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Research Article

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Growth and yield response of wheat varieties under different spacings of poplar (*Populus deltoides*) based agroforestry system of Haryana

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ABSTRACT

A field experiment was conducted to assess the the growth and yield performance of wheat varieties under poplar based agroforestry system in semi-arid ecosystem of Haryana during 2020-21. One-year-old poplar saplings were transplanted during January-February 2017 at six spacings: 3×3 m, 4×3 m, 5×3 m, 6×3 m, 7×3 m and 8×3 m. After four years of plantation, tree growth, soil properties, light availability and crop performance were evaluated. Poplar height ranged from 14.3 to 15.7 m, while diameter at breast height (dbh) increased significantly with wider spacing, recording the highest value (22.6 cm) under 8×3 m spacing. Three wheat varieties (WH-1105, HD-2967 and WH-711) were grown as intercrops. Plant height, yield attributes and yield of wheat varieties were significantly influenced by poplar spacing. Among all the wheat varieties, HD-2967 exhibited superior growth and yield attributes under all the spacings of poplar plantation. The highest grain yield among intercrops was recorded in HD-2967 (4.10 t ha-1) followed by WH-711 (3.72 t ha-1) under 8×3 m spacing. Grain and straw yields declined significantly with closer spacing due to increased competition for light, moisture and nutrients. Maximum reduction in grain yield was observed under 3×3 m spacing, particularly in WH-1105. The study suggests that wider poplar spacings, particularly 8×3 m are more suitable for sustaining wheat productivity in poplar based agroforestry systems in the semi-arid conditions of Haryana, with HD-2967 emerging as the most suitable wheat variety for intercropping.

INTRODUCTION

In India, agroforestry plays a crucial role in supporting rural livelihoods and providing raw materials for wood-based industries. The Indo-Gangetic plains of northern India are among the most important regions where agroforestry systems have been widely adopted. Among the various tree species used in agroforestry systems, poplar (*Populus deltoides* Bartr. ex Marsh.) has emerged as one of the most suitable species for integration with agricultural crops. Poplar is a fast-growing deciduous tree species belonging to the family Salicaceae and is widely cultivated in north-western India due to its rapid growth, straight bole, high market demand and compatibility with field crops. Poplar based agroforestry systems are extensively practiced in the states of Punjab, Haryana, Uttar Pradesh and Uttarakhand. Farmers prefer poplar plantations because they provide high economic returns within a relatively short rotation period of 6-8 years while allowing cultivation of agricultural crops during the early stages of tree growth. Poplar wood is widely used in plywood, veneer, match and paper industries, making it an economically valuable species in agroforestry systems (Singh *et al.,* 2022). In addition to economic benefits, poplar plantations also improve soil properties by adding organic matter through leaf litter and root biomass. The success of poplar based agroforestry systems is largely attributed to the deciduous nature of poplar trees, which shed their leaves during winter and allow adequate sunlight penetration to understory crops such as wheat, mustard and potato during the *Rabi* season. However, as poplar trees grow older, the canopy expands and competition for light, water and nutrients between trees and crops increases. This competition may significantly influence crop growth and yield, particularly under closer tree spacing. Therefore, proper management of tree spacing is essential for optimizing tree-crop interactions and maintaining productivity in agroforestry systems.

Tree spacing is one of the most critical factors affecting the productivity of agroforestry systems. Wider spacing generally reduces competition between trees and crops for resources such as sunlight, soil moisture and nutrients, thereby enhancing crop productivity. Conversely, closer spacing may result in reduced crop yield due to increased shading and competition. Gandhi and Dhiman (2010) evaluated the performance of wheat under different spacings of poplar plantation and reported that wheat yield and yield attributes were significantly influenced by tree spacing. Apart from spacing effects, nutrient management also plays an important role in determining crop productivity in agroforestry systems. Sirohi *et al.* (2022) reported that different nitrogen levels significantly influenced growth and yield attributes of wheat varieties grown under poplar plantations. Increased nitrogen application improved plant height, number of tillers and grain yield of wheat under poplar-based agroforestry systems. Further, Smith *et al.* (2013) reported that agroforestry systems significantly increased biomass production and energy yield compared with conventional agricultural systems. Similarly, Torralba *et al.* (2016) highlighted the role of agroforestry in enhancing biodiversity and ecosystem services.

