

## Original Research Article

### **Growth and Biomass models for three fast-growing tree species under High-density Plantation**

#### **Abstract**

Three fast-growing trees, viz., *Populus deltoides* (Poplar), *Eucalyptus spp.* (Eucalyptus) and *Casuarina equisetifolia* (Casuarina) were studied, in high-density plantation at village Padilla, in Prayagraj, Uttar Pradesh with three different spacings, viz., 1×1 m, 1.2×1.2 m and 1.5×1.5 m. The trial was established in year 2021 and data was collected after one year. The maximum height was found after one year in T<sub>2</sub>: Eucalyptus (1×1m) 3.81 m followed by T<sub>5</sub>: Eucalyptus (1.2×1.2 m) 3.78 m, T<sub>8</sub>: Eucalyptus (1.5×1.5 m) 3.40 m which was at par with each other and minimum in T<sub>9</sub>: Casuarina (1.5×1.5 m) 2.42 m whereas the maximum girth was found in T<sub>4</sub>: Poplar (1.2×1.2 m) 6.91 cm followed by T<sub>2</sub>: Eucalyptus (1×1m) 6.61cm, T<sub>5</sub>: Eucalyptus (1.2×1.2m) 6.16 cm, T<sub>1</sub>: Poplar (1×1m) 5.91 cm which was at par with each other and minimum in T<sub>9</sub>: Casuarina (1.5×1.5 m) 3.22 cm. Various (27) linear function were 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 terms of estimation precision and prediction accuracy. The AGB was maximum was found in T<sub>2</sub>: Eucalyptus (1×1m) 0.676kg tree<sup>-1</sup> followed by T<sub>5</sub>: Eucalyptus (1.2×1.2 m) 0.598 kg tree<sup>-1</sup> and minimum in T<sub>9</sub>: Casuarina (1.5×1.5 m) 0.214kg tree<sup>-1</sup>. After completion of one year Eucalyptus (1×1m) showed best growth among all treatments.

**Key words:** Growth, Biomass, Linear model, Fast-growing tree species, High-density plantation

#### **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<sup>1</sup>. 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<sup>2,3</sup>.

High-density plantation systems have the advantages of higher yield and production per unit area<sup>4</sup>. High-density planting, a novel cultivation technique, enables the accommodation of more plants per unit space than is possible with conventional planting density<sup>5</sup>. High-density plantations allow for the planting of more trees in a smaller space, increasing productivity per square foot. To provide fuelwood and raw materials for the industrial process, high-density plantations are built. Forest plantations also provide non-wooden forest products and advantages as a result of the trees planted or other ecosystem characteristics, they aid in establishing.

A proportional change from one part of an organism to another is known as an allometry<sup>6</sup>. Regression methods can be used to determine an allometric relationship between tree dimension and biomass<sup>7</sup>. 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<sup>8</sup>. Forest 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<sup>9</sup>. Also, the standing biomass indicates the forest's potential production and gives a sense of the types of products that can be harvested. For process-based 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<sup>7,10,11</sup>.

### **Material and methods**

The experiment was established at Padilla, Prayagrajin year 2021 and the data was collected after one year (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 T<sub>1</sub>: Poplar (1×1m), T<sub>2</sub>: Eucalyptus (1×1m), T<sub>3</sub>: Casuarina (1×1m), T<sub>4</sub>: Poplar (1.2×1.2 m), T<sub>5</sub>: Eucalyptus (1.2×1.2 m), T<sub>6</sub>: Casuarina (1.2×1.2 m), T<sub>7</sub>: Poplar (1.5×1.5 m), T<sub>8</sub>: Eucalyptus (1.5×1.5 m) and T<sub>9</sub>: 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.

### **Stem biomass (kg tree<sup>-1</sup>)**

Weighing at the stem was done on the twenty selected trees. 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  $100 \pm 2$  0C. Dry matter content was calculated by using the formula:

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

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.

#### **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:

$$\text{Total stem dry weight} = \text{Total stem fresh weight} \times \text{Stem dry matter content (\%)}$$

#### **Branches biomass (kg tree<sup>-1</sup>)**

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 ( $100 \pm 2$  0C) to determine the oven dry weight of the branch biomass. The weight achieved remained consistent. Dry matter content was calculated by using the formula:

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

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.

#### **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:

$$\text{Total branch dry weight} = \text{Total branch fresh weight} \times \text{Branch dry matter content (\%)}$$

#### **Leave biomass (kg tree<sup>-1</sup>)**

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  $70 \pm 2$  °C. Leaves dry matter content was calculated by using the following formula:

$$\text{Leaves Dry matter content (\%)} = \frac{DL_1 + DL_2 + DL_3 + DL_4}{FL_1 + FL_2 + FL_3 + FL_4} \times 100$$

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.

