# Growth, biomass and carbon sequestration of fast-growing tree species under high-density plantation in Prayagraj, Uttar Pradesh, India

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**We studied the growth performance of fast-growing trees, viz. *Eucalyptus* spp., *Casuarina equisetifolia*, *Gmelina arborea* and *Melia dubia* in high-density plantation in Prayagraj, Uttar Pradesh, India, with different spacings, viz. 1 × 1 m, 1.2 × 1.2 m and 1.5 × 1.5 m. The experiment was established in July 2019 and data were recorded for the first and second year. In the second year maximum height increment was found in $T_1$ (*Eucalyptus* 1 × 1 m; 3.42 m) followed by $T_5$ (*Eucalyptus* 1.2 × 1.2 m; 3.40 m) and minimum in $T_2$ (*Casuarina* 1 × 1 m; 1.39 m), whereas maximum girth increment was found in $T_1$ (*Eucalyptus* 1 × 1 m; 12.43 cm) followed by $T_9$ (*Eucalyptus* 1.5 × 1.5 m; 10.66 cm) and minimum in $T_6$ (*Casuarina* 1.2 × 1.2 m; 6.46 cm). Maximum biomass 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 minimum in $T_{12}$ (*Melia* 1.5 × 1.5 m; 0.66 t $ha^{-1}$), whereas in the second year maximum biomass was found in $T_1$ (*Eucalyptus* 1 × 1 m; 202.72 t $ha^{-1}$), followed by $T_5$ (*Eucalyptus* 1.2 × 1.2 m; 98.81 t $ha^{-1}$) and minimum in $T_{12}$ (*Melia* 1.5 × 1.5 m; 17.34 t $ha^{-1}$). Carbon stock and carbon sequestration were maximum in the first year in $T_6$ (*Casuarina* 1.2 × 1.2 m) followed by $T_1$ (*Eucalyptus* 1 × 1 m) and minimum in *Melia* (1.5 × 1.5 m), with values of 7.75, 7.35, 0.33 t $ha^{-1}$, and 28.42, 26.96, 1.21 t $ha^{-1}$ respectively. Whereas in the second year maximum was found in $T_1$ (*Eucalyptus* 1 × 1 m) followed by $T_5$ (*Eucalyptus* 1.2 × 1.2 m) and minimum in $T_{12}$ (*Melia* 1.5 × 1.5 m), with values of 101.36, 49.41, 8.67 t $ha^{-1}$, and 371.59, 181.12 and 31.78 t $ha^{-1}$ respectively. Maximum productivity was found in $T_1$ (*Eucalyptus* 1 × 1 m; 188.01 t $ha^{-1}$) followed by $T_5$ (*Eucalyptus* 1.2 × 1.2 m; 89.88 t $ha^{-1}$) and minimum in $T_{12}$ (*Melia* 1.5 × 1.5 m; 16.68 t $ha^{-1}$).**

**Keywords:** Biomass, carbon sequestration, fast-growing trees, high-density plantation.

INDIA is under tremendous pressure to meet the growing demand for wood and wood products, such as pulp and paper. The projected demand by 2020 is a staggering 13.2 million tonnes. The use of paper is directly related to the economic growth of a country[1]. India has large tracts of unused land/wastelands, both in the forest and non-forest areas which could be used for energy-tree plantations. Approximately 68.35 million hectares (M ha) land in the country is under wastelands[2].

High-density plantation (HDP) is defined as planting at a density in excess of that which gives maximum crop yield at maturity if the individual tree grows to its full natural size. Fast-growing wood species have been widely used for plantation forest and community forest, so that sustainability of the wood is more promising[3]. Tree plantations are artificial forests that differ from natural forests in terms of their structure and functions[4]. Afforestation combined with revegetation is the dominant focus for landscape planning designed to promote the recovery of goods and services provided by these ecosystems. Such efforts improve the livelihoods of people in local communities and yield other environmental benefits[5]. Recently, fast-growing species and plantations have been considered to play an important role in overall strategies aimed at mitigating climate change, favouring the progressive shift from a fossil fuel-based economy to a bio-based economy[6,7].

