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Biomass Estimation Models of Three Fast-growing Tree Species in Prayagraj, Uttar Pradesh, India

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Authors' contributions

This work was carried out in collaboration among all authors. Author BKS collect the data of tree, data analysis and write the paper, author AS help in data analysis and author AT guide, write and correction of paper. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted to develop the regression models of biomass for three fast-growing trees, *viz., Populus deltoides* (Poplar), *Eucalyptus spp.* (Eucalyptus) and *Casuarina equisetifolia* (Casuarina) in high-density plantation after two years at three different spacings, *viz.,* 1m×1m, 1.2m×1.2m and 1.5m×1.5m in village Padilla, Prayagraj, Uttar Pradesh, India. The trial was established in year 2021 and data was collected after two years. The result indicateds the maximum height range was found in T_2: Eucalyptus (1m×1m) 7.5m followed by T_8: Eucalyptus (1.5m×1.5m) 5.3m whereas the maximum girth range was found in T_2: Eucalyptus (1m×1m) 12.5cm followed by T_7: Poplar (1.5m×1.5m) 11.7cm. The bole linear function for height and girth in 2[nd] year maximum R^2 was found in T_8: Eucalyptus (1.5m×1.5m) 0.969 followed by T_6: Casuarina (1.2m×1.2m) 0.958

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whereas the branch's linear function for height and girth was maximum R^2 in 2nd year maximum in T_2: Eucalyptus (1m×1m) 0.947 followed by T_4: Poplar (1.2m×1.2m) 0.838. The leaves' linear function for height and girth was maximum R^2 in 2nd year maximum found in T_9: Casuarina (1.5m×1.5m) 0.903 followed by T_5: Eucalyptus (1.2m×1.2m) 0.861 whereas the AGB linear function for height and girth was maximum R^2 in 2nd year maximum found in T_2: Eucalyptus (1m×1m) 0.976 followed by T_6: Casuarina (1.2m×1.2m) 0.965. The bole biomass maximum found after 2nd year T_4: Poplar (1.2m×1.2m) 2.801 kgtree^{-1} followed by T_2: Eucalyptus (1m×1m) 2.801 kgtree^{-1} whereas in 2nd year branch biomass maximum found in T_8: Eucalyptus (1.5m×1.5m) 1.130 kgtree^{-1} followed by T_4: Poplar (1.2m×1.2m) 0.982 kgtree^{-1}. The leaves biomass maximum found in 2nd year maximum found in T_8: Eucalyptus (1.5m×1.5m) 1.950 kgtree^{-1} followed by T_2: Eucalyptus (1m×1m) 1.617 kgtree^{-1} whereas in 2nd year AGB maximum in T_2: Eucalyptus (1m×1m) 5.285 kgtree^{-1} followed by T_8: Eucalyptus (1.5m×1.5m) 4.803 kgtree^{-1}.

Keywords: Regression model; Biomass; fast-growing tree species; height; girth.

1. INTRODUCTION

Fast-growing wood species have been frequently used in plantation forests and community forests to improve the woods' long-term viability. These wood species can be used to bridge the gap between supply and demand for wood [1]. Planting density has a major impact on each individual tree's available growing resources and crown features [2], affecting wood volume growth, biomass increment, and wood quality [3,4]. Trees have a critical role in the environment [5] and are also visible and quantifiable indicators of ecological health. Trees transform and alter the environment in which they grow, making them important ecosystem engineers [6]. Trees also provide a variety of ecosystem services such as water purification, prevention of soil erosion, flood defence, carbon sequestration, air temperature regulation and air quality regulation [7].

Based on diameter at breast height (DBH) and height data, biomass estimation equations, also known as allometric equations or regression models, are used to estimate the biomass or volume of aboveground tree components. These equations are generated from sample trees' measured tree weights in relation to their DBH and height. Estimating the biomass of tree species present in a forest or plantation using biomass equations is a standard and cost-effective method [8]. Direct and indirect methods, as well as remote sensing methods, can be used to estimate biomass. Destructive sampling is the most accurate method for estimating tree biomass [9,10,11,12]. This direct method permits allometric equations to be developed, which may be utilised to translate ground-based observations into biomass [9,10].

