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# Effect of defoliation on tree growth of *Populus deltoides* Bartr. ex Marsh in India

**Arvind Kumar[1,]*, Jitendra Kumar[1] and Girish Chandra[2]**

[1]Forest Entomology Discipline, Forest Protection Division, Forest Research Institute, PO-New Forest, Dehradun 248 006, India
[2]Division of Statistics, Indian Council of Forestry Research and Education, PO-New Forest, Dehradun 248 006, India

**To assess the impact of artificial leaf defoliation of *Populus deltoides* on its different growth parameters, a study was conducted on G-48 clone under field condition and four defoliation treatments, i.e. 25%, 50%, 75% and 100%, were done in addition to control. Defoliation pattern was simulated with insect defoliator *Clostera* spp. feeding and the experiment was conducted from July to December. Significant variation was observed in tree height and DBH growth loss in all the treatments with respect to control, and 24.16–66.03% volume increment loss was observed under 25–100% leaf defoliation respectively.**

**Keywords:** Artificial defoliation, *Clostera* species, growth loss, *Populus deltoides.*

*POPULUS deltoides* Bartr. ex Marsh. (family: Salicaceae), commonly known as poplar or eastern cottonwood, is a native of North America and has been introduced to the temperate world, viz. Europe, Australia and many countries of Southeast Asia[1–5]. *P. deltoides* clones and its hybrids were introduced in India by the Forest Research Institute, Dehradun, Uttarakhand, during 1959 to 1976 and successfully grown in about 2.7 lakh ha farmland in the subtropical regions of the country with a short rotation of 5–8 years[6,7]. *P. deltoides* has become popular among Indian farmers due to its easy propagation, fast-growth, short rotation and suitability for agroforestry. It has been extensively grown by the farmers of the sub-tropical regions of northwestern

*For correspondence. (e-mail: arvind.ento@gmail.com)

**Table 1.** Details of planting, location and other activities related to defoliation experiment conducted on *Populus deltoides*

| Year of plantation | Location | Latitude, longitude | Date of treatment | Date of final observation |
|---|---|---|---|---|
| Two-year-old trees | | | | |
| January 2017 | Saharanpur | 30.02112°N, 77.76756°E | 6 August 2018 | 11 December 2018 |
| January 2017 | Haridwar | 30.05394°N, 77.78084°E | 6 August 2018 | 11 December 2018 |
| January 2017 | Roorkee | 29.88813°N, 77.85355°E | 7 August 2018 | 11 December 2018 |
| January 2018 | Saharanpur | 30.03277°N, 77.77222°E | 1 August 2019 | 9 December 2019 |
| February 2018 | Haridwar | 29.90555°N, 77.99361°E | 2 August 2019 | 9 December 2019 |
| January 2018 | Roorkee | 29.86833°N, 77.95000°E | 2 August 2019 | 9 December 2019 |
| January 2019 | Saharanpur | 29.95542°N, 77.65864°E | 4 August 2020 | 13 December 2020 |
| January 2019 | Haridwar | 29.86590°N, 77.95015°E | 4 August 2020 | 13 December 2020 |
| January 2019 | Roorkee | 29.83813°N, 77.86109°E | 3 August 2020 | 13 December 2020 |
| Three-year-old trees | | | | |
| January 2016 | Saharanpur | 30.12162°N, 77.79754°E | 6 August 2018 | 11 December 2018 |
| January 2016 | Haridwar | 29.95384°N, 77.85181°E | 7 August 2018 | 11 December 2018 |
| February 2016 | Roorkee | 29.85425°N, 77.79325°E | 7 August 2018 | 11 December 2018 |
| January 2017 | Saharanpur | 30.03277°N, 77.77222°E | 1 August 2019 | 9 December 2019 |
| January 2017 | Haridwar | 29.91245°N, 77.96612°E | 1 August 2019 | 9 December 2019 |
| January 2017 | Roorkee | 29.83233°N, 77.91560°E | 2 August 2019 | 9 December 2019 |
| February 2018 | Saharanpur | 30.15542°N, 77.62864°E | 3 August 2020 | 13 December 2020 |
| January 2018 | Haridwar | 29.94654°N, 77.81015°E | 3 August 2020 | 13 December 2020 |
| January 2018 | Roorkee | 28.83813°N, 77.76109°E | 4 August 2020 | 13 December 2020 |

