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Carbon Storage Potential and Allometric Models for *Acacia catechu* in Forest Land use Systems in Sub-Tropics of Jammu

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Abstract: The study was carried out in *kandi* region of Jammu province to assess carbon storage potential and allometric models for *Acacia catechu* in forest land use systems involving Jammu, Samba and Kathua districts. The vegetation in the study area is represented by Northern dry mixed deciduous forest ($5B/C_1$), Himalayan sub-tropical pine forest (Type $9/C_1$) and sub-type $9/C_{1a}$ (Lower shivalik chir forest) with *Acacia catechu* as main species among broadleaves. The phytosociology showed that the highest Importance Value Index (IVI) was in *Acacia catechu* (61.62) which shows its pre-dominance in the study area. The total carbon stock from *Acacia catechu* was 4.45 Mg ha^{-1}, out of which 74.15% (3.30 $Mgha^{-1}$) is contributed by aboveground components and 25.85 % (1.15 Mg ha^{-1}) from below ground components. Allometric models were developed for evaluating the best fit equation for aboveground biomass and carbon. The best allometric model for total biomass assessment was (Biomass = $4.152 \times 0.453^{DBH2 \times Height}$) on $DBH^2 \times$ Height with adjusted R^2 = 0.8026 and AIC = 39.627.

Keywords: Carbon, Biomass, Allometric models, Allometric equations, *Acacia catechu*

Forests play a critical role in global carbon cycle as growing trees remove carbon dioxide from the atmosphere through photosynthesis and have potential to sequester carbon, thus, form an important climate change mitigation option (Kumar and Singh 2003). Theoretically, trees are considered to be the major part of global carbon sink, which involves minimum cost due to natural process of photosynthesis. Consequently, the managed forests can conceptually sequester/ store carbon both *in-situ* (soil and biomes) and *ex-situ* (end products as finished products). The rationale for carbon inventory methods is to estimate emissions or removal of CO_2 from biomass and soil or changes in carbon stocks from a given land-use system resulting from human interventions such as Land-use and land-use changes, felling/ removal of biomass, afforestation, reforestation, forest conservation, burning of above and belowground biomass, soil disturbance leading to reduction in soil organic matter, deep ploughing/tillage and other management practices. Carbon inventory is not directly aimed at climate change mitigation, however, required for activities related to climate change in land-use sector. Forest landuse systems are critical in stabilizing CO_2 concentration in the atmosphere as they offer large mitigation potential besides providing multiple sustainable benefits such as biodiversity conservation, watershed protection, increased crop and grass productivity for stakeholders (Ravindranath and Ostwald 2008).

MATERIAL AND METHODS

Study area: The study was carried out in sub-montane region of the outer Himalayas fringing *Shivalik* hills is popularly known as *bhabar* or *kandi* which stretches between longitude 74° 21' to 75° 45' E and latitude 32° 22' to 32° 55' N covering three districts, namely Jammu, Samba and Kathua. The vegetation in study area was classified into various forest types as per the classification made by Champion and Seth (1968). Northern dry mixed deciduous forest ($5B/C_1$) is major forest type of the study area with *Acacia catechu, Dalbergia sisoo, Grewia optiva, Dendrocalamus strictus, Acacia modesta, Mallotus philippensis*, *Bombax ceiba, Carissa spinarum, Dodonea viscosa* etc. being the main species. The fringe zone of *kandi* towards its higher reaches comprise of Himalayan sub-tropical pine forest (Type $9/C_1$) sub-type $9/C_{1a}$ (Lower shivalik chir forest). The general floristic composition in the study area of this sub-type includes *Pinus roxburghii*, *Acacia catechu, Dalbergia sissoo, Butea monosperma, Mallotus philippensis, Zizyphus jujuba, Syzygium cumini, Ficus glomerata,* etc. *Acacia catechu* being the one of the main species was selected to assess the carbon storage potential and prediction of biomass models. For selection of random sample points in forest land-use system, the Conservator of Forests (East Circle), Jammu was consulted and the sample points were randomly selected on topographic maps (topo-sheets) after discussions held with Divisional Forest Officers of Jammu and Kathua forest division. In all, 15 sample points were selected in study area comprising three districts viz., Jammu, Samba and Kathua. Global Positioning System (GPS) was used during the field survey exercise to locate the geo-coordinates and altitude of sampling points.