Woody biomass offers major advantages over biomass from pastures and agricultural crops as it has better energy properties and less carbon dioxide ($CO_2$) emissions[8]. Trees play a vital role in mitigating the diverse effects of environmental degradation and increasing $CO_2$ concentration in the atmosphere, and also climate change[9]. Planting high-value agricultural crops is not feasible on degraded community and private lands due to soil moisture and fertility constraints. Establishing high-density woody plantations followed by intensive management serve as the key to utilizing such lands productively.

A HDP experiment was established in July 2019 at Prayagraj, Uttar Pradesh, India. In this experiment four fast-growing species, viz. *Eucalyptus* spp., *Casuarina equisetifolia*, *Gmelina arborea* and *Melia dubia* were planted at different spacings, viz. 1 × 1 m, 1.2 × 1.2 m and 1.5 × 1.5 m.

The experimental design adopted was randomized block design (RBD) with 12 treatments and three replications, viz. $T_1$: *Eucalyptus* (1 × 1 m), $T_2$: *Casuarina* (1 × 1 m), $T_3$: *Gmelina* (1 × 1 m), $T_4$: *Melia* (1 × 1 m), $T_5$: *Eucalyptus* (1.2 × 1.2 m), $T_6$: *Casuarina* (1.2 × 1.2 m), $T_7$: *Gmelina* (1.2 × 1.2 m), $T_8$: *Melia* (1.2 × 1.2 m), $T_9$: *Eucalyptus* (1.5 × 1.5 m), $T_{10}$: *Casuarina* (1.5 × 1.5 m), $T_{11}$: *Gmelina* (1.5 × 1.5 m) and $T_{12}$: *Melia* (1.5 × 1.5 m). The growth performance data were collected for the first and second years.

Girth at breast height (GBH) of standing trees was recorded with a measuring tape at 1.37 m above ground level. The height of standing trees was recorded using a clinometer. Volume of the trees was calculated using the quarter girth formula as follows.

$$V = \left(\frac{g}{4}\right)^2 \times h,$$

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**Table 1.** Height (m), height increment (m), girth (cm) and girth increment (cm) of fast-growing tree species

| Treatment | Treatment combination | Height (m) | | Height increment (m) | Girth (cm) | | Girth increment (cm) |
|---|---|---|---|---|---|---|---|
| | | First year | Second year | | First year | Second year | |
| $T_1$ | *Eucalyptus* (1 × 1 m) | 3.53 | 6.95 | 3.42 | 7.18 | 19.61 | 12.43 |
| $T_2$ | *Casuarina* (1 × 1 m) | 3.76 | 5.15 | 1.39 | 5.61 | 12.49 | 6.88 |
| $T_3$ | *Gmelina* (1 × 1 m) | 2.35 | 5.05 | 2.69 | 5.80 | 14.09 | 8.29 |
| $T_4$ | *Melia* (1 × 1 m) | 2.33 | 5.27 | 2.94 | 5.69 | 15.60 | 9.92 |
| $T_5$ | *Eucalyptus* (1.2 × 1.2 m) | 3.16 | 6.55 | 3.40 | 6.68 | 16.07 | 9.38 |
| $T_6$ | *Casuarina* (1.2 × 1.2 m) | 3.66 | 5.60 | 1.94 | 7.34 | 13.80 | 6.46 |
| $T_7$ | *Gmelina* (1.2 × 1.2 m) | 2.36 | 5.32 | 2.96 | 6.00 | 15.56 | 9.56 |
| $T_8$ | *Melia* (1.2 × 1.2 m) | 1.48 | 4.24 | 2.76 | 3.61 | 11.97 | 8.36 |
| $T_9$ | *Eucalyptus* (1.5 × 1.5 m) | 2.70 | 5.62 | 2.92 | 5.61 | 16.28 | 10.66 |
| $T_{10}$ | *Casuarina* (1.5 × 1.5 m) | 3.27 | 5.68 | 2.41 | 6.04 | 14.23 | 8.19 |
| $T_{11}$ | *Gmelina* (1.5 × 1.5 m) | 1.82 | 4.54 | 2.73 | 5.02 | 14.61 | 9.59 |
| $T_{12}$ | *Melia* (1.5 × 1.5 m) | 1.45 | 3.78 | 2.33 | 3.47 | 12.47 | 9.00 |
| | SE (m) | – | – | 0.42 | – | – | 1.31 |
| | CV | – | – | 27.58 | – | – | 25.07 |