India, viz. Punjab, Haryana, Himachal Pradesh, Uttarakhand and Uttar Pradesh as bund plantation, block plantation and agroforestry have transformed the rural economy[8]. The wood of this species is widely utilized as raw material for pulp and paper industry, plywood, board, match factory, fuelwood, charcoal, pencil, packing cage and artificial limbs industries. It also has importance in fodder, soil and water conservation, etc.[7,9–11]. It has also been successfully introduced in humid subtropical regions of India, viz. Tamil Nadu, Assam, Bihar, Andhra Pradesh and Telangana[7,12–14]. Large scale clonal plantation of poplar represents fast growth, low genetic diversity and distinctive spatial homogeneity, this situation generally favours the outbreak of insect pests[15–19]. *P. deltoides* is susceptible to about 65 insect pests among these, *Clostera* spp. (Lepidoptera: Notodontidae) are the major defoliator insect pests in northwestern India[20,21]. Infestation of *Clostera* spp. defoliator was observed in more than 50% poplar plantations and defoliation ranged from 50% to 100% during July to October, leading to significant growth loss and sometimes tree mortality[22,23]. Tree leaves are the food-production units of the plant; therefore, defoliation adversely impacts tree growth and biomass production in the fast-growing trees[24–26].

To assess the effect of defoliation, simulative artificial defoliation is the most common and effective method[27–29] though, plant defence mechanism responds differently to artificial defoliation than natural insect defoliation[30]. Therefore, greater plant growth reduction was recorded under artificial defoliation in Doglas fir[28]. In contrast, less effect of artificial defoliation was recorded than natural defoliation by beetles in poplar[19]. Nevertheless, many researchers have reported that artificial defoliation is suitable for determining the effects of defoliation on plant growth[27,31–34]. Moreover, the actual effect of defoliation depends on tree species, site, variety and environmental conditions[35]. The artificial leaf defoliation studies conducted in temperate countries on poplar and willow reported that increase in tree growth loss, with an increase in defoliation level, and young trees being more sensitive to the defoliation[27,31,36,37]; while, no such studies have been carried out in the subtropical regions of India. The earlier studies carried out were mainly on potted plants or seedlings and in the temperate countries, which cannot be correlated with the Indian conditions. Therefore, the present study was undertaken to quantify the impact of defoliation in *P. deltoides*, with the hypothesis that defoliation negatively influences tree height and DBH (diameter at breast height) growth.

The study was conducted on G-48 clone planted at the farmer's field in block plantation of two- and three-year-old trees planted at 3 m × 3 m distance in Uttarakhand and Uttar Pradesh at Saharanpur, Haridwar and Roorkee (Table 1). In the study, four artificial defoliation treatments were applied, viz. 25%, 50%, 75% and 100% in addition to control. For 25% defoliation, randomly one leaf was defoliated out of four leaves. Similarly, two leaves for 50%, three for 75% and all for 100% out of four were defoliated (Figure 1). Artificial defoliation was done using an iron nail comb and the mid rib was not removed to simulate the defoliation pattern of *Clostera* spp. larvae. The experiment was designed using randomized block design (RBD) and each treatment was replicated on 10 trees at 3 locations. The experiment was repeated for three years, i.e. 2018, 2019 and 2020, on different sets of trees of the same age group (Table 1). The defoliation treatment was done in August and observations on height and DBH were recorded in the same month (initial observation) just before treatment and in January at the time of natural leaf-fall (final observation). The extent of growth loss was assessed based on tree height and DBH