### **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:

$$\text{Total leaves dry weight} = \text{Total leaves fresh weight} \times \text{Branch dry matter content (\%)}$$

### **Above ground biomass (kg tree<sup>-1</sup>)**

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

$$\text{AGB} = \text{Bole biomass} + \text{Branches biomass} + \text{Leaves Biomass}$$

**Biomass expansion factor (BEF):** The BEF was calculated by Above ground biomass divided by the bole biomass<sup>13</sup>.

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

**Statistical analysis:** MS-Excel and online software WASP, OPSTAT statistical software was used for computation of descriptive statistics and appropriate **of linear/non-linear models**. The best **fir** 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  $R^2$  (Ref; 14,15,16).

### **Result 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)<sup>17</sup>. 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)<sup>18</sup>. The maximum height was recorded in poplar clone L-200-84 (9.98 m) followed by Udai (9.57 m) at Prayagraj<sup>19</sup>. 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<sup>20</sup>.

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

Treatment	Height (m)	Girth (cm)
T <sub>1</sub> : Poplar (1×1m)	3.19 <sup>cd</sup>	5.91 <sup>cd</sup>
T <sub>2</sub> : Eucalyptus (1×1m)	3.81 <sup>a</sup>	6.61 <sup>ab</sup>
T <sub>3</sub> : Casuarina (1×1m)	2.70 <sup>ef</sup>	3.42 <sup>e</sup>
T <sub>4</sub> : Poplar (1.2×1.2 m)	3.53 <sup>ab</sup>	6.91 <sup>a</sup>
T <sub>5</sub> : Eucalyptus (1.2×1.2 m)	3.78 <sup>a</sup>	6.16 <sup>bc</sup>
T <sub>6</sub> : Casuarina (1.2×1.2 m)	2.68 <sup>ef</sup>	3.53 <sup>e</sup>
T <sub>7</sub> : Poplar (1.5×1.5 m)	2.91 <sup>de</sup>	5.57 <sup>d</sup>
T <sub>8</sub> : Eucalyptus (1.5×1.5 m)	3.40 <sup>bc</sup>	5.63 <sup>d</sup>
T <sub>9</sub> : Casuarina (1.5×1.5 m)	2.42 <sup>f</sup>	3.22 <sup>e</sup>
SEm	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.

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<sup>2</sup> for height and grith was found in T<sub>1</sub>: Poplar (1×1m) 0.874 followed by T<sub>2</sub>: Eucalyptus (1×1m) 0.773 and minimum in T<sub>3</sub>: Casuarina (1×1 m) 0.456. The R<sup>2</sup>for height was maximum found in T<sub>1</sub>: Poplar (1×1m) 0.839 followed by T<sub>7</sub>: Poplar (1.5×1.5 m) 0.688 and minimum in T<sub>3</sub>: Casuarina (1×1 m) 0.076. The R<sup>2</sup>forgrith was maximum found in T<sub>2</sub>: Eucalyptus (1×1m) 0.727 followed by T<sub>5</sub>: Eucalyptus (1.2×1.2 m) 0.649 and minimum in T<sub>1</sub>: Poplar (1×1m) 0.018. The branches biomass the R<sup>2</sup>for height and grith was maximum in T<sub>4</sub>: Poplar (1.2×1.2 m) 0.947 followed by T<sub>6</sub>: Casuarina (1.2×1.2 m) 0.754 and minimum in T<sub>1</sub>: Poplar (1×1m) 0.317. The R<sup>2</sup>for height was maximum found in T<sub>4</sub>: Poplar (1.2×1.2 m) 0.843 followed by T<sub>7</sub>: Poplar (1.5×1.5 m) 0.621 and minimum in Casuarina (1.5×1.5 m) and T<sub>2</sub>: Eucalyptus (1×1m) 0.002. The R<sup>2</sup>forgrith was maximum found in T<sub>2</sub>: Eucalyptus (1×1m) 0.526; T<sub>3</sub>: Casuarina (1×1m) 0.526 followed by T<sub>3</sub>: Casuarina (1×1m) 0.408 and minimum in T<sub>5</sub>: Eucalyptus (1.2×1.2 m) 0.044. The leaves biomass R<sup>2</sup>for height and grith was maximum in T<sub>8</sub>: Eucalyptus (1.5×1.5 m) 0.793 followed by T<sub>6</sub>: Casuarina (1.2×1.2 m) 0.779 and minimum in

T<sub>1</sub>: Poplar (1×1m) 0.370. The R<sup>2</sup> for height was maximum found in T<sub>7</sub>: Poplar (1.5×1.5 m) 0.698 followed by T<sub>4</sub>: Poplar (1.2×1.2 m) 0.646 and minimum in T<sub>1</sub>: Poplar (1×1m) 0.003.

