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Growth and Biomass Models for Three Fast-growing Tree Species under High-density Plantation

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Authors' contributions

This work was carried out by author BKS under the supervision of author AT. Both authors read and approved the final manuscript.

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ABSTRACT

Three fast-growing trees, viz., Populus deltoides, Eucalyptus spp. and Casuarina equisetifolia were studied, in high-density plantation at Padilla, Prayagraj, Uttar Pradesh with following treatments viz., T1: Poplar (1×1m), T2: Eucalyptus (1×1m), T3: Casuarina (1×1m), T4: Poplar (1.2×1.2 m), T5: Eucalyptus (1.2×1.2 m), T6: Casuarina (1.2×1.2 m), T7: Poplar (1.5×1.5 m), T8: Eucalyptus (1.5×1.5 m) and T9: Casuarina (1.5×1.5 m). The experiment was established in year July 2021 and data was collected in June 2022. The result indicate the maximum height was recorded in T2: Eucalyptus (1×1 m) 3.81 m followed by T5: Eucalyptus (1.2×1.2 m) 3.78 m, T8: Eucalyptus (1.5×1.5 m) 3.40 m which was at par with each other and minimum in T9: Casuarina (1.5×1.5 m) 2.42 m whereas the maximum girth was found in T4: Poplar (1.2×1.2 m) 6.91 cm followed by T2: Eucalyptus (1×1 m) 6.61 cm, T5: Eucalyptus (1.2×1.2 m) 6.16 cm, T1: Poplar (1×1 m) 5.91 cm which was at par with each other and minimum in T9: Casuarina (1.5×1.5 m) 3.22 cm after one year. Various linear function was attempted to predict biomass based on GBH (G) and Height (H). Prediction accuracy of Height, girth model was slightly better than the height and girth model. Linear model (Y=a + bH + cG), where Y denotes dependent variable (biomass) and H and G denotes independent variable (Height or Girth), performed better (than the remaining tested models) in

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terms of estimation precision and prediction accuracy. The AGB was maximum was found in T2: Eucalyptus (1×1m) 0.676 kg tree-1 followed by T5: Eucalyptus (1.2×1.2 m) 0.598 kg tree-1 and minimum in T9: Casuarina (1.5×1.5 m) 0.214 kg tree-1. After completion of one year Eucalyptus (1×1 m) showed best growth among all treatments.

Keywords: Growth; biomass; linear model; fast-growing tree species; high-density plantation.

1. INTRODUCTION

Fast-growing species to assess productivity thresholds looked to be particularly apparent following the large establishment of wood plantations in developing countries, with the main objective of delivering as much wood as possible in a short length of time [1]. Over the world, efforts are being made to establish plantations of fast-growing tree species as a means of achieving objectives like boosting the wood-based industry's demand for timber [2,3].

High-density plantation systems have the advantages of higher yield and production per unit area [4]. High-density planting, a novel cultivation technique, enables the accommodation of more plants per unit space than is possible with conventional planting density [5]. High-density plantations allow for the planting of more trees in a smaller space, increasing productivity per unit area. High-density plantations are built to provide raw materials and fuelwood for the industries.

Regression methods can be used to determine an allometric relationship between tree dimension and biomass [6]. For both practical forestry difficulties and scientific reasons, it is crucial to quantify the biomass of trees and forests. The interest in using biomass and the worth of trees and forests has increased with the rising economic value of wood, bark, roots, and leaves [7]. Biomass is crucial for research into the productivity of ecosystems, energy flow, and dynamics of nutrients and carbon, in addition to being used for commercial purposes [8]. Also, the standing biomass indicates the tree potential production and gives a sense of the types of products that can be harvested. For individual tree growth models, the tree biomass models may be crucial. Many allometric models exist in different parts of the world that link biomass to tree dimensions [6,9,10].

2. MATERIALS AND METHODS

The experiment was established at Padilla, Prayagraj in year 2021 and the data was collected after one year in June 2022. The GPS location of site longitude (25.54° N) and latitude (81.89° E). The experiment was conducted for evaluation of growth performance of three fast-growing tree species under high-density plantation. In this experiment three fast growing species *viz.,* Poplar (*Populus deltoides*), Eucalyptus (*Eucalyptus spp.*) and Casuarina (*Casuarina equisetifolia*) was established in randomized block design (RBD) with 9 treatments and 3 replication with following treatments *viz.,* T_1: Poplar (1×1m), T_2: Eucalyptus (1×1m), T_3: Casuarina (1×1m), T_4: Poplar (1.2×1.2 m), T_5: Eucalyptus (1.2×1.2 m), T_6: Casuarina (1.2×1.2 m), T_7: Poplar (1.5×1.5 m), T_8: Eucalyptus (1.5×1.5 m) and T_9: Casuarina (1.5×1.5 m).