Phytosociology of *Acacia catechu* under forest land use system was calculated. The relative dominance, relative density, relative frequency and importance value index (IVI) were computed. The aboveground standing biomass comprising of all woody stems, branches, leaves of the living trees (deadwood not accounted as the same is removed from the system as fuel), was calculated for marked *Acacia catechu* trees in selected sample point. Non-destructive method was used, which is more rapid and much larger area and number of trees can be sampled, reducing the sampling error encountered with the destructive method (Hairiah et al 2011).

The quadrat size of 10 m x 10 m (0.01 ha) was used in estimation of biomass. All the living trees with stem size >3 cm were measured for estimating the volume of growing stock. The non-destructive measurements of stem diameters were used and allometric equations on the basis of DBH and height were applied. Trees were reckoned and their diameter at breast height (DBH) and height were measured. The stem volume of trees was calculated by using basal area (BA), height and form factor. For standing trees, general form factor of 0.5 was taken regardless of taper or form (Butterfield and Espinoza 1995). The stem volume of *Acacia catechu* was converted into biomass by using wood density (Mg m^{-3}) which was taken as 0.88 Mg m^{-3} (Brown 1997). Irrespective of size and length, the total number of branches were counted on each of the sample tree and were categorized into three parts *viz*., lower, middle and upper. Fresh weight of one sampled branch from each group was recorded separately. The dry weight of branches was determined by as suggested by Chidumaya (1990). The fresh leaves segregated from the harvested branch were weighed and a representative sample thereof (0.1 kg) was retained to estimate the dry weight of leaves. Leaves were oven dried to obtain the constant weight. The below ground biomass of trees was calculated by using the ratio of below-ground to above-ground biomass (Mokany *et al* 2006). Carbon concentration in plants was calculated (Negi et al 2003).

Carbon (%) = 100 – (Ash weight+ molecular weight of O_2 (53.3) in $C_6H_{12}O_6$)

Oven dried plant components (leaves, bark and wood) were burnt in electric furnace at 400°C temperature, ash content (inorganic elements in the form of oxides) left after burning was weighed and carbon was calculated. This carbon concentration was converted in to carbon stock (Mg ha^{-1}) by multiplying it with the biomass. The proportion of stem wood used as long-lived wood products was estimated (Wang and Feng 1995).

The estimated carbon stock was converted into CO_2 equivalent by multiplying the carbon stock of 3.67 (Van Kooten 2004) for calculating CO_2 assimilation by biomass.

Long-lived carbon storage = carbon mass in stem wood 42% stem wood put for long term locking

Heat from biomass combustion and carbon storage from coal substitution (Mg ha^{-1}) was simulated on the basis of thermal efficiency of biomass (Wang and Feng 1995).

Heat from biomass combustion = [Biomass – (stem wood weight 0.42)] 18 10^9 J ton^{-1}

$$\text{Carbon storage from coal substitution} = \frac{(\text{Heat of biomass combustion} \times 0.60 \times 0.70)}{(18 \times 10^9)}$$

The estimated carbon stock was converted into CO_2 equivalent by multiplying the carbon stock of 3.67 (Van Kooten 2004) for calculating CO_2 assimilation by biomass.

Allometric models /equations for the estimating aboveground biomass and carbon were developed and applied on the inventoried data based on direct measurements. Diameter at breast height (DBH) and height were taken as independent variables. The data obtained were subjected to statistical analysis by using SPSS-16, GRETL and OPSTAT.

RESULTS AND DISCUSSION

Phytosociology of *Acacia catechu* and associated trees under forest land use system: The various forest types in the study area were 5B/C_2-Northern dry mixed deciduous forest, 5B/DS_1-Dry deciduous scrub, 5B/E_9-Dry bamboo brakes, 5B/1S_2-Khair-sissoo forest and 9C_1/1a-Lower or shiwalik chir pine (Ashutosh et al 2010).