where $V$ is the volume ($m^3$), $g$ the GBH (m) and $h$ is the height of the tree (m).

Aboveground biomass (AGB): To estimate biomass, volume was multiplied by wood density (WD) of the tree and biomass expansion factor (BEF). The stem wood biomass was then 'expanded' to total AGB of the tree, including leaves, twigs, branches, bole and bark using BEF[10]. For this study BFF value of 1.5 was used[11].

$$\text{AGB (t ha}^{-1}\text{)} = \text{Volume (m}^3\text{)} \times \text{WD} \times \text{BEF}.$$

Below Ground Biomass (BGB): This was estimated by multiplying AGB with a factor of 0.26 (ref. 12).

$$\text{BGB (t ha}^{-1}\text{)} = \text{AGB} \times 0.26.$$

Total biomass (TB): This was estimated by adding the biomass values of all components (AGB and BGB)

$$\text{TB (t ha}^{-1}\text{)} = \text{AGB} + \text{BGB}.$$

Productivity ($P$) was estimated as follows

$$P = B_2 - B_1,$$

where $B_1$ is the biomass in the first year and $B_2$ is the biomass in the second year.

The carbon stock of tree was computed by multiplying biomass value with carbon concentration conversion factor value[13] (generally taken as 0.50 t $ha^{-1}$) and the same method adopted for calculation[10,14,15].

$$\text{Carbon stock (t ha}^{-1}\text{)} = \text{TB (t ha}^{-1}\text{)} \times \text{CF},$$

where CF is conversion factor. The carbon stock was then multiplied by 44/12 to estimate $CO_2$ sequestration[15].

Height, height increment, girth and girth increment of the trees were calculated after two years under HDP of fast-growing species (Table 1). The data indicate that maximum height 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 in the second year maximum height was found in $T_1$ (6.95 m; *Eucalyptus* 1 × 1 m) followed by $T_5$ (6.55 m; *Eucalyptus* 1.2 × 1.2 m). Maximum height increment was found in $T_1$ (3.42 m; *Eucalyptus* 1 × 1 m) followed by $T_5$ (3.40 m; *Eucalyptus* 1.2 × 1.2 m) and minimum in $T_2$ (1.39 m; *Casuarina* 1 × 1 m). Maximum girth was found in the first year in $T_6$ (7.34 cm; *Casuarina* 1.2 × 1.2 m) followed by $T_1$ (7.18 cm; *Eucalyptus* 1 × 1 m), whereas in the second year maximum girth was found in $T_1$ (19.61 cm; *Eucalyptus* 1 × 1 m) followed by $T_9$ (16.28 cm; *Eucalyptus* 1.5 × 1.5 m). Maximum girth increment was found in $T_1$ (12.43 cm; *Eucalyptus* 1 × 1 m) followed by $T_9$ (10.66 cm; *Eucalyptus* 1.5 × 1.5 m) and minimum in $T_6$ (6.46 cm; *Casuarina* 1.2 × 1.2 m).