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

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

Weighing at the stem was done on the twenty selected trees [11]. To reduce root damage, a few carefully chosen trees were chopped down. To make estimating biomass easier, the stem was cut into logs and split 20 cm above the ground. 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. Dry matter content was calculated by using the formula:

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

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.

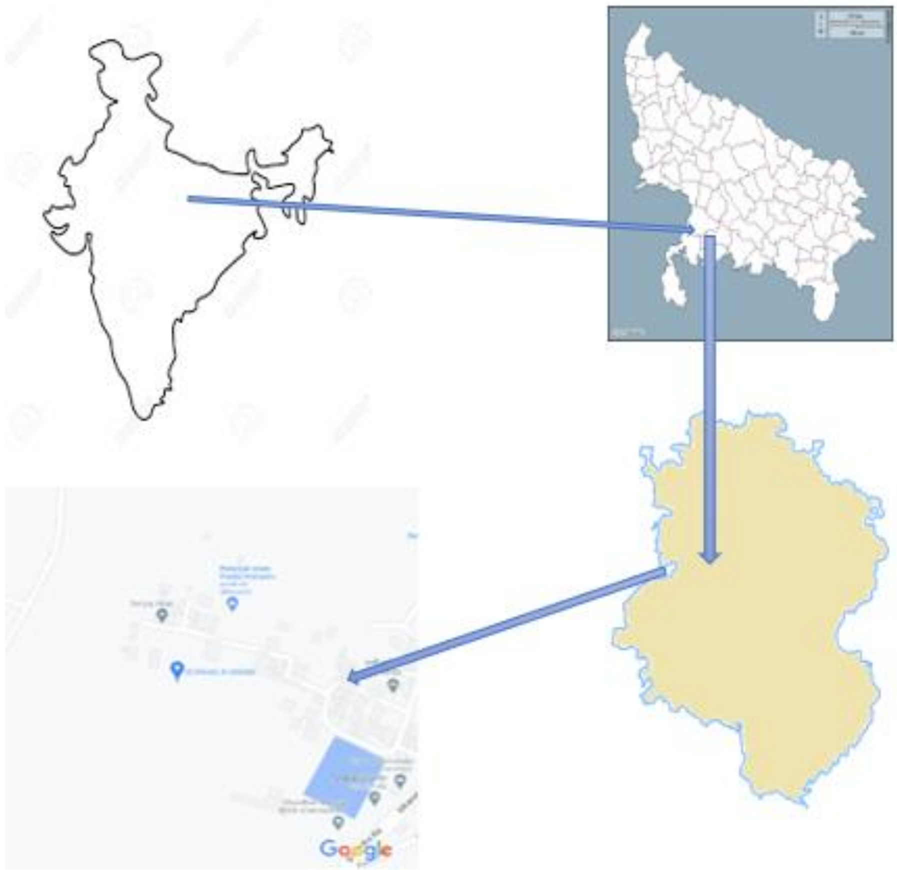

Fig. 1. Map of study site

2.2 Total Stem Dry Weight (kg)

The total fresh weight of the stem part was multiplied by the dry matter content to obtain the total dry weight using the following equation:

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

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

The branch biomass in the absence of leaves was calculated for twenty randomly selected trees. After the branches were cut off from the shoots, they were promptly weighed in the field using an electronic scale to determine their present weight. Three randomly selected branch samples from different parts of were dried in an oven (100±2 ^{0}C) to determine the oven dry weight of the branch biomass. The weight achieved remained consistent. Dry matter content was calculated by using the formula:

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

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 total fresh weight of each tree branch was multiplied by the dry matter content using the following calculation to determine the total branch dry weight:

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

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

The chosen trees' leaves were separated from their branches in the field, and the newly weighted leaves were then immediately weighed using an electronic balance there. Four representative leaf samples were dried until the leaf biomass achieved a constant weight in an oven set at 70±2 ^{0}C. Leaves dry matter content was calculated by using the following formula:

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

Where:
DL_1, DL_2, DL_3, DL_4 = Dry weight of branch one, two, three and four respectively.