The maximum relative frequency was in *Acacia catechu* (13.51), followed by *Butea monosperma*, *Cassia fistula, Leucaena leucocephala* and *Mallotus philippensis*. The minimum values (2.70) were exhibited by *Albizia lebbeck*, *Eucalyptus*, *Ficus palmata* and *Prosopis juliflora*. The highest Importance Value Index (IVI) was in *Acacia catechu* (61.62), followed by *A. modesta* (32.94) and *Pinus roxburghii* (31.92). Sharma and Raina (2018) also reported predominance of tree species like *Pinus roxburghii, Acacia modesta, Mallotus philippensis, Dalbergia sissoo* in foot hills of shivaliks. However, in *Pinus roxburghii* the per cent frequency is lower (13.33). This is mainly due to distribution of *Pinus roxburghii* in very constricted patches which are exposed to southern aspect. The findings are also in agreement with the findings of Jhangir (2004). The average diameter and height of 0.11 m and 3.89 m, respectively was recorded in *Acacia catechu* across the forest landuse system (N=51). The average volume of 4.37 m^3 ha^{-1} was with average basal area of 1.18 m^2 ha^{-1}. The average total biomass (17.55 Mg ha^{-1}) with 13.71 Mg ha^{-1} as aboveground biomass and 3.84 Mg ha^{-1} as belowground biomass was recorded. The biomass of a tree and correspondingly its carbon stock depends greatly on its diameter, structure, age, density and intensity of canopy management. Tree growth attributes are decisive components of biomass productivity and hence the carbon content (Newaj et al 2007). The total carbon stock from *Acacia catechu* was 4.45 Mg ha^{-1}, out of which 74.15% (3.30 Mg ha^{-1}) is contributed by aboveground components and 25.85 % (1.15 Mg ha^{-1}) from below ground components. Biomass pattern clearly reflects that the more carbon is allocated to aboveground components than belowground components. These results are in conformity with the results obtained earlier by Mahajan et al (2018), Jha (2005), Chauhan et al (2009) and Pal et al (2009). The long lived carbon storage of 0.70 Mg ha^{-1} was in *Acacia catechu* with CO_2e of 16.32 Mg ha^{-1}. Similar results were reported by Mahajan et al (2021) for trees in agriculture land-use system. Yadav (2010) and Kanime et al (2013) emphasized on estimating the end use of wood for assessing the carbon sequestration potential.

Allometric models for *Acacia catechu* were developed for evaluating the best fit equation for aboveground biomass and carbon. Here, the DBH and height were taken as independent variables. Two equations were framed for assessing aboveground biomass based on DBH× Height, DBH^2 × Height, respectively. The best allometric model for total biomass assessment was (Biomass = 4.152 × $0.453^{DBH2×Height}$) on DBH^2× Height with adjusted R^2= 0.8026 and AIC = 39.627. Also, five allometric equations were developed for carbon assessment based on total biomass, DBH, height, DBH× Height, DBH^2 × Height, respectively. The best fit equation for carbon assessment was CS = −1.235 × $0.937^{TotalBiomass}$ on the basis of total biomass with adjusted R^2= 0.8819 and AIC = 14.67. On the basis of independent variables of DBH and height, the best fit equation was for DBH x Height (CS = 2.019 × $0.769^{DBH × Height}$) with adjusted R^2 =0.845 and AIC = 27.71. It was followed by equation based on DBH^2× Height (CS = 2.775 × $0.458^{DBH2 × Height}$) with adjusted R^2=0.825 and AIC = 23.317. The selected models are tested for accuracy based on measured data. The best model should have higher R^2-adj and correlation and AIC than other developed equations. The coefficients for all selected models are statistically significant, which showed strong correlation of AGB with dendrometric variables. The choice of allometric equations has a significant effect on the biomass calculations since the forest biomass estimates vary with age of the forest,

Table 1. Overview of the method used

Parameter	Quadrat size	Method
Living tree with stem size > 3cm	10 m x 10 m (0.01 ha)	Non-destructive measurement of stem diameters; Allometric equations on the basis of DBH and height were applied

Table 2. Relative dominance, relative density, relative frequency and importance value index (IVI) of *Acacia catechu* and associated tree species