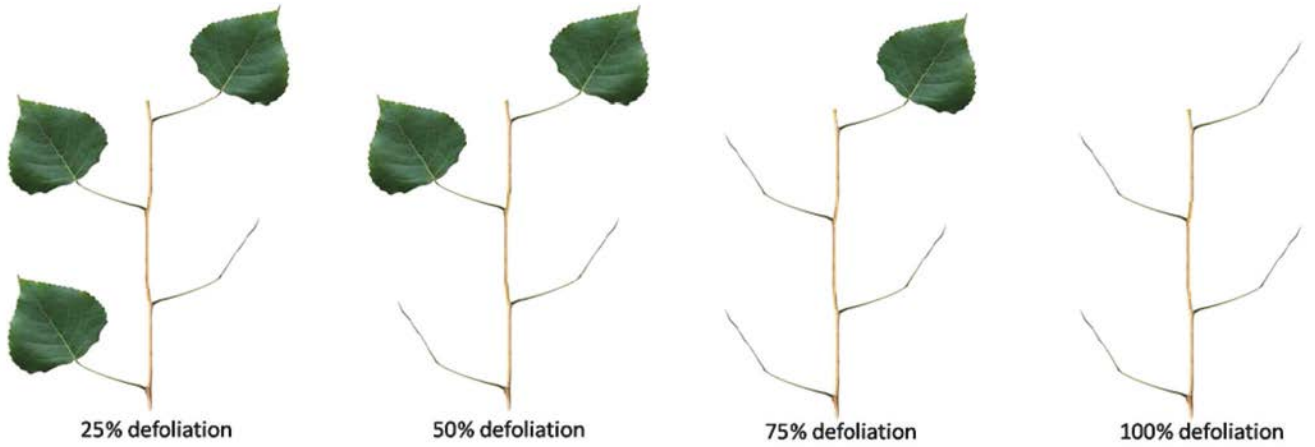


**Figure 1.** Defoliation pattern of the treatment in the field.

growth at different levels of defoliation. The height and diameter of the tree were recorded with the Haga altimeter (for height) and vernier calliper (for DBH).

Based on the height and DBH observations, increment was calculated as follows:

Height increment (%)

$$= \frac{\text{Final height} - \text{Initial height}}{\text{Initial height}} \times 100. \quad (1)$$

DBH increment (%)

$$= \frac{\text{Final DBH} - \text{Initial DBH}}{\text{Initial DBH}} \times 100. \quad (2)$$

Volume increment (%)

$$= \frac{\text{Final volume} - \text{Initial volume}}{\text{Initial volume}} \times 100. \quad (3)$$

On the basis of the above observations, growth (height) reduction due to defoliation was calculated as follows

Height growth reduction (%)

$$= \left[ \frac{\text{Height growth of control tree} - \text{Growth of defoliated tree}}{\text{Height growth of control tree}} \right] \times 100. \quad (4)$$

Similarly, per cent tree DBH growth reduction due to defoliation was estimated as follows

DBH reduction (%)

$$= \left[ \frac{\text{DBH of control tree} - \text{DBH of defoliated tree}}{\text{DBH of control tree}} \right] \times 100. \quad (5)$$

Similarly,

$$\text{Volume loss (\%)} = [(\text{Volume of control tree} - \text{volume of defoliated tree})/\text{volume of control tree}] \times 100. \quad (6)$$

The tree volume was calculated as follows

$$\text{Tree volume} = D \times H, \quad (7)$$

where $D$ is the basal area = $\pi(\text{DBH})^2/4$, and $H$ is the height.

The data were subjected to statistical analysis and Duncan's Multiple Range Test (DMRT) after satisfying the required assumptions of analysis of variance (ANOVA) against RBD design of the experiment to check the significant difference among various treatments for both ages along with the pooled observations. Box plots were drawn for both variables, i.e. increment and loss to identify any outliers or spatial units in the data using SPSS 25.

Results revealed that in two-year-old trees, the tree height increment varied with defoliation levels and 10.85%, 9.42%, 7.63% and 5.41% over control (13.26%) with respect to 25%, 50%, 75% and 100% defoliation level (Figure 2). Similar trend was observed in three-year-old trees and 9.42%, 7.46%, 5.88% and 4.45% increment respectively over control (11.48%). Tree DBH increment was significantly different in all the treatments and exhibited 12.79%, 10.23%, 8.71% and 6.17% over control (16.08%) in two-year-old trees and 11.10%, 8.59%, 7.00% and 5.56% over control (14.02%) in three-year-old trees with respect to the defoliation level. The tree volume increment was significantly different in all the treatments and exhibited 43.28%, 34.78%, 28.34% and 19.52% over control (56.82%), in two-year-old trees and 38.41%, 28.55%, 22.41% and 17.08% over control (50.60%) in three-year-old tees with respect to defoliation level.

The increment loss revealed that tree height significantly decreased with defoliation level over control and height loss was 19.12%, 28.74%, 43.29% and 58.80% in two-year-old

trees and 17.71%, 34.82%, 48.91% and 61.20% in three-year-old trees respectively over control (Figure 3). Similarly, tree DBH increment loss was significantly different and found to be 20.42%, 36.14%, 45.58% and 61.48% in two-year-old trees and 20.57%, 38.58%, 49.91% and 60.19% in three-year-old trees respectively over control. The tree volume increment loss also significantly differed with defoliation level; it was 25.53%, 38.81%, 50.21% and 65.12% in two-year-old trees and 24.16%, 43.35%, 55.59% and 66.03% in three-year-old trees respectively over control ($F = 63.15$, $P < 0.000$ at 5%).