Efficient integration of trees into agroforestry systems requires a clear understanding of tree growth patterns and their interaction with environmental resources, particularly solar radiation, to minimize negative effects on intercrop yields (Reisner *et al.,* 2007; Eichhorn *et al.,* 2006). Therefore, careful planning of suitable tree-crop combinations, system design such as row orientation and spacing, and management practices including pruning is essential for optimizing productivity. Tree rows oriented in a north-south direction are generally less competitive for solar radiation compared with east-west oriented rows (Dufur *et al.,* 2013). Moreover, pruning of lower branches from the second year onwards not only promotes the production of knot-free timber but also enhances light availability for understory crops (Chauhan *et al.,* 2011). Selection of deciduous tree species with phenological patterns compatible with the growth cycle of intercrops is also crucial for maximizing radiation use efficiency. Piotto *et al.* (2024) conducted a study on poplar based silvo-arable systems and emphasized the importance of tree-crop interactions in agroforestry systems. Their research demonstrated that the presence of trees influenced the phenology and productivity of intercrops, where shading from poplar trees reduced the yield of some crops but, under certain climatic conditions, improved the performance of winter wheat, thereby highlighting the complex interactions between trees and crops in agroforestry systems.

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops in the world and serves as a staple food for a large proportion of the global population. In India, wheat occupies a prominent position in the agricultural economy and is widely cultivated in the Indo-Gangetic plains. The state of Haryana is one of the leading wheat-producing states in the country and contributes significantly to national food grain production. Wheat is commonly grown as an intercrop in poplar based agroforestry systems because its growth period coincides with the leafless phase of poplar trees. However, the performance of wheat under agroforestry systems is influenced by several factors including tree spacing, tree age, crop variety, soil fertility and management practices. Different wheat varieties exhibit varying degrees of tolerance to shading and competition, which affects their growth and yield under tree canopies.

Therefore, identifying suitable wheat varieties that can perform well under poplar plantations is essential for improving the productivity of agroforestry systems. Although several studies have been conducted on poplar based agroforestry systems in northern India, information regarding the combined effect of tree spacing and wheat varieties on crop growth and yield under semi-arid conditions of Haryana is still limited. Understanding the interaction between poplar spacing and wheat varieties is essential for developing appropriate management strategies to optimize productivity in agroforestry systems. Therefore, the present study was conducted to evaluate the growth and yield response of different wheat varieties under varying spacings of poplar based agroforestry system in Haryana. The findings of this study provide valuable insights into identifying suitable tree spacings and wheat varieties for enhancing overall system productivity and sustainability under the semi-arid conditions of the region.

MATERIALS AND METHODS

A field experiment was carried out at the research farm of the Department of Forestry, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana during *Rabi* season of 2020-21. The experimental site is situated in the north-western arid region of India at 29°09′ N latitude and 75°43′ E longitude with an elevation of 215.2 m above mean sea level.

During the study period, a total rainfall of 317.5 mm of rainfall was recorded during July-March against long term mean rainfall of 410.6 mm during this period. The reduced rainfall was mainly attributed to the frequent occurrence of western disturbances during the winter months. The climatic conditions of the region are characterized by extremely hot summers, with maximum temperatures ranging from 39. 5°C during May, whereas December and January represent the coldest months of the year.

Poplar trees were established between 30 January and 2 February 2017 under six different spacing geometries, namely 3×3 m, 4×3 m, 5×3 m, 6×3 m, 7×3 m and 8×3 m. At the time of planting, the average height, basal diameter and diameter at breast height (DBH) of the poplar saplings were 5.46 m, 3.51 cm and 2.83 cm, respectively. The experiment was laid out in a factorial randomized block design with three replications.