FL_1, FL_2, FL_3, FL_4 = Fresh weight of branch one, two, three and four respectively.

2.6 Total Leaves Dry Weight (kg)

Using the following calculation, the fresh weight of each tree's leaves was multiplied by the amount of dry matter in each tree to determine total leaf dry weight:

Total leaves dry weight = Total leaves fresh weight × Branch 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 Biomass Expansion Factor (BEF)

The BEF was calculated by Above ground biomass divided by the bole biomass [12].

$$BEF = \frac{Above\ ground\ biomass\ (Bole + branches + leaves\ biomass)}{Bole\ biomass}$$

2.9 Statistical Analysis

Randomly selected the tree for calculation of biomass. After measurement, calculation of green and dry biomass of wood, branches and leaves. MS-Excel and online software WASP, OPSTAT statistical software was used for computation of descriptive statistics and appropriate of linear models. The best tree biomass models were evaluated using twenty-seven distinct equations (Table 2) in an effort to determine their estimation accuracy using the coefficient of determination, or R^2 [13,14,15].

3. RESULTS AND DISCUSSION

The maximum height was found after one year (2022) in T_2: Eucalyptus (1×1m) 3.81 m followed by T_5: Eucalyptus (1.2×1.2 m) 3.78 m, T_4: Poplar (1.2×1.2 m) 3.53 m which was at par with each other and minimum in T_9: Casuarina (1.5×1.5 m) 2.42 m whereas the maximum girth was found after one year (2022) in T_4: Poplar (1.2×1.2 m) 6.91 cm followed by T_2: Eucalyptus (1×1m) 6.61 cm and minimum in T_9: Casuarina (1.5×1.5 m) 3.22 cm shown in Table 1. Similarly, the maximum height was found in the first year was found in T_2 (3.76 m; *Casuarina* 1 × 1 m) followed by T_6 (3.66 m; *Casuarina* 1.2 × 1.2 m) whereas maximum girth was found in T_6 (7.34 cm; *Casuarina* 1.2 × 1.2 m) followed by T_1 (7.18 cm; *Eucalyptus* 1 × 1 m) [16]. The maximum height was documented in 3018 (12.55 m), followed by P-32 (12.29 m), P-23 (11.89 m) and P-13 (11.77 m) and lowest in clone 413 (9.99 m), 288 (9.95 m) and 2136 (9.28 m) [17]. The maximum height was recorded in Poplar clone L-200-84 (9.98 m) followed by Udai (9.57 m) at Prayagraj [18]. The growth performance of 20 clones of Eucalyptus on parameters height and DBH. The height range varied from 18.5 to 23.6 m whereas DBH varied 11.47 to 16.07 cm [19].

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

Treatment	Height (m)	Girth (cm)
T_1: Poplar (1×1m)	3.19^{cd}	5.91^{cd}
T_2: Eucalyptus (1×1m)	3.81^{a}	6.61^{ab}
T_3: Casuarina (1×1m)	2.70^{ef}	3.42^{e}
T_4: Poplar (1.2×1.2 m)	3.53^{ab}	6.91^{a}
T_5: Eucalyptus (1.2×1.2 m)	3.78^{a}	6.16^{bc}
T_6: Casuarina (1.2×1.2 m)	2.68^{ef}	3.53^{e}
T_7: Poplar (1.5×1.5 m)	2.91^{de}	5.57^{d}
T_8: Eucalyptus (1.5×1.5 m)	3.40^{bc}	5.63^{d}
T_9: Casuarina (1.5×1.5 m)	2.42^{f}	3.22^{e}
S Em	0.10	0.16
CD (0.05)	0.29	0.48
CV %	5.23	5.31

Means followed by the letter are not significantly different at a 5% probability level