2. MATERIALS AND METHODS

The experiment was established at Padilla, Prayagraj in year July, 2021 and the data was collected after two year (June, 2023). The GPS location of site longitude (25.54° N) and latitude (81.89° E). The experiment was conducted to evaluate the growth performance and develop the regression equation of biomass for three fast-growing tree species under high-density plantation. In this experiment plantation of three fast growing species *viz.,* Poplar (*Populus deltoides*), Eucalyptus (*Eucalyptus spp.*) and Casuarina (*Casuarina equisetifolia*) were established in randomized block design (RBD) with the 9 treatments and 3 replication with following treatments *viz.,* T1: Poplar (1m×1m), T2: Eucalyptus (1m×1m), T3: Casuarina (1m ×1m), T4: Poplar (1.2m×1.2m), T5: Eucalyptus (1.2m×1.2m), T6: Casuarina (1.2m×1.2m), T7: Poplar (1.5m×1.5m), T8: Eucalyptus (1.5m× 1.5m) and T9: Casuarina (1.5m×1.5m).

Height (m) of the tree was documented with help of clinometer and pole method whereas girth (cm) was documented above 1.37 m ground level with help of measuring tape.

2.1 Stem Biomass (kg tree^{-1})

The weight of the twenty trees chosen was weighed at the stem. The selected trees were carefully cut, minimising root damage. The stem was chopped into logs for ease of biomass estimate and separated 20 cm above the ground level. The fresh weight of the logs was then instantly determined by weighing them on an electronic scale in the field. To achieve the appropriate weight, a representative sample was taken from the stem of each tree and placed in an oven set at 100±2 ^{0}C. and dried until a constant weight was attained. Dry matter content was calculated by using the [formula 13]:

$$Stem\ Dry\ matter\ content\ (\%) = \frac{DS_1 + DS_2 + DS_3}{FS_1 + FS_2 + FS_3} \times 100$$

Where:
DS_1, DS_2, DS_3 = Dry weight of sample one, two and three, respectively.
FS_1, FS_2, FS_3 = Fresh weight of sample one, two and three, respectively.

2.2 Total Stem Dry Weight (kg)

Using the following formula, the total dry weight of the stem portion was calculated by multiplying its total fresh weight by its dry matter content:

Total stem dry weight = Total stem fresh weight × Stem dry matter content (%)

2.3 Branches Biomass (kg Tree^{-1})

Twenty randomly chosen trees were used to compute the branch biomass without leaves. The branches were immediately detached from the shoots and weighed in the field with an electronic scale to obtain the current weight. To obtain the oven dry weight of the branch biomass, three randomly chosen branch samples from various portions of the tree were taken, dried in an oven at 100±2 ^{0}C, until a constant weight was attained. Dry matter content was calculated using the [formula 13]:

$$Dry\ matter\ content\ (\%) = \frac{DB_1 + DB_2 + DB_3}{FB_1 + FB_2 + FB_3} \times 100$$

Where:
DB_1, DB_2, DB_3 = Dry weight of branch one, two and three, respectively.
FB_1, FB_2, FB_3 = Fresh weight of branch one, two and three, respectively.

2.4 Total Branch dry Weight (kg)

The following formula was used to get the total branch dry weight for each tree branch: total fresh weight multiplied by dry matter content:

Total branch dry weight = Total branch fresh weight × Branch dry matter content (%)

2.5 Leave Biomass (kg tree^{-1})

200 gram leaves of selected trees were detached from the branches in the field and weighed instantly with the help of electronic balance in the field to get the fresh weight. In an oven set at 70±2 ^{0}C, four representative leaf samples were dried until the leaf biomass reached a consistent weight. Leaves dry matter content was calculated by using the following formula [13]:

$$Leaves\ Dry\ matter\ content\ (\%) = \frac{DL_1 + DL_2 + DL_3 + DB_4}{FL_1 + FL_2 + FL_3 + FL_4} \times 100$$

Where:
DL_1, DL_2, DL_3, DL_4 = Dry weight of leaves one, two, three and four respectively.
FL_1, FL_2, FL_3, FL_4 = Fresh weight of leaves one, two, three and four respectively.

2.6 Total Leaves Dry Weight (kg)

The total dry weight of the leaves on each tree was calculated by multiplying their fresh weight by the dry matter content of each tree:

Total leaves dry weight = Total leaves fresh weight × Leaves dry matter content (%)

2.7 Above Ground Biomass (kg tree^{-1})

For the calculation of above ground biomass (AGB) addition of dry biomass of bole. Branches and leaves.