During the 1st fortnight of November 2020, three wheat varieties, namely WH-1105, HD-2967 and WH-711, were sown as intercrops under the different poplar spacing treatments mentioned above. The crop was planted with a row spacing of 22.5 cm using a seed rate of 100 kg ha^{-1}. In addition, the same wheat varieties were also grown in an open field without trees to serve as a control. Fertilizers were applied according to the recommended dose for wheat, i.e., 150 kg N ha^{-1}, 60 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1}. The entire quantity of phosphorus and potassium along with half of the nitrogen was applied as basal at the time of sowing, while the remaining nitrogen was applied as top dressing in the form of urea at the crown root initiation stage.

Observations on wheat growth and yield parameters were recorded both under the poplar spacings and in the control plots. Plant height (cm) of different wheat varieties was measured at various growth stages. At crop maturity, observations were taken on total number of tillers per square meter, number of ear heads per square meter, number of grains per ear head and test weight of 1000 grains (g). The crop from the net plot area was harvested separately to determine grain and straw yield. Similar observations were also recorded from the control plots, and the collected data were subjected to statistical analysis for interpretation of results.

Table 1: Growth parameters of 4 year old poplar plantation under different spacings

Spacing (m)	2020-2021	
	Height (m)	dbh (cm)
3 × 3	14.7	17.1
4× 3	15.0	18.7
5× 3	15.7	19.1
6 × 3	14.3	20.4
7 × 3	14.7	21.2
8 × 3	14.4	22.6
C.D. at 5%	0.09	0.31

RESULTS AND DISCUSSION

Growth of poplar under different spacings

The growth performance of poplar under different spacings after four years of plantation is presented in Table 1. The results clearly indicate that tree spacing had a considerable influence on the growth characteristics of poplar plantations. In the present investigation, one-year-old saplings were transplanted during January 30 to February 2, 2017 at six spacings (3×3 m, 4×3 m, 5×3 m, 6×3 m, 7×3 m and 8×3 m). At the time of transplantation, the average height, basal diameter and diameter/girth at breast height (DBH/GBH) of the saplings were 5.46 m, 3.51 cm and 2.83/8.9 cm, respectively. After four years of growth, noticeable differences in growth parameters were observed under different spacing treatments. The data presented in Table 1 revealed that tree height ranged from 14.3 m to 15.7 m under different spacings. The maximum height (15.7 m) was recorded under 5×3 m spacing, followed by 4×3 m spacing (15.0 m), whereas the minimum height (14.3 m) was observed under 6×3 m spacing. The relatively greater height under intermediate spacing could be attributed to moderate competition for light among trees, which promotes apical growth. Under closely spaced conditions, trees compete for light and tend to grow taller, while under wider spacing lateral crown expansion occurs rather than increased vertical growth.

The diameter at breast height (DBH) showed a clear and statistically significant response to spacing. The maximum DBH (22.6 cm) was recorded under the widest spacing of 8×3 m, followed by 7×3 m (21.2 cm) and 6×3 m (20.4 cm), whereas the minimum DBH (17.1

cm) was observed under the closest spacing of 3×3 m. However, the difference between 4×3 m spacing (18.7 cm) and 5×3 m spacing (19.1 cm) was statistically non-significant. The increase in DBH with increasing spacing may be attributed to reduced inter-tree competition for essential resources such as solar radiation, soil moisture, nutrients and rooting space. Wider spacing enables better crown development and root expansion, which enhances photosynthetic efficiency and accumulation of biomass in the stem. Conversely, closer spacing results in intense competition among trees, thereby limiting radial growth and reducing stem diameter.

The results of the present study are consistent with the findings of Dhillon *et al.* (2017) and Sirohi *et al.* (2022a) who reported that wider spacing in poplar plantations significantly increased tree diameter due to reduced competition for growth resources in semi-arid agroforestry systems. Similarly, Chauhan *et al.* (2012) observed that poplar trees planted at wider spacings showed higher DBH growth and improved canopy development compared with closely spaced plantations, primarily because of greater availability of light and soil nutrients. Further, Kumar *et al.* (2019) reported that wider spacing in poplar-based agroforestry systems promoted greater stem girth and biomass accumulation because trees were able to expand their crowns and root systems more effectively under reduced competition.