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	-0.154, 0.096, 0.018	0.874	0.089, 0.008, -0.009	0.317	0.220, 0.001, -0.023	0.370	0.153, 0.105, -0.013	0.841
(1×1m)	W=a + bH	a, b	-0.043, 0.095	0.839	0.036, 0.008	0.136	0.080, 0.002	0.003	0.072, 0.106	0.799
	W=a + cG	a, c	0.160, 0.012	0.018	0.113, -0.009	0.200	0.222, -0.023	0.370	0.495, -0.019	0.031
T_2: Eucalyptus	W=a + bH + cG	a. b. c	-0.188, 0.041, 0.057	0.773	-0.060, -0.001, 0.023	0.526	-0.069, 0.009, 0.042	0.651	-0.318, 0.049, 0.122	0.776
(1×1m)	W=a + bH	a, b	0.124, 0.056	0.083	0.069, 0.004	0.002	0.160, 0.020	0.018	0.353, 0.080	0.040
	W=a + cG	a, c	-0.055, 0.058	0.727	-0.065, 0.023	0.526	-0.040, 0.042	0.648	-0.160, 0.124	0.761
T_3: Casuarina	W=a + bH + cG	a. b. c	-0.033, 0.006, 0.032	0.456	0.016, -0.002, 0.005	0.548	0.002, 0.0034, 0.025	0.599	-0.014, 0.007, 0.062	0.672
(1×1m)	W=a + bH	a, b	0.050, 0.024	0.076	0.028, 0.001	0.010	0.065, 0.018	0.092	0.143, 0.043	0.099
	W=a + cG	a, c	-0.022, 0.033	0.458	0.013, 0.004	0.526	0.008, 0.026	0.596	-0.0003, 0.063	0.670
T_4: Poplar	W=a + bH + cG	a. b. c	-0.396, 0.082, 0.059	0.714	-0.188, 0.052,0.014	0.947	-0.301, 0.084, 0.024	0.737	-0.884, 0.218, 0.097	0.835
(1.2×1.2 m)	W=a + bH	a, b	-0.065, 0.105	0.424	-0.111, 0.057	0.843	-0.167, 0.093	0.646	-0.342, 0.255	0.652
	W=a + cG	a, c	-0.213, 0.073	0.470	-0.071, 0.022	0.294	-0.112, 0.038	0.244	-0.396, 0.133	0.406
T_5: Eucalyptus	W=a + bH + cG	a. b. c	0.081, -0.002, 0.036	0.651	-0.005, 0.026, -0.002	0.507	-0.174, 0.072, 0.020	0.688	-0.096, 0.095, 0.055	0.804
(1.2×1.2 m)	W=a + bH	a, b	0.346, -0.016	0.031	-0.016, 0.026	0.501	-0.029, 0.064	0.495	0.301, 0.075	0.253
	W=a + cG	a, c	0.072, 0.036	0.649	0.098, -0.004	0.044	0.111, 0.014	0.093	0.28, 0.046	0.407
T_6: Casuarina	W=a + bH + cG	a. b. c	0.020, 0.010, 0.014	0.716	-0.048, 0.019, 0.012	0.754	-0.091, 0.027, 0.035	0.779	-0.118, 0.056, 0.061	0.824
(1.2×1.2 m)	W=a + bH	a, b	0.058, 0.014	0.406	-0.018, 0.022	0.632	0.0001, 0.037	0.471	0.040, 0.073	0.548
	W=a + cG	a, c	0.034, 0.017	0.537	-0.022, 0.018	0.345	-0.054, 0.045	0.558	-0.042, 0.080	0.541
T_7: Poplar	W=a + bH + cG	a. b. c	-0.249, 0.099, 0.044	0.743	0.009, 0.020, 0.0003	0.621	-0.010, 0.023, 0.008	0.735	-0.250, 0.143, 0.052	0.884
(1.5×1.5 m)	W=a + bH	a, b	-0.102, 0.141	0.688	0.010, 0.020,	0.621	0.015, 0.030	0.698	-0.078, 0.192	0.834
	W=a + cG	a, c	-0.274, 0.0979	0.578	0.004, 0.011	0.328	-0.016, 0.020	0.537	-0.287, 0.129	0.661
T_8: Eucalyptus	W=a + bH + cG	a. b. c	-0.058, 0.047, 0.025	0.601	0.001, 0.009, 0.008	0.461	-0.057, 0.022, 0.016	0.793	-0.114, 0.077, 0.048	0.734
(1.5×1.5 m)	W=a + bH	a, b	0.002, 0.067	0.505	0.020, 0.015	0.335	-0.017, 0.035	0.608	0.005, 0.116	0.589
	W=a + cG	a, c	0.005, 0.043	0.435	0.013, 0.011	0.386	-0.028, 0.025	0.634	-0.010, 0.079	0.588
T_9: Casuarina	W=a + bH + cG	a. b. c	0.065, 0.011, -0.002	0.676	0.048, 0.0007, -0.006	0.413	0.110, 0.006, -0.008	0.575	0.223, 0.018, -0.015	0.566
(1.5×1.5 m)	W=a + bH	a, b	0.057, 0.012	0.669	0.023, 0.003	0.173	0.075, 0.010	0.429	0.154, 0.025	0.478
	W=a + cG	a, c	0.118, -0.009	0.273	0.051, -0.006	0.408	0.138, -0.011	0.465	0.307, -0.027	0.399