Result of pooled data of both age group revealed that, overall height increment was 10.14%, 8.44%, 6.75% and 4.93% over control (12.37%), under 25%, 50%, 75% and 100% leaf defoliation respectively (Figure 4). Similarly, DBH increment was 11.95%, 9.42%, 7.85%, and 5.86% over control (15.05%) respectively. The pooled data of both age groups revealed that the height increment loss was 18.41%, 31.78%, 46.11% and 60.01% respectively, over control (Figure 5). Similarly, DBH increment loss was 20.49%, 37.35%, 47.75% and 60.84% and overall volume loss was 24.84%, 41.08%, 52.89% and 65.57% respectively, over control. It was observed that only few outliers were coming out of the third interquartile range limit, which shows data has substantial homogeneity under each treatment.

The tree growth increment and its loss in both the age groups were also compared using *t* test. It was found that height, DBH and volume increment loss was non-significantly different with each other with d*f* = 1 and significance level 5% (Table 2).

*P. deltoides* is a fast-growing forestry species, which is substantially defoliated during the insect herbivory period from July to December, but economic loss due to defoliation was not quantified till date in India. In this regard, our findings revealed that, defoliation in *P. deltoides* significantly impact the height, DBH and volume growth. In the study period, 11.48–13.26% increment in height, 14.02–16.08% DBH and 50.60–65.82% volume increment were recorded. Earlier studies suggested that one-year-old poplar trees with a height of 6.63 m and a DBH 6.78 cm attain 54.41% and 130.76% increment and in three-year-old trees with a 15.30 m height and a 16.33 cm DBH attain 68.40% and 240.85% increment in two years in India[4]. Sarsekova[38] reported a height increment of 74.00% and 31.70% and a

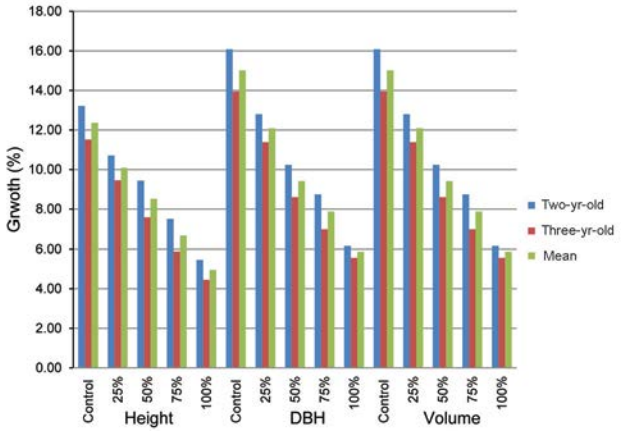


**Figure 2.** Growth increment in *Populus deltoides* due to artificial defoliation.

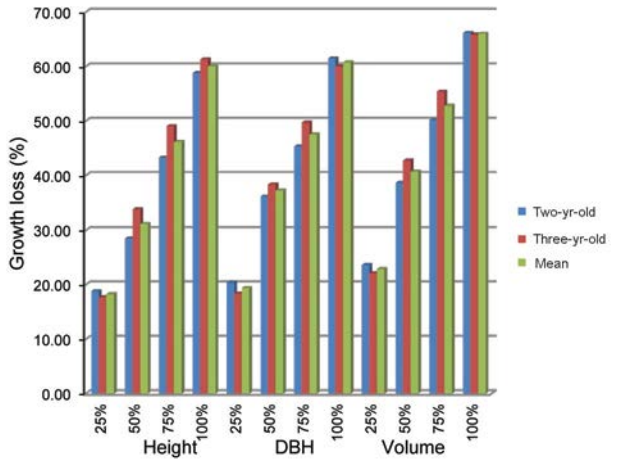


**Figure 3.** Growth loss in *P. deltoides* due to artificial defoliation.

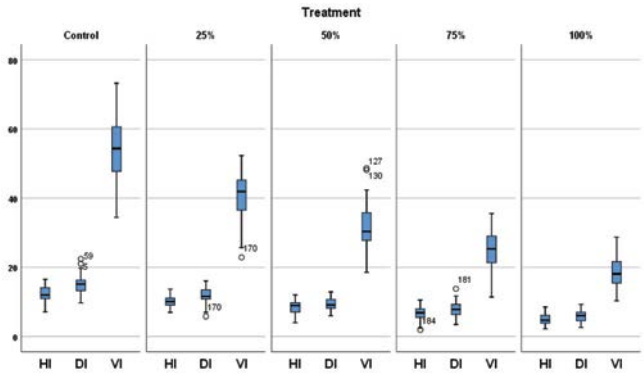


**Figure 4.** Box plot analysis of increment at different treatments (25–100% leaf defoliation) based on pooled data of two age groups. HI, height increment; DI, diameter increment; VI, volume increment.

