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## Sowing time and tree spacing as determinants of wheat growth and poplar performance in a poplar-based agroforestry system

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#### ABSTRACT

A field experiment was conducted at CCS Haryana Agricultural University, Hisar, during rabi 2023–24 to evaluate the effect of poplar (*Populus deltoides*) spacing and wheat sowing time on tree growth and intercropped wheat performance. Three wheat varieties (WH-1105, WH-1184, DBW-187) were sown on four dates under two poplar geometries (4×3 m and 6×3 m) and a sole-crop control in a Factorial Randomized Block Design. Poplar height did not differ significantly between spacings, but girth at breast height and crown spread were significantly greater under wider (6×3 m) spacing, indicating a trade-off between vertical and lateral growth under inter-tree competition. Germination was delayed and plant population reduced under closer spacing due to modified microclimate and root competition, while mid-November sowing produced optimal establishment. Plant height and dry matter accumulation were significantly higher in sole-crop wheat than under poplar at all stages (30–120 DAS), with the closest spacing (4×3 m) consistently recording the lowest values; the gap between control and agroforestry treatments widened progressively through the season, reflecting cumulative light and resource competition. Among varieties, WH 1105 exhibited superior height growth and comparatively greater tolerance to shading, whereas DBW 187 and WH 1184 were most suppressed at early and later growth stages, respectively. Sowing time significantly influenced germination and plant population but not final dry matter. These findings emphasize that wider poplar spacing and optimal sowing timing can substantially minimize competitive effects on wheat growth in agroforestry systems.

**Keywords:** Agroforestry, Growth, Poplar, Spacing, Wheat

#### Introduction

India's cultivated land base has been relatively static at approximately 143 million hectare in spite of the ever-increasing population and the Green Revolution's impact, has resulted in a legacy of degradation and decline in soil fertility and an increased vulnerability to climate change. This has triggered interest in climate-smart and resource-saving land-use systems such as agroforestry which increases the level of soil organic carbon and nutrient (Pardon *et al.*, 2017) [1] and improves soil aggregation and structure in areas covered by trees (Gupta *et al.*, 2009) [2].

Poplar (*Populus deltoides*) has been widely adopted agroforestry species for the Indo-Gangetic plains due to its fast-growing nature, deciduous behavior, its capacity to tolerate pruning, and its ability to intercrop with cereal crops offering significantly higher profits to farmers than sole-crop (Chavan *et al.*, 2019) [3]. The poplar species have also shown significant contribution to carbon sequestration in the long-term (Chavan *et al.*, 2023) [4] and optimize overall land-use return using boundary and block plantation methods (Chavan *et al.*, 2022) [5].

However, the benefit of using poplar based agroforestry to wheat intercropping has a strong dependence on the age and spacing of the trees. A study carried out on wheat intercropped under *Populus deltoides* at Punjab reported that a 23.3% decrease in wheat yield under three-year-old plantation with a significant relationship between poplar girth increment and wheat yield reduction even though, the pruning of poplar following the third year allowed partial recovery (Rahlan *et al.*, 1992) [6]. Tree spacing has been considered as a major factor for managing the competition between the crop and the tree as seen from a two-year's field trial in Haryana conducted to evaluate wheat grain yield and determine the effect on plant growth under various geometrical spacing of poplar ranging from 3 m × 3 m to 8 m × 3 m and as the distance between trees increases wheat grain yield increased progressively while the closest geometry recorded a 44-46% and 39% decrease in wheat grain and straw, respectively, compared to the sole-crop control but, the widest geometry reduced the difference considerably (Kumar *et al.*, 2024) [7].

Sowing time is equally important as a management practice since the delayed sowing reduces the germination, tillering, plant population, and dry matter accumulation of wheat mainly due to unfavorable temperature conditions during the early growth stages. However, these effects are modified by the presence of poplar canopies particularly due to its deciduous characteristic; as the tree loses its leaves in the winter season and

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flushes them in the early spring season, early sown wheat can fully utilize the high-light period before the new canopy development while, the competition for late sown wheat intensifies with the active growth of the canopy further reducing the plant stand and plant growth.

Despite individual evidence on spacing effects (Kumar *et al.*, 2024) [7] and tree-age (Rahhan *et al.*, 1992) [6], the interactions between sowing time and poplar spacing along with the poplar's own growth behavior within the entire duration of the cropping cycle, were scarcely studied. Therefore, this study aimed to (i) evaluate poplar growth performance from pre-sowing (November 2023) to post-harvest (April 2024) of wheat and (ii) assess the effect of sowing time on wheat germination, plant population, and growth (plant height, dry matter accumulation) under varied spacing of poplar.