Where, a and b= Intercept; c= slope

Table 3. Stem, branches, leaves and AGB (kg tree^{-1}) of 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 (1×1m)	0.258^{c}	0.061^{d}	0.087^{e}	0.407^{d}
T_2: Eucalyptus (1×1m)	0.345^{a}	0.088^{a}	0.243^{a}	0.676^{a}
T_3: Casuarina (1×1m)	0.093^{d}	0.028^{f}	0.097^{de}	0.217^{e}
T_4: Poplar (1.2×1.2 m)	0.302^{b}	0.093^{a}	0.162^{c}	0.556^{b}
T_5: Eucalyptus (1.2×1.2 m)	0.295^{b}	0.081^{b}	0.222^{b}	0.598^{b}
T_6: Casuarina (1.2×1.2 m)	0.096^{d}	0.045^{e}	0.105^{d}	0.246^{e}
T_7: Poplar (1.5×1.5 m)	0.286^{b}	0.069^{c}	0.101^{de}	0.456^{c}
T_8: Eucalyptus (1.5×1.5 m)	0.243^{c}	0.077^{b}	0.108^{d}	0.427^{cd}
T_9: Casuarina (1.5×1.5 m)	0.085^{d}	0.030^{f}	0.099^{de}	0.214^{e}
S Em	0.01	0.001	0.01	0.01
CD (0.05)	0.03	0.01	0.02	0.04
CV %	6.77	6.92	6.71	5.98

Means followed by the letter are not significantly different at a 5% probability level

Linear regression model of bole, branches, leaves and above ground biomass of tree was shown in Table 2**.** The regression model for bole biomass maximum R^2 for height and grith was found in T_1: Poplar (1×1m) 0.874 followed by T_2: Eucalyptus (1×1m) 0.773 and minimum in T_3: Casuarina (1×1 m) 0.456. The R^2 for height was maximum found in T_1: Poplar (1×1m) 0.839 followed by T_7: Poplar (1.5×1.5 m) 0.688 and minimum in T_3: Casuarina (1×1 m) 0.076. The R^2 for grith was maximum found in T_2: Eucalyptus (1×1m) 0.727 followed by T_5: Eucalyptus (1.2×1.2 m) 0.649 and minimum in T_1: Poplar (1×1m) 0.018. The branches biomass the R^2 for height and grith was maximum in T_4: Poplar (1.2×1.2 m) 0.947 followed by T_6: Casuarina (1.2×1.2 m) 0.754 and minimum in T_1: Poplar (1×1 m) 0.317. The R^2 for height was maximum found in T_4: Poplar (1.2×1.2 m) 0.843 followed by T_7: Poplar (1.5×1.5 m) 0.621 and minimum in Casuarina (1.5×1.5 m) and T_2: Eucalyptus (1×1m) 0.002. The R^2 for grith was maximum found in T_2: Eucalyptus (1×1m) 0.526; T_3: Casuarina (1×1m) 0.526 followed by T_3: Casuarina (1×1m) 0.408 and minimum in T_5: Eucalyptus (1.2×1.2 m) 0.044. The leaves biomass R^2 for height and grith was maximum in T_8: Eucalyptus (1.5×1.5 m) 0.793 followed by T_6: Casuarina (1.2×1.2 m) 0.779 and minimum in T_1: Poplar (1×1m) 0.370. The R^2 for height was maximum found in T_7: Poplar (1.5×1.5 m) 0.698 followed by T_4: Poplar (1.2×1.2 m) 0.646 and minimum in T_1: Poplar (1×1m) 0.003.