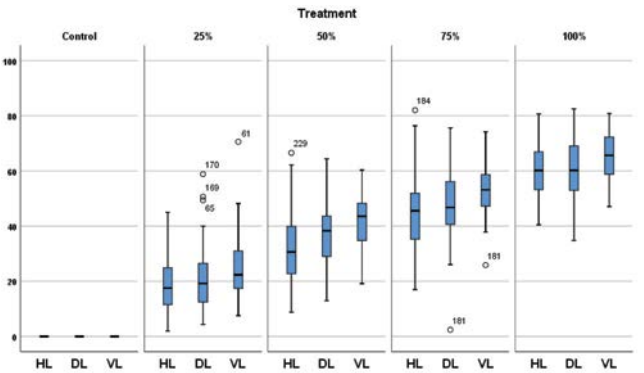


**Figure 5.** Box plot analysis of increment loss at different treatments (25–100% leaf defoliation) based on pooled data of two age groups. HL, Height loss; DL, diameter loss; VL, volume loss.

**Table 2.** Comparative *t* test of different parameters for two-year-old and three-year-old trees

| Dependent variable | Sum of squares | d*f* | Mean square | *F* | *P*-value (at 5%) |
|---|---|---|---|---|---|
| Height increment | 186.93 | 1 | 186.93 | 81.62 | 0.000 |
| Diameter increment | 177.67 | 1 | 177.67 | 51.42 | 0.000 |
| Volume increment | 1977.87 | 1 | 1977.87 | 63.15 | 0.000 |
| Height loss | 483.87 | 1 | 483.87 | 4.85 | 0.028 |
| Diameter loss | 95.15 | 1 | 95.15 | 0.94 | 0.333 |
| Volume loss | 268.63 | 1 | 268.63 | 3.81 | 0.052 |

DBH increment of 115.00% and 31.81% in 2–4-year-old and 4–6-year-old trees respectively.

The infestation of poplar defoliator *Clostera* spp. occurs from July to October in northwestern India. The results of this study indicate that 12.37% height, 15.05% DBH growth and 53.71% volume increment occurs in this duration. Subsequently, a notable negative effect of defoliation on the tree growth has been reported as a result of this study and up to 60.01% height, 60.84% DBH and 65.57% overall volume loss recorded. If we correlate with the recorded natural defoliation caused by *Clostera* spp., i.e. 50–100% (refs 21, 22), we can conclude that there is nearly 52.89–65.57% tree volume loss in northwestern India every year. The tree foliage plays a viral role in its growth, and insect herbivory or human made defoliation influences negatively and significantly decreases the height, diameter and tree volume[39–41]. The results of the present study reveal that the growth rate is significantly greater in two-year-old trees than in three-year-old trees. Subsequently, increment loss is more in two-year-old trees. It was also observed that DBH was more sensitive to defoliation and exhibited more loss than height in both age groups. Overall growth loss in poplar trees increased with an increase in defoliation level and overall volume loss ranged between 24.16% and 66.03%.

Similar studies conducted in pot and nursery experiments in temperate countries reported 20–31% loss in tree height with 75% defoliation in poplar with respect to control[24,29,35,42]. In the present study, poplar trees were more sensitive to defoliation and 46.11% height loss was exhibited, with a 75% level of defoliation in India. Similarly, 23–62% volume loss was reported in *Tectona grandis* at defoliation level of 25–100% in two-year-old plantations[43]. Our findings also reveal that DBH is more sensitive than height, with a 46% reduction in height and 62% in DBH under 100% defoliation, a somewhat similar trend was reported in willows[44].

Thus, it can be concluded from the present study that height, DBH and tree volume increment loss an increase with increase in leaf defoliation level. If we correlate our results with the previous findings, then we may conclude that farmers are loosing 24.16–66.03% economic growth loss each year in poplar, *P. deltoides* farming in northwestern India.

*Conflict of interest:* The authors declare that there is no conflict of interest.


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