## 2. Materials and Methods

The present research was conducted in the Department of Forestry, CCS Haryana Agricultural University, Hisar (29°10' N, 75°43' E; 215.2 m amsl) located in the dry, subtropical monsoon zone of north-western India, where approximately 90% of the cultivated area is irrigated with canal or tube-well water. The experiment was conducted in an existing plantation of poplar (*Populus deltoides*), established in February 2017, with wheat (*Triticum aestivum*) intercropped during the rabi season of 2023–24 under two poplar spacing geometries (4 m × 3 m and 6 m × 3 m) and a sole-crop (tree-free) control. Three wheat varieties (WH-1105, WH-1184, and DBW-187) were sown at four dates — late October (28th), mid-November (14th), late November (29th), and mid-December (13th) — in rows 20 cm apart at a seed rate of 100 kg/ha under sole-crop and 125 kg/ha under the agroforestry system. The experiment used a Factorial Randomized Block Design with three replications.

Standard cultural practices were followed throughout the experiment. The seedbed was prepared by two ploughings with a disc harrow and one with a cultivator followed by planking after pre-sowing irrigation. A standard fertilizer dose of 150 kg N, 60 kg P<sub>2</sub>O<sub>5</sub>, 50 kg K<sub>2</sub>O, and 10 kg ZnSO<sub>4</sub> per hectare was applied, with half the nitrogen and the full phosphorus and potassium doses at sowing and the remaining ni-

trogen top-dressed as urea after the first irrigation. Five irrigations were conducted at recommended critical growth stages. Crops were hand-harvested with a sickle at 19–20% grain moisture and harvested in the morning to limit shattering losses and sun-dried for 3–4 days before threshing.

Poplar growth parameters, viz. girth at breast height (measured at 1.37 m by a measuring tape), tree height (measured with an altimeter), and canopy spread (mean of north–south and east–west crown measurements), were recorded before sowing and after wheat harvest. Wheat growth was evaluated by days to germination, plant population per square meter at 20 days after sowing (DAS) (recorded using a 1 × 1 m quadrant), plant height (measured on ten randomly tagged plants per plot at 30, 60, 90, and 120 DAS), days to 50% heading and days to maturity, and dry matter accumulation (sampled at 30-day intervals using a 1 × 1 m quadrant, oven-dried at 70 °C to constant weight, and weighed on a digital balance).

## Results and Discussion

### Growth performance of poplar under different spacing

It is observed from Table 1 that the Poplar height was slightly greater in 4 × 3 m spacing (18.8 m before sowing and 19.0 m after harvest) than in 6 × 3 m spacing (18.3 m and 18.5 m), but the difference was not significant. However, the GBH and crown spread were significantly higher for 6 × 3 m spacing treatment at both observation points (GBH: 66.8 cm vs. 62.9 cm before sowing, 67.4 cm vs. 63.3 cm after harvest; crown spread: 8.8 m vs. 7.6 m before sowing, 9.3 m vs. 8.1 m after harvest). The inverse relationship between the height and lateral growth suggests the resource-allocation response of the trees to the inter-tree competition. Under closer spacing, the neighboring canopies competed for the incident light and induced anisotropic tree growth where the vertical growth was prioritized over the radial and lateral growth. On the contrary, the wider spacing eliminated competition for light, resulting in higher allocation of photosynthetic products to the girth increment and crown spread. This is in line with findings that wider poplar geometries promote significantly better tree growth in agroforestry than closer configurations (Kumar *et al.*, 2024) [7].

**Table 1.** Growth performance of poplar before sowing (November, 2023) and after harvesting (April, 2024) of the wheat crop

| 2023-24              |               |          |                  |               |          |                  |
|----------------------|---------------|----------|------------------|---------------|----------|------------------|
| Spacing (m)          | Before sowing |          |                  | After harvest |          |                  |
|                      | Height (m)    | GBH (cm) | Crown spread (m) | Height (m)    | GBH (cm) | Crown spread (m) |
| 4 × 3                | 18.8          | 62.9     | 7.6              | 19.0          | 63.3     | 8.1              |
| 6 × 3                | 18.3          | 66.8     | 8.8              | 18.5          | 67.4     | 9.3              |
| CD ( $P \leq 0.05$ ) | NS            | 3.13     | 0.4              | NS            | 3.99     | 0.6              |
| SE(m)                | 0.30          | 1.07     | 0.2              | 0.4           | 1.37     | 0.2              |

### 5.2 Number of days to germination

Germination was considerably delayed under closer spacing, taking 7.5 days under 4 × 3 m spacing compared to 6.7 days under 6 × 3 m spacing and 6.5 days in the sole-crop control (CD = 0.92). The effect of sowing time was even more pronounced, with germination time rising steadily from 5.3 days (late October) to 9.0 days (mid-December) (CD = 0.1).