Availability of light intensity during Rabi season under different spacings of poplar

The availability of solar radiation under different spacings of poplar during the *Rabi* season (November 2020 to April 2021) was measured and expressed as percent reduction in available sunlight compared with open conditions (sole crop). The data presented in Table 2 clearly indicate that the presence of poplar trees significantly influenced the penetration of sunlight to the understory crop canopy and the magnitude of reduction varied according to tree spacing and seasonal phenology of poplar. During November, when poplar trees still retained a considerable amount of foliage, the reduction in light intensity was relatively high under closer spacings. The maximum reduction (72.01%) was recorded under 3×3 m spacing, followed by 4×3 m spacing (66.26%) and 5×3 m spacing (55.70%), whereas wider spacings such as 7×3 m (22.16%) and 8×3 m (17.47%) recorded comparatively lower reductions in sunlight. This pattern indicates that increased tree density resulted in greater canopy overlap and shading, thereby restricting solar radiation reaching the understory crops. During the winter months (December to February), the reduction in sunlight declined considerably across all spacing spacings. This reduction ranged from 70.87% to 7.74% in December, 53.58% to 4.59% in January, and 52.67% to 5.36% in February, from closest to widest spacing, respectively. The lower shading effect during these months can be attributed to the deciduous nature of poplar, which sheds its leaves during winter, allowing greater penetration of sunlight to the crop layer. Among all spacings, 8×3 m spacing consistently recorded the lowest reduction in light intensity, followed by 7×3 m spacing, indicating that wider spacing enhances light transmission even during periods of partial canopy presence.

From March onwards, the reduction in available solar radiation began to increase again due to the emergence of new foliage and canopy development in poplar trees. During March, the reduction ranged from 58.05% under 3×3 m spacing to 11.00% under 8×3 m spacing, while in April the reduction increased further, reaching 74.72% under the closest spacing (3×3 m) and 20.84% under the widest spacing (8×3 m). This increase in shading during late *Rabi* season corresponds with the active leaf development stage of poplar, which increases canopy density and consequently reduces the amount of sunlight reaching the crop canopy. Overall, the results clearly demonstrate that tree spacing plays a significant role in regulating light availability in poplar-based agroforestry systems. Closer spacing treatments (3×3 m and 4×3 m) resulted in substantially higher shading, whereas wider spacings (7×3 m and 8 3 m) allowed greater light penetration, thereby creating more favorable conditions for the growth of understory crops such as wheat. The observed trend is consistent with the findings of Chauhan *et al.* (2011), who reported that poplar based agroforestry systems allow winter crops to receive sufficient sunlight during the leafless period of poplar, which minimizes competition for solar radiation during early crop growth stages. Swieter *et al.* (2021) also reported that light availability in agroforestry systems decreases with increasing tree density and canopy size, and wider row spacing significantly improves photosynthetically active radiation available to crops.

Further, Dupraz *et al.* (2019) explained that seasonal variation in canopy development strongly affects the distribution of solar radiation in agroforestry systems. During the leafless period, solar radiation reaching crops increases considerably, while during the active canopy period shading becomes more pronounced.

Table 2: Per cent reduction in available sun light under different spacing's of poplar over control during *Rabi* seasons (November, 2020-April, 2021)

Spacing (m)	November, 2020	December, 2020	January, 2021	February, 2021	March, 2021	April, 2021
3×3	72.01	70.87	53.58	52.67	58.05	74.72
4×3	66.26	57.29	40.46	40.24	53.79	65.15
5×3	55.70	47.15	33.54	32.97	44.94	50.83
6×3	41.51	34.49	23.46	22.74	36.25	45.77
7×3	22.16	14.03	8.05	7.53	15.56	26.94
8×3	17.47	7.74	4.59	5.36	11.00	20.84

Table 3: Plant height (cm) of wheat varieties at different stages of growth under different spacings of poplar