AGB= Bole biomass + Branches biomass + Leaves Biomass

2.8 Statistical Analysis

With the assistance of MS-Excel and the web programme WASP, the regression equation for the stem, branches, leaves, and aboveground biomass was created. OPSTAT statistical software was utilised to compute descriptive statistics and determine which linear and non-linear models were appropriate. Twenty-seven different equations (Table 2) were used to assess the biomass models of fast-growing tree species in an attempt to calculate the estimation accuracy of each model using the coefficient of determination, or R^2 [14,15,16].

3. RESULTS AND DISCUSSION

Range of height and girth are shown in Table 1. The maximum height range of 7.5 m was found in T_2: Eucalyptus (1m×1m), followed by 5.3 m in T_8: Eucalyptus (1.5m×1.5m) and minimum of 2.1 m in T_1: Poplar (1m×1m) whereas the maximum girth range of 12.5 cm was found in T_2: Eucalyptus (1m×1m) followed by 11.7 cm in T_7:

Poplar (1.5m×1.5 m) and minimum of 3.5 cm in T_3: Casuarina (1m×1m). Similarly, result was reported in Poplar clone maximum height in Udai clone (11.57 ± 0.23 m) followed by L - 87 (10.22 ± 0.42 m) and minimum in Bahar (6.74 ± 0.19 m) at age of four years [17]. In first year the maximum height of 3.76 m was recorded in T_2 (*Casuarina* 1m×1m) followed by T_6 3.66 m (*Casuarina* 1.2m×1.2m) whereas maximum girth 7.34 cm was recorded in T_6 (*Casuarina* 1.2m×1.2m) followed by 7.18 cm T_1 (*Eucalyptus* 1m×1m) [18]. The *E. tereticornis* height and DBH range varied from 11.20-18.70 m and 8.59-18.13 cm, respectively [19]. The maximum height of 12.55 m was documented in 3018, followed by 12.29 m in P-32, 11.89 m in P-23 and 11.77 m in P-13 and lowest 9.99 m in 413 clone [20]. The maximum height was recorded in Poplar clone L-200-84 (9.98 m) followed by Udai (9.57 m) at Prayagraj [21].

Linear regression model of bole, branches, leaves and above ground biomass of tree is shown in Table 2. The bole linear function showed for height and girth in 2nd year maximum R^2 was 0.969 in T_8: Eucalyptus (1.5m×1.5m) followed by 0.958 in T_6: Casuarina (1.2m×1.2m) and minimum of 0.755 in T_7: Poplar (1.5m×1.5m) whereas a maximum height R^2 of 0.842 was found in 2nd year T_6: Casuarina (1.2m×1.2m) followed by 0.808 in T_4: Poplar (1.2m×1.2m) and minimum of 0.485 in T_3: Casuarina (1m×1m). The bole linear function for grith was maximum R^2 of 0.956 in T_2: Eucalyptus (1m×1m) followed by 0.950 in T_6: Casuarina (1.2m×1.2m) and minimum of 0.597 in T_7: Poplar (1.5m×1.5m). Similarly, height based allometric equations R^2 values for bole 0.94 reported in *E. camaldulensis* biomass [22]. The bole biomass of *C. equisetifolia* regression equation displayed maximum correlation with dbh R^2 = 0.97 [23]. The *E. tereticornis* adjusted R^2 for fitted functions varied from 0.911 to 0.995 for different components [24]. The logarithmic Black willow and eastern cottonwood model that used square of dbh then multiplied by height was the best fitting model (Adj. R^2 = 0.982) for the single tree AGB. Whereas a model that used dbh and total stem height as separate predictors was the best fitting model (Adj. R^2 = 0.954) for eastern cottonwood [25].

The branch's linear function showed for height and grith was maximum R^2 in 2nd year found in T_2: Eucalyptus (1m×1m) 0.947 followed by T_4: Poplar (1.2m×1.2m) 0.838 and minimum in T_9: Casuarina (1.5m×1.5m) 0.709 whereas height was maximum R^2 found in 2nd year in T_2: Eucalyptus (1m×1m) 0.850 followed by T_6: Casuarina (1.2m×1.2m) 0.825 and minimum in T_7: Poplar (1.5m×1.5 m) 0.634. The branch's linear function showed for girth maximum R^2 found in T_2: Eucalyptus (1m×1m) 0.918 followed by T_5: Eucalyptus (1.2m×1.2m) 0.793 and minimum in T_7: Poplar (1.5m×1.5m) 0.382. Similarly, allometric equations R^2 values 0.95 found for height and branch biomass of *E. camaldulensis* [22]. The *C. equisetifolia* regression equation for branches displayed maximum R^2 value of 0.92 [23].