The delay under closer spacing probably reflects modification of the microclimate under denser canopies, where reduced solar radiation

reaching the surface lowers soil temperatures, slowing the metabolic processes governing seed imbibition and radicle emergence. The reduced light transmission under denser poplar geometries has been shown to modify the growing microclimate for intercropped wheat in agroforestry (Jia *et al.*, 2021) [8]. The progressive delay with later sowing parallels the seasonal decline in ambient and soil temperature through November and December, which is a known constraint for wheat germination regardless of tree presence.

**Table 2.** Effect of different sowing time on number of days to germination of various wheat varieties under different spacing of poplar:

| Wheat Varieties        | Spacing (m) | Sowing time                     |              |               |              | Mean | Mean (varieties) |
|------------------------|-------------|---------------------------------|--------------|---------------|--------------|------|------------------|
|                        |             | Late October                    | Mid November | Late November | Mid December |      |                  |
| WH 1184                | 4×3         | 6.0                             | 7.0          | 8.0           | 9.0          | 7.5  | 6.9              |
|                        | 6×3         | 5.0                             | 6.0          | 7.0           | 9.0          | 6.7  |                  |
|                        | Control     | 5.0                             | 5.0          | 7.0           | 9.0          | 6.5  |                  |
|                        | Mean        | 5.3                             | 6.0          | 7.3           | 9.0          |      |                  |
| WH 1105                | 4×3         | 6.0                             | 7.0          | 8.0           | 9.0          | 7.5  | 6.9              |
|                        | 6×3         | 5.0                             | 6.0          | 7.0           | 9.0          | 6.7  |                  |
|                        | Control     | 5.0                             | 5.0          | 7.0           | 9.0          | 6.5  |                  |
|                        | Mean        | 5.3                             | 6.0          | 7.3           | 9.0          |      |                  |
| DBW 187                | 4×3         | 6.0                             | 7.0          | 8.0           | 9.0          | 7.5  | 6.9              |
|                        | 6×3         | 5.0                             | 6.0          | 7.0           | 9.0          | 6.7  |                  |
|                        | Control     | 5.0                             | 5.0          | 7.0           | 9.0          | 6.5  |                  |
|                        | Mean        | 5.3                             | 6.0          | 7.3           | 9.0          |      |                  |
| Mean (Sowing time)     |             | 5.3                             | 6.0          | 7.3           | 9.0          |      |                  |
| Mean (Spacing)         |             |                                 |              | 4m x 3m : 7.5 |              |      |                  |
|                        |             |                                 |              | 6m x 3m : 6.7 |              |      |                  |
|                        |             |                                 |              | Control : 6.5 |              |      |                  |
| C.D. ( $P \leq 0.05$ ) |             | Spacing                         |              |               |              | 0.92 |                  |
|                        |             | Variety                         |              |               |              | NS   |                  |
|                        |             | Sowing time                     |              |               |              | 0.1  |                  |
|                        |             | Spacing × Variety               |              |               |              | NS   |                  |
|                        |             | Spacing × sowing time           |              |               |              | NS   |                  |
|                        |             | Variety × Sowing time           |              |               |              | NS   |                  |
|                        |             | Spacing × Variety × Sowing time |              |               |              | NS   |                  |

### 5.3 Plant population at 20 DAS

Plant population increased consistently with wider spacing, from 165.5 plants/m<sup>2</sup> under 4 × 3 m spacing to 167.7 under 6 × 3 m spacing and 170.3 in the sole-crop control (CD = 2.0). Mid-November sowing produced the highest population (170.6 plants/m<sup>2</sup>), significantly ahead of late-October (167.8) and mid-December (164.1) sowing (CD = 2.3).