Spacing (m)	Plant height (cm) at 30 DAS				Plant height (cm) at 60 DAS			
	Variety			Mean	Variety			Mean
	WH-1105	HD-2967	WH-711		WH-1105	HD-2967	WH-711	
3 × 3	25.4	27.7	26.8	26.6	39.3	58.4	53.3	50.3
4× 3	26.9	28.6	27.6	27.7	46.8	59.6	54.4	53.6
5× 3	28.2	29.2	28.3	28.6	47.6	60.9	55.3	54.6
6 × 3	29.7	30.7	29.2	29.9	50.0	61.9	56.5	56.1
7 × 3	30.4	31.1	30.1	30.5	50.0	63.0	57.1	56.7
8 × 3	31.4	32.7	31.6	31.9	54.5	65.6	59.5	59.9
Control	33.5	34.6	33.5	33.9	57.8	68.1	62.9	62.9
Mean	29.4	30.7	29.6		49.4	62.5	57.0	
C.D. at 5%	Variety: 0.70 Spacing: 1.031 Variety × Spacing: NS				Variety: 1.51 Spacing: 2.15 Variety × Spacing: NS			

Growth and yield attributes of wheat varieties under different spacings of poplar

The data presented in Tables 3 and 4 revealed that the plant height of wheat varieties was significantly influenced by poplar spacing as well as varietal differences at all growth stages (30, 60, 90 and 120 DAS). However, the interaction between variety and spacing was non-significant, indicating that all varieties responded similarly to variation in tree spacing. At 30 DAS, plant height ranged from 25.4 to 33.5 cm across the spacings. The maximum plant height (33.9 cm) was recorded under the control (sole crop) condition, whereas the minimum height (26.6 cm) was observed under 3×3 m spacing. Among the varieties, HD-2967 recorded significantly higher plant height (30.7 cm) than WH-711 (29.6 cm) and WH-1105 (29.4 cm). At 60 DAS, similar trends were observed. The highest mean plant height (62.9 cm) was recorded under the control, whereas the lowest (50.3 cm) occurred at 3×3 m spacing. Among varieties, HD-2967 (62.5 cm) exhibited significantly higher plant height than WH-711 (57.0 cm) and WH-1105 (49.4 cm). At 90 DAS, plant height further increased and ranged from 73.5 cm to 89.1 cm. The control treatment recorded the maximum mean plant height (84.5 cm) followed by 8×3 m spacing (83.1 cm), whereas the minimum height (76.3 cm) occurred at 3×3 m spacing. Among the varieties, HD-2967 (84.3 cm) performed significantly better than WH-711 (78.3 cm) and WH-1105 (77.2 cm). Similar results were recorded at 120 DAS, where the maximum plant height (86.4 cm) occurred in control and the minimum (77.7 cm) under 3×3 m spacing.

The reduction in plant height under closer spacing of poplar can be attributed to competition for solar radiation, soil moisture and nutrients between trees and crops, resulting in suppressed crop growth. Poplar canopy reduces photosynthetically active radiation reaching the understory crops, which adversely affects crop growth parameters. Similar findings were reported by Dhillon *et al.* (2017) and Sirohi *et al.* (2022b) who observed significant reduction in plant height of wheat under closer poplar spacing due to shading and root competition. Previous studies have also reported that growth of wheat is directly related to available light intensity under agroforestry systems, and wider tree spacing allows better light penetration and reduces competition, thereby improving crop growth (Chauhan *et al.*, 2012).

Yield attributes of wheat varieties

The yield attributing parameters of wheat varieties such as tillers m^{-2}, ear heads m^{-2}, grains per ear head and test weight were significantly affected by poplar spacing (Tables 5 and 6). The number of tillers m^{-2} varied significantly among spacings, ranging from 248.0 under 3×3 m spacing to 344.5 under the control. Among the varieties, HD-2967 recorded the highest mean number of tillers (285.3 m^{-2}) followed by WH-711 (282.1 m^{-2}) and WH-1105 (281.5 m^{-2}). A similar pattern was observed for ear heads m^{-2}, which ranged from 239.9 under 3×3 m spacing to 337.1 under control conditions. Wider spacings such as 7×3 m and 8×3 m significantly improved ear head formation, which may be attributed

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Table 4: Plant height (cm) of wheat varieties at different stages of growth under different spacings of poplar