The R^2 for grith was maximum found in T_2: Eucalyptus (1×1m) 0.648 followed by T_8: Eucalyptus (1.5×1.5 m) 0.634 and minimum in T_5: Eucalyptus (1.2×1.2 m) 0.092. The above ground biomass R^2 for height and girth maximum in T_7: Poplar (1.5×1.5 m) 0.884 followed by T_1: Poplar (1×1m) 0.841 and minimum in T_9: Casuarina (1.5×1.5 m) 0.566. The R^2 for height, the maximum found in T_7: Poplar (1.5×1.5 m) 834 followed by T_1: Poplar (1×1m) 0.799 and minimum in T_2: Eucalyptus (1×1m) 0.040. The R^2 for girth maximum found in T_2: Eucalyptus (1×1m) 761 followed by T_3: Casuarina (1×1m) 670 and minimum in T_1: Poplar (1×1m) 0.031. Similarly, finding was reported in allometric equations for *E. camaldulensis* for biomass height calculated R^2 values for bole 0.94 and 0.97 for leaves [20]. *C. equisetifolia* developed regression equation in bole displayed maximum correlation with dbh (R^2 = 0.97 at P> 0.01) and branches 0.95 [21]. *E. tereticornis* adjusted R^2 for fitted functions varied from 0.911 to 0.995 for different components [22].

Table 4. Biomass expansion factor of fast-growing species under HDP

Treatment	BEF
T_1: Poplar (1×1m)	1.58
T_2: Eucalyptus (1×1m)	1.96
T_3: Casuarina (1×1m)	2.34
T_4: Poplar (1.2×1.2 m)	1.84
T_5: Eucalyptus (1.2×1.2 m)	2.02
T_6: Casuarina (1.2×1.2 m)	2.55
T_7: Poplar (1.5×1.5 m)	1.60
T_8: Eucalyptus (1.5×1.5 m)	1.76
T_9: Casuarina (1.5×1.5 m)	2.16

The biomass of bole, branches, leaves and above ground biomass (AGB) was shown in Table 3. The bole biomass (kg tree^{-1}) maximum found after one year (2022) in T_2: Eucalyptus (1×1m) 0.345 kg tree^{-1} followed by T_4: Poplar (1.2×1.2 m) 0.302 kg tree^{-1} and minimum in T_9: Casuarina (1.5×1.5 m) 0.085 kg tree^{-1}. The branches biomass maximum found in T_4: Poplar (1.2×1.2 m) 0.093 kg tree^{-1} followed by T_2: Eucalyptus (1×1m) 0.088 kg tree^{-1} and minimum in T_3: Casuarina (1×1m) 0.028 kg tree^{-1}. The leaves biomass maximum found in T_2:

Table 5. Correlation matrix of height, girth, biomass of stem, branches, leaves and AGB

Parameters	Height	Girth	Bole biomass tree^{-1}	Branches biomass tree^{-1}	Leaves biomass tree^{-1}	ABG tree^{-1}
Height	1.000					
Girth	0.902	1.000				
Bole biomass tree^{-1}	0.880	0.976	1.000			
Branches biomass tree^{-1}	0.909	0.961	0.940	1.000		
Leaves biomass tree^{-1}	0.812	0.611	0.644	0.672	1.000	
ABG tree^{-1}	0.941	0.936	0.960	0.942	0.830	1.000

Eucalyptus (1×1m) 0.243 kg tree^{-1}, followed by T_5: Eucalyptus (1.2×1.2 m) 0.222 kg tree^{-1} and minimum in T_9: Casuarina (1.5×1.5 m) 0.099 kg tree^{-1}.

The AGB was maximum was found in T_2: Eucalyptus (1×1m) 0.676 kg tree^{-1} followed by T_5: Eucalyptus (1.2×1.2 m) 0.598 kg tree^{-1} and minimum in T_9: Casuarina (1.5×1.5 m) 0.214 kg tree^{-1}. Similarly, the highest biomass was found in the first year was found in T_6 (*Casuarina* 1.2 × 1.2 m; 15.51 t ha^{-1}), followed by T_1 (*Eucalyptus* 1 × 1 m; 14.71 t ha^{-1}) and lowest in T_{12} (*Melia* 1.5 × 1.5 m; 0.66 t ha^{-1})[16]. The total assessed AGB production of *E. camaldulensis* coppice is 18.21 t ha^{-1} at 3 years of age [23]. The stems, branches, leaves and total dry biomass after one year growth was the minimum 2.92, 0.86, 1.36 and 5.15 t ha^{-1} [24]. The poplar biomass was higher in agroforestry trees (1,223 kg tree^{-1}) than in monoculture plantation trees (1,102 kg tree^{-1}) [25]. The *P. deltoides* clones, where the total biomass reached from 48.5 Mg ha^{-1} to 62.2 Mg ha^{-1} at Chhattisgarh [26].