The reduced plant stand under closer spacing is consistent with intensified below-ground competition. Poplar develops a dense network of

superficial fine roots concentrated in the upper 15–30 cm of soil — the same zone exploited by wheat roots — creating direct competition for moisture and nutrients that can suppress seedling establishment even when higher seed rates are used to compensate (Sharma *et al.*, 2012) [9]. The peak population under mid-November sowing mirrors findings from a related poplar–wheat sowing-time study in north-western India, where this window consistently produced the best crop performance across seasons, while both earlier and later sowings reduced establishment (Gill *et al.*, 2009) [10]

**Table 3.** Effect of different sowing time on plant population/m<sup>2</sup> of various wheat varieties at 20 DAS under different spacing of poplar

| Wheat Varieties    | Spacing (m) | Sowing time  |              |               |              | Mean  | Mean (varieties) |
|--------------------|-------------|--------------|--------------|---------------|--------------|-------|------------------|
|                    |             | Late October | Mid November | Late November | Mid December |       |                  |
| WH 1184            | 4×3         | 169.56       | 172.66       | 170.46        | 165.06       | 169.4 | 172.6            |
|                    | 6×3         | 172.3        | 175.95       | 173.66        | 169.86       | 172.9 |                  |
|                    | Control     | 175.64       | 178.64       | 176.74        | 170.42       | 175.4 |                  |
|                    | Mean        | 172.5        | 175.7        | 173.6         | 168.4        |       |                  |
| WH 1105            | 4×3         | 165.75       | 167.88       | 166.45        | 162.3        | 165.6 | 167.8            |
|                    | 6×3         | 166.84       | 169.72       | 168.75        | 164.94       | 167.6 |                  |
|                    | Control     | 170.46       | 172.38       | 171.56        | 167.02       | 170.4 |                  |
|                    | Mean        | 167.68       | 170.0        | 168.9         | 164.8        |       |                  |
| DBW 187            | 4×3         | 161.45       | 163.78       | 162.58        | 157.68       | 161.4 | 163.2            |
|                    | 6×3         | 162.3        | 165.75       | 163.87        | 159.45       | 162.8 |                  |
|                    | Control     | 165.65       | 168.56       | 166.76        | 160.32       | 165.3 |                  |
|                    | Mean        | 163.1        | 166.0        | 164.4         | 159.1        |       |                  |
| Mean (Sowing time) |             | 167.8        | 170.6        | 169.0         | 164.1        |       |                  |
| 4×3m               |             | 172.5        | 175.8        | 173.6         | 168.4        |       | 165.5            |
| 6×3m               |             | 167.7        | 170.0        | 168.9         | 164.8        |       | 167.7            |
| Control            |             | 163.1        | 166.0        | 164.4         | 159.2        |       | 170.3            |

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| Wheat Varieties        | Spacing (m)                                   | Sowing time  |              |               |              | Mean | Mean (varieties) |
|------------------------|-----------------------------------------------|--------------|--------------|---------------|--------------|------|------------------|
|                        |                                               | Late October | Mid November | Late November | Mid December |      |                  |
| C.D. ( $P \leq 0.05$ ) | Spacing                                       |              |              |               |              | 2.0  |                  |
|                        | Variety                                       |              |              |               |              | 2.0  |                  |
|                        | Sowing time                                   |              |              |               |              | 2.3  |                  |
|                        | Spacing $\times$ Variety                      |              |              |               |              | NS   |                  |
|                        | Spacing $\times$ sowing time                  |              |              |               |              | NS   |                  |
|                        | Variety $\times$ Sowing time                  |              |              |               |              | NS   |                  |
|                        | Spacing $\times$ Variety $\times$ Sowing time |              |              |               |              | NS   |                  |

### 5.4 Plant height

The investigation results revealed that poplar spacing, wheat variety, and their interactions had a significant effect on plant height at 30, 60, 90, and 120 days after sowing (DAS) as presented in Tables 4 to 7.

The sole wheat (control) treatment registered the maximum plant height (29.0, 54.3, 86.2, and 88.9 cm at 30, 60, 90, and 120 DAS) due to the absence of competition for sunlight and nutrients from poplar trees. On the other hand, increasing the tree spacing reduced the plant height as demonstrated by the control treatment registering the highest plant height, followed by wider spacing (6 $\times$ 4 m) and the nearest spacing (4 $\times$ 3 m) registering the minimum plant height (24.3, 46.2, 78.7, and 81.0 cm at 30, 60, 90, and 120 DAS). This could be explained by the fact that narrow spacing increases competition for sunlight between poplar trees and wheat crops, thus lowering the plant height.

WH 1105 variety registered the maximum plant height (29.0, 51.3, 88.0, and 90.6 cm at 30, 60, 90, and 120 DAS), which could be explained by its ability to tolerate the shaded environment under poplar trees. On the other hand, DBW 187 variety recorded the minimum plant height at early growth stages (23.9 cm at 30 DAS and 46.2 cm at 60 DAS), while WH 1184 variety registered the minimum plant height at later growth stages (76.9 cm at 90 DAS and 79.0 cm at 120

DAS). This suggests that different wheat varieties respond differently to shaded environments caused by poplar trees.