Tree height of *Eucalyptus* varied from 18.5 to 23.6 m with diameter at breast height (DBH) range 11.47–16.07 cm (ref. 16). The highest increment in GBH was recorded in *Eucalyptus* clone P-13 (33.80 cm), followed by P-23 (33.43 cm), P-32 (33.27 cm), 526 (32.68 cm), IFGTB-4 (32.10 cm), 3018 (30.53 cm) and P-50 (29.60 cm), whereas the lowest in P-66 (22.50 cm) and control (20.38 cm)[17]. In similar studies of *G. arborea* at 1 × 1 m spacing, the average height of the plantation was 8.02 m with 10.4 cm collar diameter and 7.10 cm DBH (ref. 18). In three-year-old plantation of *E. tereticornis* at 1 × 1 m spacing, tree height was 550–990 cm and girth 5–35 cm. In the larger (category A) trees, average height was 990 cm and GBH was 29.0 cm (ref. 19). *M. dubia* planting density of 714 trees $ha^{-1}$ having girth and height 46.85 cm, 10.59 m; 50.14 cm, 10.99 m; 52.99 cm, 11.22 m and 55.76 cm, 11.43 m respectively[20]. *E. tereticornis* with

**Table 2.** Volume ($m^3\ ha^{-1}$), total biomass ($t\ ha^{-1}$), carbon stock ($t\ ha^{-1}$) and carbon dioxide sequestration ($t\ ha^{-1}$) of fast-growing tree species

| | | Volume ($m^3\ ha^{-1}$) | | Total biomass ($t\ ha^{-1}$) | | Carbon stock ($t\ ha^{-1}$) | | Carbon dioxide sequestration ($t\ ha^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|
| Treatment | Treatment combination | First year | Second year | First year | Second year | First year | Second year | First year | Second year |
| $T_1$ | *Eucalyptus* (1 × 1 m) | 12.72 | 175.26 | 14.71 | 202.72 | 7.35 | 101.36 | 26.96 | 371.59 |
| $T_2$ | *Casuarina* (1 × 1 m) | 7.42 | 50.97 | 11.63 | 79.95 | 5.82 | 39.98 | 21.32 | 146.55 |
| $T_3$ | *Gmelina* (1 × 1 m) | 5.68 | 65.94 | 4.84 | 56.08 | 2.42 | 28.04 | 8.86 | 102.80 |
| $T_4$ | *Melia* (1 × 1 m) | 6.14 | 98.88 | 4.64 | 74.75 | 2.32 | 37.38 | 8.51 | 137.02 |
| $T_5$ | *Eucalyptus* (1.2 × 1.2 m) | 7.72 | 85.43 | 8.93 | 98.81 | 4.47 | 49.41 | 16.37 | 181.12 |
| $T_6$ | *Casuarina* (1.2 × 1.2 m) | 9.88 | 51.24 | 15.51 | 80.38 | 7.75 | 40.19 | 28.42 | 147.34 |
| $T_7$ | *Gmelina* (1.2 × 1.2 m) | 4.50 | 59.11 | 3.83 | 50.27 | 1.91 | 25.14 | 7.01 | 92.15 |
| $T_8$ | *Melia* (1.2 × 1.2 m) | 0.92 | 28.99 | 0.69 | 21.91 | 0.35 | 10.96 | 1.27 | 40.17 |
| $T_9$ | *Eucalyptus* (1.5 × 1.5 m) | 2.66 | 51.41 | 3.08 | 59.46 | 1.54 | 29.73 | 5.64 | 109.00 |
| $T_{10}$ | *Casuarina* (1.5 × 1.5 m) | 3.44 | 32.33 | 5.39 | 50.71 | 2.70 | 25.36 | 9.88 | 92.95 |
| $T_{11}$ | *Gmelina* (1.5 × 1.5 m) | 1.56 | 31.18 | 1.33 | 26.52 | 0.66 | 13.26 | 2.44 | 48.60 |
| $T_{12}$ | *Melia* (1.5 × 1.5 m) | 0.87 | 22.93 | 0.66 | 17.34 | 0.33 | 8.67 | 1.21 | 31.78 |