The Biomass Expansion Factor (BEF) of fast-growing species under high density plantation are presented in Table 4. The maximum BEF after first year was found in T_6: Casuarina (1.2×1.2 m) 2.55 followed by T_3: Casuarina (1×1m) 2.34 and minimum in T_1: Poplar (1×1m) 1.58. The BEF value for *Ailanthus excelsa* plantation was 1.23 at Uttarakhand [12]. The BEF of 7-year-old Poplar was 1.47 and *E.* hybrid at age of 18, 28 and 30 years 1.93, 1.23 and 1.31 respectively at Punjab [27]. The BEF value of *E. globulus* 0.77 at Portugal reported by Soares and Tome [28].

The correlation matrix of height, girth, biomass of bole, branches, leaves and AGB per tree was showed in Table 5. The height was significantly positively correlated with girth 0.902, bole biomass 0.880, branch biomass 0.909, leaves biomass 0.812 and AGB 0.941. The girth was significantly positively correlated with bole biomass 0.976, branch biomass 0.961, leaves biomass 0.611 and AGB 0.936. The bole biomass was significantly positively correlated with branch biomass 0.940, leaves biomass 0.644 and AGB 0.960. The branches biomass was significantly positively correlated with leaf biomass 0.672 and AGB 0.942. The leaves biomass was significantly positively correlated with AGB 0.830.

4. CONCLUSION

Fast-growing tree species under HDP after one year showed that the maximum height was found in Eucalyptus (1×1m) spacing whereas the maximum girth was found in Poplar (1.2×1.2 m) spacing. The maximum bole, leaves and above ground biomass was found in Eucalyptus (1×1m) spacing whereas branches biomass was maximum in Poplar (1.5×1.5 m) spacing. The biomass expansion factor was maximum found in Casuarina (1.5×1.5 m) spacing. After one year among the three species recommend the Eucalyptus planted in (1×1m) spacing for better growth and biomass production.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. FAO, Fast -growing tree species for industrial plantation in developing countries. Unasylva. 1965;79:19(4). Available:http://www.fao.org/docrep/30280e/30280e02.htm
2. Sedjo RA, The potential of high-yield plantation forestry for meeting timber needs. New For.1999; 17:339–359.
3. McKenney DW, Yemshanov D, Fox G, Ramlal E, Cost estimates for carbon sequestration from fast growing poplar plantations in Canada. For Policy Econ. 2004;6:345–358.
4. Dhiman N. Effect of planting density on growth, yield and fruit quality of apple

(*Malus domestica* Borkh.) cv. Jeromine. (Nauni) Solan (HP): Dr. Yashwant Singh Parmar University of Horticulture and Forestry, 2018. [Google Scholar]