At early growth stages (30 and 60 DAS), WH 1184 variety grown in control treatment registered the maximum plant height (32.2 and 56.2 cm at 30 and 60 DAS), while DBW 187 variety grown in 4 $\times$ 3 m spacing recorded the minimum plant height (22.3 and 43.1 cm at 30 and 60 DAS). This could be explained by the fact that WH 1184 variety is more tolerant to the shaded environment under poplar trees, while DBW 187 variety is highly sensitive to such an environment. On the other hand, at later growth stages (90 and 120 DAS), WH 1105 variety grown in control treatment registered the maximum plant height (93.2 and 95.3 cm at 90 and 120 DAS), while WH 1184 variety grown in 4 $\times$ 3 m spacing recorded the minimum plant height (74.3 and 76.3 cm at 90 and 120 DAS). This suggests that WH 1105 variety grows taller when exposed to a shaded environment, while WH 1184 variety grows shorter when exposed to the same environment.

Light competition is one of the main reasons why poplar trees negatively affect plant growth and development. Poplar trees intercept a significant amount of solar radiation before it reaches the lower wheat crops, thus reducing the amount of light available for photosynthesis (Jia *et al.*, 2021) [8]. This competition for light explains why closer spacing recorded lower plant heights compared to wider spacing as the former intercepts more solar radiation than the latter.

**Table 4.** Effect of different sowing time on plant height (cm) of various wheat varieties under different spacing of poplar at 30 DAS

| Wheat Varieties    | Spacing (m)   | Sowing time  |              |               |              | Mean | Mean (varieties) |
|--------------------|---------------|--------------|--------------|---------------|--------------|------|------------------|
|                    |               | Late October | Mid November | Late November | Mid December |      |                  |
| WH 1184            | 4 $\times$ 3  | 26.7         | 27.6         | 25.8          | 24.9         | 26.2 | 29.0             |
|                    | 6 $\times$ 3  | 29.9         | 30.1         | 28.9          | 27.9         | 29.2 |                  |
|                    | Control       | 32.6         | 33.3         | 31.9          | 30.8         | 32.2 |                  |
|                    | Mean          | 29.7         | 30.3         | 28.9          | 27.9         |      |                  |
| WH 1105            | 4 $\times$ 3  | 24.8         | 25.6         | 23.9          | 22.8         | 24.3 | 25.7             |
|                    | 6 $\times$ 3  | 24.8         | 25.7         | 23.7          | 22.9         | 24.2 |                  |
|                    | Control       | 28.8         | 29.3         | 27.8          | 28.9         | 28.7 |                  |
|                    | Mean          | 26.1         | 26.8         | 25.1          | 24.9         |      |                  |
| DBW 187            | 4 $\times$ 3  | 22.9         | 23.5         | 21.8          | 20.1         | 22.3 | 23.9             |
|                    | 6 $\times$ 3  | 23.9         | 24.3         | 22.9          | 21.8         | 23.2 |                  |
|                    | Control       | 26.9         | 27.5         | 25.7          | 24.7         | 26.2 |                  |
|                    | Mean          | 24.5         | 25.1         | 25.8          | 25.0         |      |                  |
| Mean (Sowing time) |               | 26.8         | 27.4         | 25.9          | 25.0         |      |                  |
|                    | 4 $\times$ 3m | 24.8         | 25.6         | 28.9          | 27.9         |      | 24.3             |
|                    | 6 $\times$ 3m | 26.2         | 26.7         | 25.1          | 24.9         |      | 25.6             |
|                    | Control       | 29.4         | 30.0         | 23.5          | 22.5         |      | 29.0             |

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| Wheat Varieties        | Spacing (m)                                   | Sowing time  |              |               |              | Mean | Mean (varieties) |
|------------------------|-----------------------------------------------|--------------|--------------|---------------|--------------|------|------------------|
|                        |                                               | Late October | Mid November | Late November | Mid December |      |                  |
| C.D. ( $P \leq 0.05$ ) | Spacing                                       |              |              |               |              | 0.3  |                  |
|                        | Variety                                       |              |              |               |              | 0.3  |                  |
|                        | Sowing time                                   |              |              |               |              | 0.37 |                  |
|                        | Spacing $\times$ Variety                      |              |              |               |              | 0.5  |                  |
|                        | Spacing $\times$ sowing time                  |              |              |               |              | NS   |                  |
|                        | Variety $\times$ Sowing time                  |              |              |               |              | NS   |                  |
|                        | Spacing $\times$ Variety $\times$ Sowing time |              |              |               |              | NS   |                  |