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**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 <sup>2</sup>	Dry branches biomass	R <sup>2</sup>	Dry leaves biomass	R <sup>2</sup>	Above ground biomass	R <sup>2</sup>
T <sub>1</sub> : Poplar (1×1m)	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
	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 <sub>2</sub> : Eucalyptus (1×1m)	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
	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 <sub>3</sub> : Casuarina (1×1m)	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
	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 <sub>4</sub> : Poplar (1.2×1.2 m)	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
	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 <sub>5</sub> : Eucalyptus (1.2×1.2 m)	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
	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 <sub>6</sub> : Casuarina (1.2×1.2 m)	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
	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 <sub>7</sub> : Poplar (1.5×1.5 m)	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
	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 <sub>8</sub> : Eucalyptus (1.5×1.5 m)	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
	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 <sub>9</sub> : Casuarina (1.5×1.5 m)	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
	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

The  $R^2$  for girth was maximum found in T<sub>2</sub>: Eucalyptus (1×1m) 0.648 followed by T<sub>8</sub>: Eucalyptus (1.5×1.5 m) 0.634 and minimum in T<sub>5</sub>: Eucalyptus (1.2×1.2 m) 0.092. The above ground biomass  $R^2$  for height and girth maximum in T<sub>7</sub>: Poplar (1.5×1.5 m) 0.884 followed by T<sub>1</sub>: Poplar (1×1m) 0.841 and minimum in T<sub>9</sub>: Casuarina (1.5×1.5 m) 0.566. The  $R^2$  for height, the maximum found in T<sub>7</sub>: Poplar (1.5×1.5 m) 834 followed by T<sub>1</sub>: Poplar (1×1m) 0.799 and minimum in T<sub>2</sub>: Eucalyptus (1×1m) 0.040. The  $R^2$  for girth maximum found in T<sub>2</sub>: Eucalyptus (1×1m) 761 followed by T<sub>3</sub>: Casuarina (1×1m) 670 and minimum in T<sub>1</sub>: Poplar (1×1m) 0.031.

The biomass of bole, branches, leaves and above ground biomass (AGB) was shown in table 3. The bole biomass (kg tree<sup>-1</sup>) maximum found after one year (2022) in T<sub>2</sub>: Eucalyptus (1×1m) 0.345kg tree<sup>-1</sup> followed by T<sub>4</sub>: Poplar (1.2×1.2 m) 0.302kg tree<sup>-1</sup> and minimum in T<sub>9</sub>: Casuarina (1.5×1.5 m) 0.085kg tree<sup>-1</sup>. The branches biomass maximum found in T<sub>4</sub>: Poplar (1.2×1.2 m) 0.093 kg tree<sup>-1</sup> followed by T<sub>2</sub>: Eucalyptus (1×1m) 0.088kg tree<sup>-1</sup> and minimum in T<sub>3</sub>: Casuarina (1×1m) 0.028kg tree<sup>-1</sup>. The leaves biomass maximum found in T<sub>2</sub>: Eucalyptus (1×1m) 0.243kg tree<sup>-1</sup>, followed by T<sub>5</sub>: Eucalyptus (1.2×1.2 m) 0.222 kg tree<sup>-1</sup> and minimum in T<sub>9</sub>: Casuarina (1.5×1.5 m) 0.099kg tree<sup>-1</sup>.