**Table 3.** Productivity of fast-growing tree species

| Treatment | Treatment combination | Productivity ($t\ ha^{-1}$) |
|---|---|---|
| $T_1$ | *Eucalyptus* (1 × 1 m) | 188.01 |
| $T_2$ | *Casuarina* (1 × 1 m) | 68.32 |
| $T_3$ | *Gmelina* (1 × 1 m) | 51.25 |
| $T_4$ | *Melia* (1 × 1 m) | 70.11 |
| $T_5$ | *Eucalyptus* (1.2 × 1.2 m) | 89.88 |
| $T_6$ | *Casuarina* (1.2 × 1.2 m) | 64.88 |
| $T_7$ | *Gmelina* (1.2 × 1.2 m) | 46.44 |
| $T_8$ | *Melia* (1.2 × 1.2 m) | 21.22 |
| $T_9$ | *Eucalyptus* (1.5 × 1.5 m) | 56.38 |
| $T_{10}$ | *Casuarina* (1.5 × 1.5 m) | 45.32 |
| $T_{11}$ | *Gmelina* (1.5 × 1.5 m) | 25.19 |
| $T_{12}$ | *Melia* (1.5 × 1.5 m) | 16.68 |

a spacing of 2 × 2 m showed height and DBH of 4.44 m and 4.23 cm respectively, at the age of 5 years; 6.35 m and 5.21 cm respectively, at 6 years; 7.31 m and 6.51 cm respectively, at 7 years, and 9.76 m and 8.68 cm respectively, at the age of 11 years[21]. A *Casuarina* plantation in Karnataka reached 6.9 m in height and 24 cm in diameter in the third year. The height of 3.4 m and diameter of 11 cm was reached in the second year. While in the fourth year, these values were 9.1 m and 36 cm respectively[22]. Mean diameter with respect to age 4, 6, 8 and 10 years of *E. hybrid* plantation in Haryana was 6.9, 9.2, 14.5 and 16.5 cm respectively[23].

Volume of the trees was calculated after two years under HDP of fast-growing species (Table 2). The data indicated that the maximum volume in the first year was found in $T_1$ (12.72 $m^3\ ha^{-1}$; *Eucalyptus* 1 × 1 m) followed by $T_6$ (9.88 $m^3\ ha^{-1}$; *Casuarina* 1.2 × 1.2 m), whereas in the second year maximum volume was found in $T_1$ (175.26 $m^3\ ha^{-1}$; *Eucalyptus* 1 × 1 m) followed $T_4$ (98.88 $m^3\ ha^{-1}$; *Melia* 1 × 1 m). Volume was the highest with *E. benthamii* at 6660 trees $ha^{-1}$ (416.4 $m^3\ ha^{-1}$) and at Paysandú, Western Uruguay, the highest production was obtained with *E. grandis* (370.7 $m^3\ ha^{-1}$) and at densities of 4440 and 6660 trees $ha^{-1}$ (305.9 and 315.3 $m^3\ ha^{-1}$ respectively)[24]. Stand volume of *M. dubia* planting density of 2500 trees $ha^{-1}$ was to be 125.00, 148.33, 165.83 and 189.25 $m^3\ ha^{-1}$ (ref. 20). Volume of standing *Eucalyptus* trees ranged from 0.12 to 0.28 $m^3$, as report by Behera *et al.*[16]. *E. urophylla* plantation had 182 trees $ha^{-1}$, with an average stand volume of 150.12 $m^3\ ha^{-1}$ as documented by Sadono *et al.*[25].