**Table 5.** Effect of different sowing time on plant height (cm) of various wheat varieties under different spacing of poplar at 60 DAS

| Wheat Varieties        | Spacing (m)                                   | Sowing time  |              |               |              | Mean | Mean (varieties) |
|------------------------|-----------------------------------------------|--------------|--------------|---------------|--------------|------|------------------|
|                        |                                               | Late October | Mid November | Late November | Mid December |      |                  |
| WH 1184                | 4 $\times$ 3                                  | 46.9         | 47.6         | 45.8          | 44.8         | 46.3 | 50.6             |
|                        | 6 $\times$ 3                                  | 49.8         | 50.9         | 48.9          | 47.7         | 49.3 |                  |
|                        | Control                                       | 56.7         | 57.5         | 55.9          | 54.7         | 56.2 |                  |
|                        | Mean                                          | 51.2         | 51.9         | 50.2          | 49.1         |      |                  |
| WH 1105                | 4 $\times$ 3                                  | 49.8         | 50.5         | 49.0          | 47.6         | 49.2 | 51.3             |
|                        | 6 $\times$ 3                                  | 49.9         | 50.6         | 48.8          | 48.0         | 49.3 |                  |
|                        | Control                                       | 55.9         | 57.0         | 54.8          | 53.9         | 55.4 |                  |
|                        | Mean                                          | 51.9         | 52.7         | 50.9          | 49.8         |      |                  |
| DBW 187                | 4 $\times$ 3                                  | 43.8         | 44.0         | 42.9          | 41.8         | 43.2 | 46.2             |
|                        | 6 $\times$ 3                                  | 44.8         | 45.3         | 44.0          | 42.9         | 44.2 |                  |
|                        | Control                                       | 51.8         | 52.1         | 50.9          | 49.8         | 51.1 |                  |
|                        | Mean                                          | 46.8         | 47.1         | 45.9          | 44.8         |      |                  |
| Mean (Sowing time)     |                                               | 50.0         | 50.6         | 49.0          | 47.9         |      |                  |
|                        | 4 $\times$ 3m                                 | 46.8         | 47.3         | 45.9          | 44.7         |      | 46.2             |
|                        | 6 $\times$ 3m                                 | 48.2         | 48.8         | 47.2          | 46.2         |      | 47.6             |
|                        | Control                                       | 54.8         | 55.5         | 53.9          | 52.8         |      | 54.3             |
| C.D. ( $P \leq 0.05$ ) | Spacing                                       |              |              |               |              | 0.5  |                  |
|                        | Variety                                       |              |              |               |              | 0.5  |                  |
|                        | Sowing time                                   |              |              |               |              | 0.6  |                  |
|                        | Spacing $\times$ Variety                      |              |              |               |              | 1.0  |                  |
|                        | Spacing $\times$ sowing time                  |              |              |               |              | NS   |                  |
|                        | Variety $\times$ Sowing time                  |              |              |               |              | NS   |                  |
|                        | Spacing $\times$ Variety $\times$ Sowing time |              |              |               |              | NS   |                  |

**Table 6.** Effect of different sowing time on plant height (cm) of various wheat varieties under different spacing of poplar at 90 DAS

| Wheat Varieties    | Spacing (m)   | Sowing time  |              |               |              | Mean | Mean (varieties) |
|--------------------|---------------|--------------|--------------|---------------|--------------|------|------------------|
|                    |               | Late October | Mid November | Late November | Mid December |      |                  |
| WH 1184            | 4 $\times$ 3  | 77.9         | 79.0         | 76.9          | 76.0         | 77.4 | 80.4             |
|                    | 6 $\times$ 3  | 78.8         | 79.7         | 78.0          | 76.9         | 78.3 |                  |
|                    | Control       | 85.9         | 86.8         | 84.9          | 83.7         | 85.3 |                  |
|                    | Mean          | 77.5         | 78.0         | 76.5          | 75.5         |      |                  |
| WH 1105            | 4 $\times$ 3  | 84.8         | 85.9         | 83.8          | 82.9         | 84.3 | 88.0             |
|                    | 6 $\times$ 3  | 86.9         | 87.8         | 85.9          | 84.9         | 86.4 |                  |
|                    | Control       | 93.8         | 94.3         | 92.9          | 92.0         | 93.2 |                  |
|                    | Mean          | 88.5         | 89.3         | 87.5          | 86.6         |      |                  |
| DBW 187            | 4 $\times$ 3  | 74.9         | 75.6         | 73.7          | 72.9         | 74.3 | 76.9             |
|                    | 6 $\times$ 3  | 76.8         | 77.6         | 76.0          | 74.9         | 76.3 |                  |
|                    | Control       | 80.9         | 81.0         | 79.2          | 78.8         | 80.1 |                  |
|                    | Mean          | 80.9         | 81.8         | 79.9          | 78.6         |      |                  |
| Mean (Sowing time) |               | 82.3         | 83.1         | 81.3          | 80.3         |      |                  |
|                    | 4 $\times$ 3m | 79.2         | 80.2         | 78.1          | 77.2         |      | 78.7             |
|                    | 6 $\times$ 3m | 80.9         | 81.7         | 79.9          | 78.9         |      | 80.3             |