Species	Per cent frequency	Abundance	Density	Relative dominance	Relative density	Relative frequency	IVI
Acacia catechu	33.33	9.60	3.20	16.53	31.58	13.51	61.62
Acacia modesta	20.00	6.33	1.27	12.34	12.50	8.11	32.94
Albizia lebbeck	6.67	3.00	0.20	1.20	1.97	2.70	5.87
Butea monosperma	26.67	2.25	0.60	8.40	5.92	10.81	25.13
Cassia fistula	26.67	1.25	0.33	1.45	3.29	10.81	15.55
Dalbergia sissoo	20.00	4.33	0.87	3.48	8.55	8.11	20.14
Eucalyptus sp.	6.67	5.00	0.33	8.83	3.29	2.70	14.82
Ficus palmate	6.67	3.00	0.20	0.51	1.97	2.70	5.19
Flacourtia indica	13.33	1.50	0.20	1.09	1.97	5.41	8.47
Lannea coromendalica	13.33	7.00	0.93	2.35	9.21	5.41	16.97
Leucaena leucocephala	26.67	3.25	0.87	9.00	8.55	10.81	28.37
Mallotus philippensis	26.67	1.75	0.47	3.73	4.61	10.81	19.14
Pinus roxburghii	13.33	2.50	0.33	23.23	3.29	5.41	31.92
Prosopis juliflora	6.67	6.00	0.40	4.87	3.95	2.70	11.52

Table 3. Allometeric models for *Acacia catechu*

Model	Dependent variable	Independent variable	Allometric equation	Estimated coefficients	F-value	Solved equation	R^2 Adjusted & AIC values
Model 1	Biomass	DBH × Height	$Biomass = \alpha \times \beta^{DBH \times Height}$	$\alpha = 3.391^{***}$ $\beta = 0.74^{***}$	184.55^{***}	$Biomass = 3.391 \times 0.749^{DBH*Height}$	$R^2 = 0.796$ AIC = 41.181
Model 2	Biomass	DBH^2 × Height	$Biomass = \alpha \times \beta^{DBH2 \times Height}$	$\alpha = 4.152^{***}$ $\beta = 0.453^{***}$	13.14^{***}	$Biomass = 4.152 \times 0.453^{DBH2 \times Height}$	$R^2 = 0.8026$ AIC = 39.627
Model 3	Carbon	Total Biomass	$CS = \alpha \times \beta^{Total\ Biomass}$	$\alpha = -1.23^{***}$ $\beta = 0.937^{***}$	659.12^{***}	$CS = -1.235 \times 0.937^{TotalBiomass}$	$R^2 = 0.8819$ AIC = 14.67
Model 4	Carbon	DBH	$CS = \alpha \times \beta^{DBH}$	$\alpha = 3.724^{***}$ $\beta = 1.0665^{***}$	140.57^{***}	$CS = 3.724 \times 1.0665^{DBH}$	$R^2 = 0.748$ AIC = 51.062
Model 5	Carbon	Height	$CS = \alpha \times \beta^{Height}$	$\alpha = -0.91^{***}$ $\beta = 1.609^{***}$	26.457^{***}	$CS = -0.914 \times 1.609^{Height}$	$R^2 = 0.630$ AIC = 69.483
Model 6	Carbon	DBH × Height	$CS = \alpha \times \beta^{DBH \times Height}$	$\alpha = 2.019^{***}$ $\beta = 0.769^{***}$	45.198^{***}	$CS = 2.019 \times 0.769^{DBH \times Height}$	$R^2 = 0.845$ AIC = 27.71
Model 7	Carbon	DBH^2 × Height	$CS = \alpha \times \beta^{DBH2 \times Height}$	$\alpha = 2.775^{***}$ $\beta = 0.458^{***}$	224.02^{***}	$CS = 2.775 \times 0.458^{DBH2 \times Height}$	$R^2 = 0.825$ AIC = 23.317

****Significant at 1% level

site class, and stand density. Similar results have been reported by Abola et al (2005), Basuki et al (2009), Kebede et al (2018) and Nam et al (2016).

CONCLUSION

The IVI was measured as the sum of relative density, relative frequency and relative dominance. The highest IVI was found in *Acacia catechu* followed by *Acacia modesta.* Allometric models for estimating the aboveground biomass and carbon were developed based on direct measurements. Diameter at breast height (DBH) and height were taken as independent variables. Based on R^2 adjusted R and akaike information criterion (AIC), models were estimated for *Acacia catechu* due to its pre-dominance in the study area. The best-fit regression model for aboveground biomass and carbon were based on combinations of diameter at breast height (DBH), and height as independent variables. These variables are easy to measure accurately in the field.

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