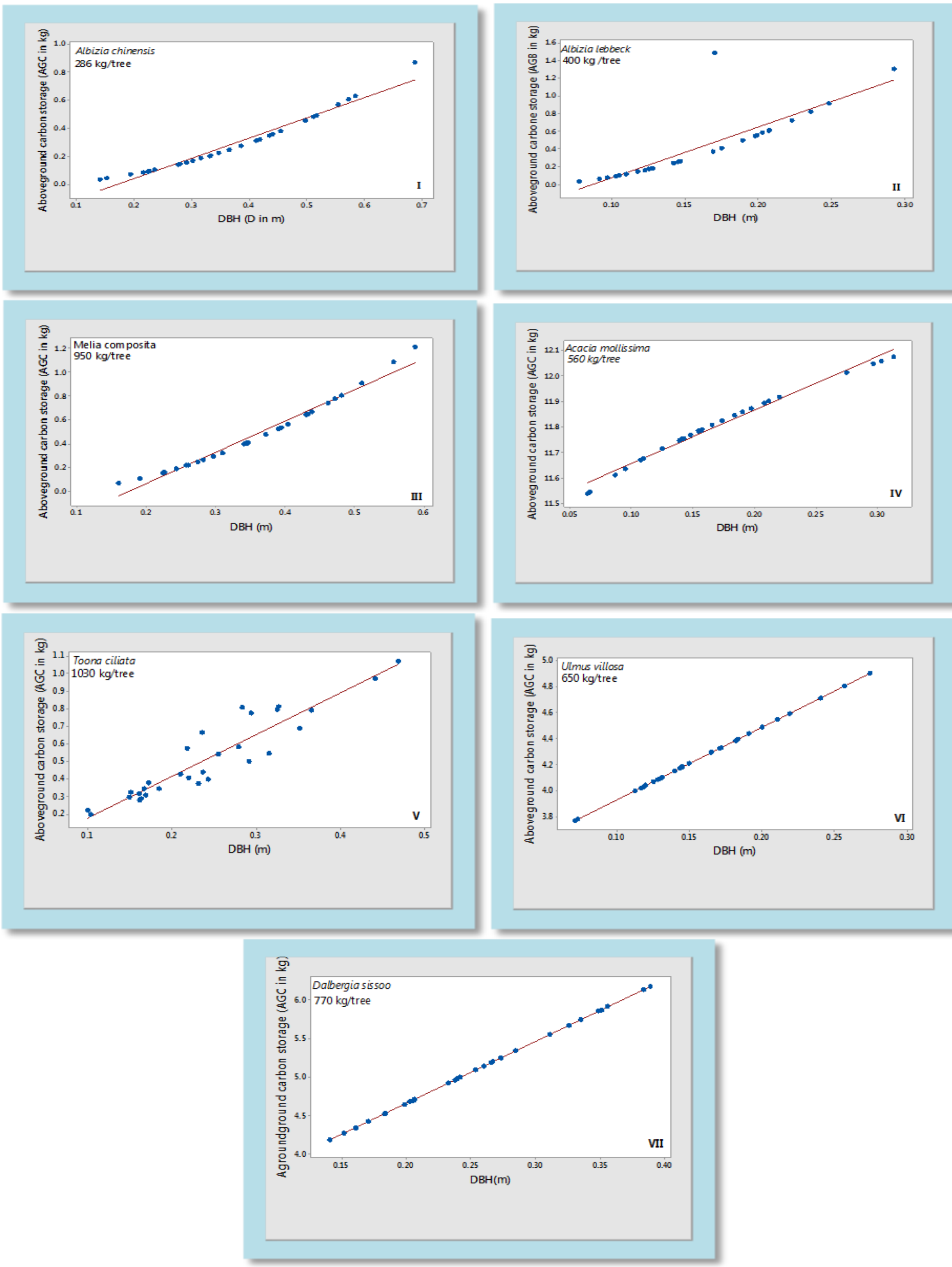


Fig.2 Scatter diagrams from carbon storage of aboveground biomass of *Albizia chinensis* (I), *Albizia lebbeck* (II), *Melia composita* (III), *Acacia mollissima* (IV), *Toona ciliata* (V), *Ulmus villosa* (VI) and *Dalbergia sissoo* (VII)



Various linear and non linear relationships used based on DBH as well as tree Height for stem volume estimation of *Dalbergia sissoo*. Trees were more significant for DBH. The power function showed highest $\bar{R}^2$ (0.98) and, in case of Height of tree sigmoid function showed highest $\bar{R}^2$ (0.54).

The allometric relationships between stem volume and DBH were significant, where power function showed highest $\bar{R}^2$ (0.98), whereas, for tree Height, the relationships were significantly strong with highest $\bar{R}^2$ (0.59).

The allometric relations for estimating stem biomass with DBH, where power function was strong with $\bar{R}^2$ (0.98) and similarly stronger relationships were found for tree Height variable with maximum value of $\bar{R}^2$ by sigmoid function (0.59).

The power function showed highest $\bar{R}^2$ (0.98) for branch and leaves with DBH and however, in case of Height of tree sigmoid function showed highest $\bar{R}^2$ (0.58).