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| Wheat Varieties        | Spacing (m) | Sowing time                                   |              |               |              | Mean | Mean (varieties) |
|------------------------|-------------|-----------------------------------------------|--------------|---------------|--------------|------|------------------|
|                        |             | Late October                                  | Mid November | Late November | Mid December |      |                  |
| Control                |             | 86.9                                          | 87.4         | 85.9          | 84.8         |      | 86.2             |
| C.D. ( $P \leq 0.05$ ) |             | Spacing                                       |              |               |              | 1.02 |                  |
|                        |             | Variety                                       |              |               |              | 1.02 |                  |
|                        |             | Sowing time                                   |              |               |              | 1.18 |                  |
|                        |             | Spacing $\times$ Variety                      |              |               |              | 1.78 |                  |
|                        |             | Spacing $\times$ sowing time                  |              |               |              | NS   |                  |
|                        |             | Variety $\times$ Sowing time                  |              |               |              | NS   |                  |
|                        |             | Spacing $\times$ Variety $\times$ Sowing time |              |               |              | NS   |                  |

**Table 7.** Effect of different sowing time on plant height (cm) of various wheat varieties under different spacing of poplar at 120 DAS

| Wheat Varieties        | Spacing (m)  | Sowing time                                   |              |               |              | Mean | Mean (varieties) |
|------------------------|--------------|-----------------------------------------------|--------------|---------------|--------------|------|------------------|
|                        |              | Late October                                  | Mid November | Late November | Mid December |      |                  |
| WH 1184                | 4 $\times$ 3 | 79.9                                          | 80.9         | 78.9          | 77.9         | 79.4 | 83.3             |
|                        | 6 $\times$ 3 | 81.7                                          | 82.1         | 80.9          | 79.9         | 81.1 |                  |
|                        | Control      | 89.9                                          | 90.5         | 88.8          | 87.9         | 89.3 |                  |
|                        | Mean         | 79.6                                          | 80.2         | 78.5          | 77.5         |      |                  |
| WH 1105                | 4 $\times$ 3 | 87.9                                          | 88.7         | 87.0          | 85.9         | 87.4 | 90.6             |
|                        | 6 $\times$ 3 | 89.9                                          | 90.2         | 89.0          | 87.8         | 89.2 |                  |
|                        | Control      | 95.9                                          | 96.7         | 94.9          | 93.8         | 95.3 |                  |
|                        | Mean         | 91.2                                          | 91.9         | 90.3          | 89.1         |      |                  |
| DBW 187                | 4 $\times$ 3 | 76.9                                          | 77.4         | 75.9          | 74.9         | 76.3 | 79.0             |
|                        | 6 $\times$ 3 | 78.9                                          | 79.6         | 77.9          | 76.9         | 78.3 |                  |
|                        | Control      | 82.9                                          | 83.4         | 81.7          | 80.9         | 82.2 |                  |
|                        | Mean         | 83.8                                          | 84.5         | 82.9          | 81.9         |      |                  |
| Mean (Sowing time)     |              | 84.9                                          | 85.5         | 83.9          | 82.9         |      |                  |
| 4 $\times$ 3m          |              | 81.6                                          | 82.3         | 80.6          | 79.5         |      | 81.0             |
| 6 $\times$ 3m          |              | 83.5                                          | 84.0         | 82.6          | 81.5         |      | 82.9             |
| Control                |              | 89.6                                          | 90.2         | 88.4          | 87.5         |      | 88.9             |
| C.D. ( $P \leq 0.05$ ) |              | Spacing                                       |              |               |              | 1.07 |                  |
|                        |              | Variety                                       |              |               |              | 1.07 |                  |
|                        |              | Sowing time                                   |              |               |              | 1.24 |                  |
|                        |              | Spacing $\times$ Variety                      |              |               |              | 1.86 |                  |
|                        |              | Spacing $\times$ sowing time                  |              |               |              | NS   |                  |
|                        |              | Variety $\times$ Sowing time                  |              |               |              | NS   |                  |
|                        |              | Spacing $\times$ Variety $\times$ Sowing time |              |               |              | NS   |                  |