Table 2 shows total biomass of the trees under HDP of fast-growing species. The data indicate that maximum biomass in the first year was found in $T_6$ (15.51 $t\ ha^{-1}$; *Casuarina* 1.2 × 1.2 m), followed by $T_1$ (14.71 $t\ ha^{-1}$; *Eucalyptus* 1 × 1 m) and minimum in $T_{12}$ (0.66 $t\ ha^{-1}$; *Melia* 1.5 × 1.5 m), whereas in the second year maximum biomass was found in $T_1$ (*Eucalyptus* 1 × 1 m) followed by $T_5$ (*Eucalyptus* 1.2 × 1.2 m) and minimum in $T_{12}$ (*Melia* 1.5 × 1.5 m) with values of 202.72, 98.81 and 17.34 $t\ ha^{-1}$ respectively. Four-year-old *E. tereticornis* above-ground dry biomass for individual trees was found to be the highest in agri-silviculture system (107.71 kg $tree^{-1}$), whereas per hectare biomass was 94.84 $t\ ha^{-1}$ (ref. 26). Mean biomass accumulation of *E. urophylla* was 171.76 Mg $ha^{-1}$ in East Nusa Tenggara, Indonesia[25]. AGB of *Melia azedarach* showed fairly high biomass production (38.4 $t\ ha^{-1}$) followed by *Ailanthus excelsa* (27.2 $t\ ha^{-1}$). The order of biomass production (kg/tree) was: *E. tereticornis* (24.1) > *A. excels* (21.8) > *M. azedarach* (12.6) > *P. deltoides* clone G48 (8.3) > *Alstonia scholaris* (6.6) > *Pongamia pinnata* (3.7)[27]. In the three-year-old plantation of *E. tereticornis* total biomass was 44.8 kg $ha^{-1}$ (ref. 19). Five-year-old fuelwood species with planting at the closest spacing (1 × 1 m) gave green biomass yield (81.0 $t\ ha^{-1}$ for *Acacia auriculiformis* and 68.9 $t\ ha^{-1}$ for *Casuarina equisetifolia*[28].

Table 2 shows carbon stock and carbon sequestration under HDP of fast-growing tree species. The data indicated that the first year maximum carbon stock was found in $T_6$ (7.75 $t\ ha^{-1}$; *Casuarina* 1.2 × 1.2 m) followed by $T_1$

**Table 4.** Correlation matrix between volume, biomass, productivity, carbon stock and carbon dioxide sequestration

| | Volume $ha^{-1}$ | Biomass | Productivity | Carbon stock | Carbon dioxide sequestration |
|---|---|---|---|---|---|
| Volume $ha^{-1}$ | 1.000 | | | | |
| Biomass | 0.935 | 1.000 | | | |
| Productivity | 0.950 | 0.998 | 1.000 | | |
| Carbon stock | 0.935 | 1.000 | 0.998 | 1.000 | |
| Carbon dioxide sequestration | 0.935 | 1.000 | 0.998 | 1.000 | 1.000 |