The leaves' linear function showed for height and girth maximum R^2 in 2nd year maximum found in T_9: Casuarina (1.5m×1.5m) 0.903 followed by T_5: Eucalyptus (1.2m×1.2m) 0.861 and minimum in T_1: Poplar (1m×1m) 0.607 whereas height was shown maximum R^2 found in 2nd year in T_2: Eucalyptus (1m×1m) 0.849 followed by T_8: Eucalyptus (1.5m×1.5m) 0.836 and minimum in T_7: Poplar (1.5m×1.5m) 0.260. The leaves' linear function showed for girth maximum R^2 found in 2nd year T_9: Casuarina (1.5m×1.5m) 0.882 followed by T_5: Eucalyptus (1.2m×1.2 m) 0.840 and minimum in T_3: Casuarina (1m×1m) and T_8: Eucalyptus (1.5m×1.5m) 0.409. Similar, result of allometric equations for *E. camaldulensis* for height calculated R^2 values for leaves biomass 0.97 [22].

Table 1. Range of height (m) and girth (cm) of three fast-growing species under HDP

Treatment	Range of height (m)	Range of girth (cm)
T_1: Poplar (1m×1m)	5.1-7.2	9.8-13.8
T_2: Eucalyptus (1m×1m)	5.0-12.5	8.5-21.0
T_3: Casuarina (1m×1m)	3.5-5.9	5.0-8.5
T_4: Poplar (1.2m×1.2 m)	5.3-8.0	10.0-19.5
T_5: Eucalyptus (1.2m×1.2 m)	4.5-9.0	8.0-19.1
T_6: Casuarina (1.2×1.2 m)	2.8-6.1	5.0-10.5
T_7: Poplar (1.5m×1.5 m)	3.8-9.0	6.8-18.5
T_8: Eucalyptus (1.5m×1.5 m)	4.0-9.3	6.5-14.9
T_9: Casuarina (1.5m×1.5 m)	2.5-5.8	3.8-9.8

Table 2. Regression model of Bole, branches, leaves and above ground biomass of fast-growing species under HDP