### 5.5 Dry matter accumulation

Dry matter accumulation followed a similar trend to that of plant height, with differences between treatments increasing sharply over time. Dry matter increased from 72.26 g/m<sup>2</sup> at 30 DAS to 377.66 g/m<sup>2</sup> at 120 DAS under 4  $\times$  3 m spacing compared to 189.17 g/m<sup>2</sup> and 1010.0 g/m<sup>2</sup> in the sole-crop control (CD = 1.60 to 7.07) — indicating that open-field wheat accumulated over 2.6 times more biomass than wheat under the closest poplar spacing by crop maturity.

While sowing time had no significant effect on dry matter at any stage, it had a clear influence on germination and plant population. The widening trend reflects the cumulation of reduced early photosynthesis and competition for water and nutrients between poplar and wheat roots throughout the season, since a plant that establishes with lower vigor falls progressively further behind under continued resource competition (Rahhan *et al.*, 1992) [6]. The lack of sowing-time effect on final dry matter indicates that, once established, the intensity of season-long tree-crop competition becomes the dominant factor influencing biomass accumulation.

**Table 8.** Effect of different sowing time on dry matter accumulation at 30 days interval (g/m<sup>2</sup>) of various wheat varieties under different spacing of poplar

| Treatments   | Dry matter accumulation at 30 days interval (g/m <sup>2</sup> ) |        |        |         |
|--------------|-----------------------------------------------------------------|--------|--------|---------|
|              | 30 DAS                                                          | 60 DAS | 90 DAS | 120 DAS |
|              | Spacing (m)                                                     |        |        |         |
| 4 $\times$ 3 | 72.26                                                           | 222.57 | 315.16 | 377.66  |
| 6 $\times$ 3 | 80.27                                                           | 247.37 | 350.39 | 419.62  |
| Control      | 189.17                                                          | 593.16 | 843.62 | 1010.0  |

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|                        |        |        |        |        |
|------------------------|--------|--------|--------|--------|
| S.E.(m)±               | 0.56   | 1.72   | 1.81   | 2.50   |
| C.D. ( $P \leq 0.05$ ) | 1.60   | 4.86   | 5.10   | 7.07   |
| <b>Wheat Variety</b>   |        |        |        |        |
| WH 1184                | 117.33 | 358.13 | 507.61 | 607.33 |
| WH 1105                | 113.64 | 354.62 | 502.90 | 602.43 |
| DBW 187                | 110.73 | 350.34 | 498.66 | 597.52 |
| S.E.(m)±               | 0.56   | 1.72   | 1.81   | 2.50   |
| C.D. ( $P \leq 0.05$ ) | 1.60   | 4.86   | 5.10   | 7.07   |
| <b>Sowing time</b>     |        |        |        |        |
| Late October           | 114.88 | 355.63 | 504.22 | 603.51 |
| Mid November           | 114.93 | 355.70 | 504.31 | 603.63 |
| Late November          | 114.83 | 355.57 | 504.12 | 603.39 |
| Mid December           | 110.96 | 350.57 | 499.57 | 599.17 |
| S.E.(m)±               | 0.65   | 1.99   | 2.09   | 2.89   |
| C.D.( $P \leq 0.05$ )  | NS     | NS     | NS     | NS     |

## Conclusion

Poplar spaced at an interval of 6×3 m showed significantly greater girth (67.4 cm) and crown spread (9.3 m) as compared to 4×3 m spacing (girth: 63.3 cm, spread: 8.1 m) after the harvest, though the height remained unaffected. The closer spacing (4×3 m) resulted in delayed germination (7.5 days) and decreased plant population (165.5/m<sup>2</sup>) as compared to control (6.5 days, 170.3/m<sup>2</sup>), while sowing in mid-November produced the best results in terms of establishment. Plant height and dry matter were highest consistently in the sole crop control and lowest under 4×3 m spacing at all stages of growth, with the yield gap widening progressively during the season (dry matter: 1010.0 vs. 377.66 g/m<sup>2</sup> at 120 DAS). A variety of WH 1105 was found to be best in terms of growth and shade tolerance, whereas, DBW 187 and WH 1184 were proved to be the most sensitive at early and later stages of growth, respectively, to closer spacing of poplar. The time of sowing significantly affected the germination and plant population but not the final dry matter accumulation.

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