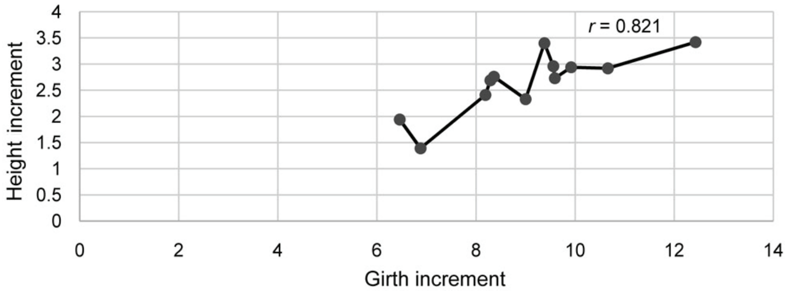


**Figure 1.** Correlation between height increment and girth increment.

(7.35 t $ha^{-1}$; *Eucalyptus* 1 × 1 m), and minimum in $T_{12}$ (0.33 t $ha^{-1}$; *Melia* 1.5 × 1.5 m), whereas maximum carbon sequestration was found in $T_6$ (28.42 t $ha^{-1}$; *Casuarina* 1.2 × 1.2 m) followed by $T_1$ (26.96 t $ha^{-1}$; *Eucalyptus* 1 × 1 m) and minimum in $T_{12}$ (1.21 t $ha^{-1}$; *Melia* 1.5 × 1.5 m). Maximum carbon stock and carbon sequestration in the second year were found in $T_1$ (*Eucalyptus* 1 × 1 m) followed by $T_5$ (*Eucalyptus* 1.2 × 1.2 m) and minimum in $T_{12}$ (*Melia* 1.5 × 1.5 m) with values of 101.36, 49.41, 8.86 t $ha^{-1}$ and 371.59, 181.12 and 31.78 t $ha^{-1}$ respectively. Carbon sequestration in the mature *Eucalyptus* plantation (8 years) varied from 85.3 to 88.7 Mg C ha (ref. 29). Carbon storage in *E. urophylla* plantation was 52.25 Mg $ha^{-1}$ (ref. 25). In five-year-old plantation age, total C storage in *Gmelina arborea* stands ranged from 4.3 to 9.4 Mg $ha^{-1}$, *P. deltoides* from 22.5 to 30.1 Mg $ha^{-1}$ and *Ceiba pentandra* from 4.5 to 10.1 Mg $ha^{-1}$ (ref. 30). The total carbon stock and $CO_2$ sequestration rate in *P. deltoides* varied from 0.89 Mg $ha^{-1}$ and 1.63 Mg $ha^{-1}$ $yr^{-1}$ at two years to 43.54 Mg $ha^{-1}$ and 26.58 Mg $ha^{-1}$ $yr^{-1}$ at 6 years (ref. 31). The above ground carbon stock in *P. deltoides* increased from 0.5 Mg $ha^{-1}$ in the first year to 90.1 Mg $ha^{-1}$ at 11 years. The carbon sequestration rate in mature plantations (7–11 years) varied from 5.8 to 6.5 MgC $ha^{-1}$ $yr^{-1}$ (ref. 32).

Table 3 shows the productivity of fast-growing tree species under HDP. The data indicate that maximum productivity was found in $T_1$ (188.01 t $ha^{-1}$; *Eucalyptus* 1 × 1 m) followed by $T_5$ (89.88 t $ha^{-1}$; *Eucalyptus* 1.2 × 1.2 m) and minimum in $T_{12}$ (16.68 t $ha^{-1}$; *Melia* 1.5 × 1.5 m). A four-year-old *Leucaena leucocephala* plantation with plant spacing of 0.6 × 0.6 m, showed high net primary productivity (33 t $ha^{-1}$ $yr^{-1}$), closely followed by *E. tereticornis* (29 t $ha^{-1}$ $yr^{-1}$)[33]. The net primary productivity of *Eucalyptus* plantation (23.4 t $ha^{-1}$ $yr^{-1}$) was similar to *P. deltoides* plantation (25 t $ha^{-1}$ $yr^{-1}$) and the natural sal forest (22 t $ha^{-1}$ $yr^{-1}$)[34].

The correlation between height increment and girth increment showed significantly positive correlation ($r$ = 0.821) (Figure 1).

Table 4 shows the correlation matrix between volume, biomass, productivity, carbon stock and carbon sequestration in the second year for fast-growing species. Biomass was significantly correlated with volume (0.935), while productivity was significantly correlated with volume (0.950) and biomass (0.998). Carbon stock was significantly correlated with volume (0.935), biomass (1) and productivity (0.998), whereas carbon sequestration was significantly correlated with volume (0.935), biomass (1), productivity (0.997) and carbon stock (1).

Fast-growing tree species under HDP showed that in the first year, among four species, viz. *Eucalyptus*, *Casuarina*, *Gmelina* and *Melia* maximum growth performance (height, girth and biomass) was observed in *Casuarina* at 1.2 × 1.2 m spacing, followed by *Eucalyptus* (1 × 1 m) and minimum in *Melia* (1.5 × 1.5 m). In the second year maximum growth performance (height, girth and biomass) was recorded for *Eucalyptus* for three spacings, viz. 1 × 1 m, 1.2 × 1.2 m and 1.5 × 1.5 m followed by *Casuarina* and minimum in *Melia*. The maximum productivity was found in $T_1$ (*Eucalyptus* 1 × 1 m) followed by $T_5$ (*Eucalyptus* 1.2 × 1.2 m) and minimum in $T_{12}$ (*Melia* 1.5 × 1.5 m). The finding also suggests that performance of *Casuarina* in the first year is best, whereas in the second year *Eucalyptus* performs best among all species.

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