5. Goswami AK, Thakre M, Nagaraja A, Prak ash J, High density planting system in fruit crops. Biotech Articles. 2014:1. [Google Scholar]
6. Keith H, Barrett D Keenan. Review of allometric relationships for estimating woody biomass for New South Wales, the Australian capital territory, victoria, Tasmania, and South Australia. National Carbon Accounting System Technical Report 5B. Australian Greenhouse Office, Canberra. 2000;114.
7. Avery TE, Burkhart HE. Forest measurement, 4 Ed. McGraw-Hill, NY. 1994;408.
8. Parresol BR. Assessing trees and stand biomass: A review with examples and critica1 comparisons. For. Sci.1999;45:573-593.
9. Ter-Mikaelian MT, Korzukhin MD. Biomass equations for sixty-five North American tree species. For. Ecol. Manage. 1997;97:1-24.
10. Zianis D, Muukkonen P, Mäkipä R, Mencuccini M. Biomass and stem volume equations for tree species in Europe. Silv. Fenn. Monogr. 2005:4:63.
11. Nirmal, Ajit, Handa AK. Biomass and volume models for clonal *Eucalyptus tereticornis* coppice under agroforestry systems in central India. Indian Journal of Agroforestry. 2021;23(1):54-60.
12. Giri N, Kumar R, Rawat L, Kumar P. Development of Biomass Expansion Factor (BEF) and estimation of carbon pool in *Ailanthus excelsa* Roxb Plantation. J Chem Eng Process Technol. 2014;5(6):1-4.
Available:http://dx.doi.org/10.4172/2157-7048.1000210
13. Caustion DR. Biometrical, structural and physiological relationship among tree parts. In; Attributes of Trees as Crops Plants (eds. M. G. R., Cannell and J. E. Jackson). Institute of Terrestrial Ecology, Huntingdon. 1985;137159.
14. Feller MC. Generalized versus site-specific biomass regression equations for coastal British Colombia. Bioresource Technology. 1992;39:9-16.;
15. Antonio N, Tome M, Tome J, Soares P, Fontes L. Effects of tree, stand, and sitevariables on the allomtry of *Eucalyptus globulus* tree biomass. Canadian Journal of Forest research. 2007;37:895-906.
16. Singh KB, Tomar A, Khan AF, Beauty K. Growth, biomass and carbon sequestration of fast-growing tree species under high-density plantation in Prayagraj, Uttar Pradesh, India. Current Science. 2022; 122(5):618-622.
17. Srivastav A, Tomar A, Agarwa lYK. Performance of *Eucalyptus* clones in Trans-Ganga region of Uttar Pradesh, India. Indian J. of Agroforestry. 2020 ;22(1):43-47.
18. Tomar A, Srivastav A. Early growth performance of *Populus deltoides* Clones in Prayagraj. Indian Journal of Plant Sciences. 2020;9:31-35.
19. Behera LK, Patel DP, Gunaga RP, Mehta AA, Jadeja DB. Clonal evaluation for early growth performance of Eucalyptus in South Gujarat, India. Journal of Applied and Natural Science. 2016;8(94):2066-2069.
20. Kumar P, Mishra KA, Kumar M, Chaudhari KS, Singh R, Singh K, Rai P, Sharma KD. Biomass production and carbon sequestration of *Eucalyptus tereticornis* plantation in reclaimed sodic soils of north-west India. Indian Journal of Agricultural Sciences. 2019;89(7):1091–1095.
21. Mandal RA, Kumar B, Yadav V, Yadav KK, Dutta IC, Haque SM. Development of allometric equation for biomass estimation of *Eucalyptus camaldulensis*: A study from Sagarnath Forest, Nepal. International Journal of Biodiversity and Ecosystems. 2013;1(1):001-007.
22. Vidyasagaran K, Paramathma M. Biomass prediction of *Casuarina equisetifolia*, forest. Plantations in the west coastal plains of Kerala, India. Ind. J. Sci. Res. and Tech. 2014;2(1):83-89.
23. Wongchai W, Promwungkwa A, Insuan W. Above-ground Biomass allometric equation and dynamics accumulation of *Eucalyptus camaldulensis* and *Acacia* Hybrid Plantations in Northern Thailand. International Journal of Renewable Energy Research. 2020; 10(4):1664- 1673.
24. Singh B, Dhillon GPS, Gill RIS, Kaur J. Biomass production of high density *Leucaena leucocephala* plantation under different levels of nutrients. The Indian Forester. 2019;145(1):34-37.
25. Jha KK. Biomass production and carbon balance in two hybrid poplar (*Populus euramericana*) plantations raised with and

without agriculture in southern France. Journal of Forestry Research. 2018; 29:1689–1701.

26. Swamy SL, Mishra A. Comparison of biomass and c storage in three promising fast growing tree plantations under agroforestry system in sub-humid tropics of Chhattisgarh, India. Universal Journal of Agricultural Research. 2014;2(8):284-296. DOI: 10.13189/ujar.2014.020802
27. Rawat L, Kamboj SK, Kandwa A. Biomass expansion factor and root-to-shoot ratio of some tree species of Punjab, India. The Indian Forester. 2015;141(2):146-153.
28. Soares P, Tome M. Biomass expansion factors for *Eucalyptus globulus* stands in Portugal. Forest Systems. 2012;21(1): 141-152.

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