**Table 3: Stem, branches, leaves and AGB (kg tree<sup>-1</sup>) of fast-growing species under HDP**

Treatment	Bole (Kg tree <sup>-1</sup> )	Branches (Kg tree <sup>-1</sup> )	Leaves (Kg tree <sup>-1</sup> )	AGB (Kg tree <sup>-1</sup> )
T <sub>1</sub> : Poplar (1×1m)	0.258 <sup>c</sup>	0.061 <sup>d</sup>	0.087 <sup>e</sup>	0.407 <sup>d</sup>
T <sub>2</sub> : Eucalyptus (1×1m)	0.345 <sup>a</sup>	0.088 <sup>a</sup>	0.243 <sup>a</sup>	0.676 <sup>a</sup>
T <sub>3</sub> : Casuarina (1×1m)	0.093 <sup>d</sup>	0.028 <sup>f</sup>	0.097 <sup>de</sup>	0.217 <sup>e</sup>
T <sub>4</sub> : Poplar (1.2×1.2 m)	0.302 <sup>b</sup>	0.093 <sup>a</sup>	0.162 <sup>c</sup>	0.556 <sup>b</sup>
T <sub>5</sub> : Eucalyptus (1.2×1.2 m)	0.295 <sup>b</sup>	0.081 <sup>b</sup>	0.222 <sup>b</sup>	0.598 <sup>b</sup>
T <sub>6</sub> : Casuarina (1.2×1.2 m)	0.096 <sup>d</sup>	0.045 <sup>e</sup>	0.105 <sup>d</sup>	0.246 <sup>e</sup>
T <sub>7</sub> : Poplar (1.5×1.5 m)	0.286 <sup>b</sup>	0.069 <sup>c</sup>	0.101 <sup>de</sup>	0.456 <sup>c</sup>
T <sub>8</sub> : Eucalyptus (1.5×1.5 m)	0.243 <sup>c</sup>	0.077 <sup>b</sup>	0.108 <sup>d</sup>	0.427 <sup>cd</sup>
T <sub>9</sub> : Casuarina (1.5×1.5 m)	0.085 <sup>d</sup>	0.030 <sup>f</sup>	0.099 <sup>de</sup>	0.214 <sup>e</sup>
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.

The AGB was maximum was found in T<sub>2</sub>: Eucalyptus (1×1m) 0.676kg tree<sup>-1</sup> followed by T<sub>5</sub>: Eucalyptus (1.2×1.2 m) 0.598 kg tree<sup>-1</sup> and minimum in T<sub>9</sub>: Casuarina (1.5×1.5 m) 0.214kg tree<sup>-1</sup>. Similarly, the highest biomass was found in the first year was found in T<sub>6</sub> (*Casuarina* 1.2 × 1.2 m; 15.51 t ha<sup>-1</sup>), followed by T<sub>1</sub> (*Eucalyptus* 1 × 1 m; 14.71 t ha<sup>-1</sup>) and lowest in T<sub>12</sub> (*Melia* 1.5 × 1.5 m; 0.66 t ha<sup>-1</sup>)<sup>17</sup>. The total assessed AGB production of *E. camaldulensis* coppice is 18.21 t ha<sup>-1</sup> at 3 years of age<sup>21</sup>. 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<sup>-1</sup> (Ref. 22). The poplar biomass was higher in agroforestry trees (1,223 kg tree<sup>-1</sup>) than in monoculture plantation trees (1,102 kg tree<sup>-1</sup>)<sup>23</sup>. The *P. deltoides* clones, where the total biomass reached from 48.5 Mg ha<sup>-1</sup> to 62.2 Mg ha<sup>-1</sup> at Chhattisgarh<sup>24</sup>.

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<sub>6</sub>: Casuarina (1.2×1.2 m) 2.55 followed by T<sub>3</sub>: Casuarina (1×1m) 2.34 and minimum in T<sub>1</sub>: Poplar (1×1m) 1.58. Similarly, the BEF value for *Ailanthus excelsa* plantation was 1.23 at Uttarakhand<sup>13</sup>. 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<sup>25</sup>. The BEF value of *E. globulus* 0.77 at Portugal reported by Soares and Tome<sup>26</sup>.

**Table 4: Biomass Expansion Factor of fast-growing species under HDP**

Treatment	BEF
T <sub>1</sub> : Poplar (1×1m)	1.58
T <sub>2</sub> : Eucalyptus (1×1m)	1.96
T <sub>3</sub> : Casuarina (1×1m)	2.34
T <sub>4</sub> : Poplar (1.2×1.2 m)	1.84
T <sub>5</sub> : Eucalyptus (1.2×1.2 m)	2.02
T <sub>6</sub> : Casuarina (1.2×1.2 m)	2.55
T <sub>7</sub> : Poplar (1.5×1.5 m)	1.60
T <sub>8</sub> : Eucalyptus (1.5×1.5 m)	1.76
T <sub>9</sub> : Casuarina (1.5×1.5 m)	2.16

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.

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

Parameters	Height	Girth	Bole biomass tree <sup>-1</sup>	Branches biomass tree <sup>-1</sup>	Leaves biomass tree <sup>-1</sup>	ABG tree <sup>-1</sup>
Height	1.000					
Girth	0.902	1.000				
Bole biomass tree <sup>-1</sup>	0.880	0.976	1.000			
Branches biomass tree <sup>-1</sup>	0.909	0.961	0.940	1.000		
Leaves biomass tree <sup>-1</sup>	0.812	0.611	0.644	0.672	1.000	
ABG tree <sup>-1</sup>	0.941	0.936	0.960	0.942	0.830	1.000

## 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.

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