Melia composita were more significant for DBH. The power function showed highest $\bar{R}^2$ (0.99) and However, in case of Height of tree sigmoid function showed highest $\bar{R}^2$ (0.59).

Ulmus villosa

The allometric relations for estimating stem volume of *Ulmus villosa* tree with DBH and Height of tree, each taken independently, resulted in highly significant $\bar{R}^2$ (0.96) which fitted by power function for stem volume with DBH and). In case of tree Height taken as predictor variable, sigmoid function showed highest $\bar{R}^2$ (0.60).

The power function showed $\bar{R}^2$ (0.98) for tree stem biomass after estimating of the allometric relations for tree stem biomass of *Ulmus villosa* with DBH and In case of Height of tree sigmoid function showed the highest adj $\bar{R}^2$ (0.59)

Ulmus villosa were significant for DBH. The power function showed highest $\bar{R}^2$ (0.98) for branch and leaves biomass and in case of Height of tree sigmoid function showed highest $\bar{R}^2$ (0.59).

Ulmus villosa showed significant allometric relations for estimating of aboveground biomass (ABG) based on DBH. The results revealed that power function was strong with adj $\bar{R}^2$ (0.95) and similarly, stronger relationships were found for tree Height variable with maximum $\bar{R}^2$ values by sigmoid function (0.62).

Growth pattern and relationship among trees components

Albizia chinensis

Growth curve pattern of morphological parameters of *Albizia chinensis* revealed that growth of crown area (Fig. 1) is best explained by sigmoid allometric equation ($\bar{R}^2$= 0.41, SE_{b0}=0.57 and SE_{b1}= 0.17).

Albizia lebbeck

Growth curve pattern of morphological parameters of *Albizia lebbeck* showed that growth of crown area, crown width, crown volume and height of tree are best explained by sigmoid curves with highest ($\bar{R}^2$= 0.59, SE_{b0}=0.32 and SE_{b1}= 0.04

Acacia mollissima

Growth curve pattern of morphological parameters of *Acacia mollissima* revealed that is best explained by linear allometric equations with highest ($\bar{R}^2$= 0.19, SE_{b0}=0.60 and SE_{b1}= 3.69).

Melia composita

Growth curve pattern of morphological parameters of *Melia composita* showed that growth of crown area (Fig. 1) is best explained by sigmoid allometric equation ($\bar{R}^2$= 0.52, SE_{b0}=0.54 and SE_{b1}= 0.35).

Toona ciliata

Growth curve pattern of morphological parameters of *Toona ciliata* revealed that growth of crown area (Fig. 1) is best explained by quadratic allometric equation ($\bar{R}^2$= 0.23, SE_{b0}=1.55 and SE_{b1}= 0.13).

Dalbergia sissoo

Growth curve pattern of morphological parameters of *Albizia lebbeck* showed that is the best explained by sigmoid curves with highest ($\bar{R}^2$= 0.44, SE_{b0}=0.34 and SE_{b1}= 0.08).

Ulmus villosa

Growth curve pattern of morphological parameters of *Ulmus villosa* revealed that is the best explained by sigmoid curves with highest ($\bar{R}^2$= 0.33, SE_{b0}=0.34 and SE_{b1}= 0.05).

Determination of carbon storage

The result revealed that biomass and carbon stored in different component trees decreased in the order: *Toona ciliata* > *Melia composita* > *Albizia lebbeck* > *Dalbergia sissoo* > *Ulmus villosa* > *Albizia chinensis* > *Acacia mollissima*. Aboveground biomass was maximum (1030 kg / tree) in *Toona ciliata* followed by *Melia composita*, (950 kg/tree), *Albizia lebbeck* (800 kg/tree), *Dalbergia sissoo* (770 kg/tree), *Ulmus villosa* (650 kg/tree), *Albizia chinensis* (572 kg/tree) and *Acacia mollissima* (560 kg /tree). Belowground biomass ranged from 280 kg/tree *Toona ciliata* to 120kg/tree *Acacia mollissima*. In case of total carbon storage potential *Toona ciliata* has a highest rate with (655 kg/tree).

Allometric equations are useful to measure the biomass of trees in areas. This study provides allometric equations for DBH, height and tree biomass that can be used for forests ecosystems. It also shows that allometric equations integrating DBH and height of tree (H) independently were significant variable for the estimation of tree stem volume, stem biomass, branch and leaf biomass and aboveground biomass (Fig. 2).

It is evident from the present study that there is highly significant relation between DBH and crown area (CA), crown width (CW), crown volume (CV) and height of tree (H) growth parameters and these growth characteristics have strongly related to dbh of tree and they increase with the increase of DBH. Among various linear and non-linear functions, the sigmoid function was the best for that component which I mentioned above. The carbon storage potential of Agroforestry tree species may be one of the important characteristics that be considered beside other factors of species selection in various part of the country. Therefore, for this sub-tropical region of Western Himalayas, the preference of the species should be in order of *Toona ciliata* > *Melia composita* > *Albizia lebbeck* > *Dalbergia sissoo* > *Ulmus villosa* > *Albizia chinensis* > *Acacia mollissima*.

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