Treatment	Variable	Parameters	Dry bole biomass	R^2	Dry branches biomass	R^2	Dry leaves biomass	R^2	Above ground biomass	R^2
T_1: Poplar	W=a + bH + cG	a. b. c	-4.20, - 0.026, 0.483	0.905	-0.443, 0.150, 0.012	0.740	-0.338, -0.007, 0.067	0.607	-4.981, 0.117, 0.562	0.912
(1m×1m)	W=a + bH	a, b	-3.847, 1.034	0.641	-0.434, 0.176	0.733	-0.289, 0.140	0.424	-4.570, 1.350	0.687
	W=a + cG	a, c	-4.232, 0.475	0.905	-0.262, 0.061	0.590	-0.346, 0.065	0.607	-4.840, 0.600	0.910
T_2: Eucalyptus	W=a + bH + cG	a. b. c	-4.081, -0.137, 0.60	0.951	-0.249, 0.078, 0.038	0.947	0.014, 0.149, 0.007	0.854	-4.316, 0.090, 0.645	0.976
(1m×1m)	W=a + bH	a, b	-7.858, 1.807	0.708	-0.487, 0.200	0.850	-0.030, 0.172	0.849	-8.376, 2.180	0.763
	W=a + cG	a, c	-4.466, 0.568	0.956	-0.03, 0.056	0.918	0.434, 0.042	0.704	-4.062, 0.667	0.976
T_3: Casuarina	W=a + bH + cG	a. b. c	-1.213, 0.037, 0.239	0.774	-0.086, 0.074, 0.009	0.700	0.091, 0.075, 0.004	0.644	-1.208, 0.186, 0.252	0.835
(1m×1m)	W=a + bH	a, b	-0.714, 0.387	0.485	-0.067, 0.088	0.688	0.099, 0.081	0.642	-0.682, 0.555	0.632
	W=a + cG	a, c	-1.185, 0.253	0.772	-0.030, 0.039	0.494	0.149, 0.033	0.409	-1.066, 0.325	0.805
T_4: Poplar	W=a + bH + cG	a. b. c	-3.02, 0.591, 0.148	0.885	-0.450, 0.139, 0.27	0.838	-0.155, 0.084, 0.009	0.772	-3.624, 0.814, 0.184	0.927
(1.2m×1.2m)	W=a + bH	a, b	-2.388, 0.901	0.808	-0.335, 0.196	0.786	-0.116, 0.103	0.752	-2.838, 1.200	0.857
	W=a + cG	a, c	-2.44, 0.304	0.731	-0.313, 0.064	0.662	-0.072, 0.031	0.550	-2.822, 0.399	0.753
T_5: Eucalyptus	W=a + bH + cG	a. b. c	-3.037, 0.174, 0.314	0.914	-0.027, 0.027, 0.042	0.805	0.067, 0.045, 0.049	0.861	-3.00, 0.246, 0.406	0.925
(1.2m×1.2m)	W=a + bH	a, b	-2.610, 0.790	0.741	0.030, 0.109	0.661	0.134, 0.142	0.731	-2.446, 1.041	0.756
	W=a + cG	a, c	-2.851, 0.378	0.905	0.002, 0.052	0.793	0.116, 0.066	0.840	-2.733, 0.496	0.914
T_6: Casuarina	W=a + bH + cG	a. b. c	-1.295, 0.127, 0.196	0.958	-0.080, 0.111, -0.004	0.826	-0.050, 0.093, 0.026	0.816	-1.425, 0.331, 0.218	0.965
(1.2m×1.2m)	W=a + bH	a, b	-1.389, 0.559	0.842	-0.078, 0.101	0.825	-0.062, 0.151	0.789	-1.529, 0.811	0.892
	W=a + cG	a, c	-1.179, 0.243	0.950	0.021, 0.037	0.641	0.035, 0.061	0.759	-1.123, 0.340	0.937
T_7: Poplar	W=a + bH + cG	a. b. c	-0.570, 0.138, 0.076	0.755	-0.256, 0.091, 0.019	0.712	-0.29, 0.018, 0.036	0.688	-1.114, 0.248, 0.131	0.834
(1.5m×1.5m)	W=a + bH	a, b	-0.025, 0.219	0.507	-0.117, 0.112	0.634	-0.029, 0.057	0.260	-0.171, 0.387	0.568
	W=a + cG	a, c	-0.294, 0.104	0.597	-0.074, 0.038	0.382	-0.252, 0.040	0.667	-0.619, 0.181	0.652
T_8: Eucalyptus	W=a + bH + cG	a. b. c	-2.913, 0.292, 0.271	0.969	-0.072, 0.080, 0.020	0.772	-0.428, 0.231, 0.005	0.837	-3.413, 0.603, 0.296	0.962
(1.5m×1.5m)	W=a + bH	a, b	-2.364, 0.746	0.668	-0.031, 0.114	0.696	-0.418, 0.240	0.836	-2.813, 1.100	0.771
	W=a + cG	a, c	-2.181, 0.350	0.913	0.128, 0.042	0.584	0.152, 0.067	0.409	-1.901, 0.458	0.835
T_9: Casuarina	W=a + bH + cG	a. b. c	-0.519, -0.033,0.185	0.912	-0.115, 0.047, 0.032	0.709	-0.064, 0.048, 0.046	0.903	-0.698, 0.061, 0.262	0.921
(1.5m×1.5m)	W=a + bH	a, b	-0.428, 0.315	0.683	-0.10, 0.106	0.652	-0.041, 0.134	0.811	-0.569, 0.556	0.757
	W=a + cG	a, c	-0.537, 0.171	0.910	-0.09, 0.051	0.681	-0.038, 0.066	0.882	-0.665, 0.287	0.919

Where, a= Intercept; b and c= slope

Table 3. Bole, branches, leaves and AGB (kg tree^{-1}) of three fast-growing species under HDP

Treatment	Bole (kg tree^{-1})	Branches (kg tree^{-1})	Leaves (kg tree^{-1})	AGB (kg tree^{-1})
T_1: Poplar (1m×1m)	1.039	0.582	0.369	1.990
T_2: Eucalyptus (1m×1m)	2.801	0.868	1.277	4.946
T_3: Casuarina (1m×1m)	0.471	0.318	0.468	1.256
T_4: Poplar (1.2m×1.2m)	2.885	0.830	0.517	4.233
T_5: Eucalyptus (1.2m×1.2m)	1.564	0.613	0.904	3.089
T_6: Casuarina (1.2m×1.2m)	0.719	0.408	0.572	1.699
T_7: Poplar (1.5m×1.5m)	1.085	0.482	0.222	1.797
T_8: Eucalyptus (1.5m×1.5m)	1.723	0.637	1.072	3.431
T_9: Casuarina (1.5m×1.5m)	0.520	0.291	0.436	1.236
S Em ±	0.08	0.01	0.02	0.11
CD (0.05)	0.25	0.04	0.06	0.33
CV %	10.01	4.46	5.15	7.27

The AGB linear function showed for height and girth of maximum R^2 in 2nd year maximum found in T_2: Eucalyptus (1m×1m) 0.976 followed by T_6: Casuarina (1.2m×1.2 m) 0.965 and minimum in T_7: Poplar (1.5m×1.5 m) 0.834 whereas height shown maximum R^2 found in 2nd year maximum in T_6: Casuarina (1.2m×1.2m) 0.892 followed by T_4: Poplar (1.2m×1.2m) 0.857 and minimum in T_7: Poplar (1.5m×1.5m) 0.568. The AGB linear function showed for girth maximum R^2 found in 2nd year T_2: Eucalyptus (1m×1m) 0.976 followed by T_6: Casuarina (1.2m×1.2m) 0.937 and minimum in T_7: Poplar (1.5m×1.5m) 0.652. Similarly, allometric equations R^2 value was reported the maximum under Poplar 1.5m×1.5m spacing in height based and girth-based regression model for one year of plantation [13]. The AGB of *E. tereticornis* adjusted R^2 for fitted functions varied from 0.911 to 0.995 [24]. The R^2 0.982 for equation of AGB of Black willow and R^2 0.954 for eastern cottonwood are logarithmic model that used square of DBH and height [25].

The bole biomass (kg tree^{-1}) maximum found after 2nd year T_4: Poplar (1.2m×1.2m) 2.885 kg tree^{-1} followed by T_2: Eucalyptus (1m×1m) 2.801kg tree^{-1} and minimum in T_3: Casuarina (1m×1m) 0.471kg tree^{-1} whereas branch biomass maximum found in T_2: Eucalyptus (1×1m) 0.868 kg tree^{-1} followed by T_4: Poplar (1.2m×1.2m) 0.830 kg tree^{-1} and minimum in T_9: Casuarina (1.5m×1.5m) 0.291kg tree^{-1}. The leaves biomass maximum found in 2nd year maximum found in T_2: Eucalyptus (1m×1m) 1.277 kg tree^{-1} followed by T_8: Eucalyptus (1.5m×1.5m) 1.072 kg tree^{-1} and minimum in T_7: Poplar (1.5m×1.5m) 0.222 kg tree^{-1} whereas AGB maximum in T_2: Eucalyptus (1m×1m) 4.946 kg tree^{-1} followed by T_4: Poplar (1.2m×1.2m) 4.233 kg tree^{-1} minimum in T_9: Casuarina (1.5m×1.5m) 1.236 kg tree^{-1} shown in Table 3.

Similarly, result was reported in *E. tereticornis* dry bole, branches, leaves and AGB 67.64, 5.17, 4.33 and 77.15 kg tree^{-1} respectively in a plantation of four years [19]. The above-ground biomass production (kg tree^{-1}) was *Eucalyptus tereticornis* 24.1 >*A. excelsa* 21.8 >*M. azedarach* 12.6 >*Populus deltoides*c lone G 48 8.3 >*Alstonia scholaris* 6.6> *Pongamia pinnata* 3.7 [26]. The Poplar biomass was reported higher in agroforestry trees (1,223 kg tree^{-1}) than in monoculture plantation trees (1,102 kg tree^{-1}) [27]. The AGB maximum were found in T_2: Eucalyptus (1m×1m) 0.676 kg tree^{-1} followed by T_5: Eucalyptus (1.2m×1.2m) 0.598 kg tree^{-1} and minimum in T_9: Casuarina (1.5×1.5m) 0.214 kg tree^{-1} after one year [13]. Individual tree growth and biomass were higher at wider spacing whereas, the total biomass per stand was higher with closer spacing [28].

4. CONCLUSION

Among the three fast growing tree species Eucalyptus (1m×1m) spacing shows maximum height, girth and biomass. Hence after two years of study Eucalyptus (1m×1m) spacing showed better growth and biomass production, so this spacing is recommended. Among all the species and spacing the regression equation of bole, branches, leaves and AGB height and girth-based model was most suitable equation for estimation and prediction of biomass. Evaluation of biomass prediction equation on the criteria of coefficient of determination (R^2) estimated that multi-variable (including both the growth characteristics *viz.,* H and G) linear functions are much more precision and accuracy.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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