Spacing (m)	Plant height (cm) at 90 DAS				Plant height (cm) at 120 DAS			
	Variety			Mean	Variety			Mean
	WH-1105	HD-2967	WH-711		WH-1105	HD-2967	WH-711	
3 × 3	73.5	80.4	74.9	76.3	75.8	81.6	75.7	77.7
4× 3	74.8	81.6	75.8	77.4	76.7	82.9	76.7	78.8
5× 3	76.0	82.9	77.4	78.8	78.0	83.7	78.2	80.0
6 × 3	77.0	84.1	78.2	79.8	79.0	85.4	78.7	81.0
7 × 3	77.4	84.1	78.0	79.8	78.9	85.2	78.6	80.9
8 × 3	79.9	88.1	81.2	83.1	82.2	88.9	82.7	84.6
Control	81.5	89.1	82.8	84.5	83.8	91.1	84.4	86.4
Mean	77.2	84.3	78.3		79.2	85.5	79.3	
C.D. at 5%	Variety: 1.85 Spacing: 2.63 Variety × Spacing: NS				Variety: 1.88 Spacing: 2.50 Variety × Spacing: NS			

Table 5: Tillers and Ear heads of wheat varieties under different poplar spacings

Spacing (m)	Tillers/m^2				Ear heads/m^2			
	Variety			Mean	Variety			Mean
	WH-1105	HD-2967	WH-711		WH-1105	HD-2967	WH-711	
3 × 3	245.7	250.0	248.3	248.0	237.1	242.9	239.6	239.9
4× 3	254.3	259.6	257.2	257.0	244.5	251.6	246.7	247.6
5× 3	263.0	269.6	265.2	265.9	252.9	260.2	255.4	256.2
6 × 3	274.5	280.3	278.6	277.8	266.3	271.2	268.4	268.6
7 × 3	284.4	287.1	283.2	284.9	274.3	280.1	277.4	277.3
8 × 3	299.2	306.3	302.8	302.8	290.9	298.6	295.1	294.9
Control	349.7	344.4	339.5	344.5	342.1	337.8	331.5	337.1
Mean	281.5	285.3	282.1		272.6	277.5	273.4	
C.D. at 5%	Variety: 9.14 Spacing: 10.87 Variety × Spacing: NS				Variety: 7.86 Spacing:9.53 Variety × Spacing: NS			

to reduced competition for growth resources and improved light availability.

The number of grains per ear head also increased with wider poplar spacing. The maximum grains per ear head (48.1) were recorded under control, whereas the minimum (35.6) occurred under 3×3 m spacing. Among varieties, HD-2967 recorded significantly higher grains per ear head (41.4) compared with WH-711 (40.1) and WH-1105 (39.5). Similarly, test weight ranged from 38.2 g under 3×3 m spacing to 47.9 g under control conditions, indicating significant improvement with wider tree spacing. Kaur and Singh (2022) also observed that wheat growth and yield attributes were significantly affected by poplar age. They reported reductions of 4.9-13.8% in tillers m^{-1}, 9.1-22.7% in ear length, 5.5-16.6% in grains per ear, and 7.8-19.6% in 1000-grain weight compared with the control as poplar age increased from 2 to 6 years. The reduction in yield attributes under closer spacing may be due to reduced availability of photosynthetically active radiation and increased competition for soil resources, which ultimately affects tiller formation and grain development. These findings are consistent with the results of earlier studies where wheat grown under poplar plantations exhibited lower yield attributes under closer spacings but improved performance under wider spacings (Sirohi *et al.,* 2020). Agroforestry studies have also reported that moderate shade can alter crop physiological processes such as photosynthesis and biomass accumulation, which directly affects yield components (Neto *et al.,* 2024).

Grain and straw yield of wheat varieties

The grain and straw yield of wheat varieties were significantly influenced by both variety and poplar spacing (Table 7). However, the interaction effect between variety and spacing was significant only for grain yield. The grain yield ranged from 2.39 t ha^{-1} under 3×3 m spacing to 4.41 t ha^{-1} under control conditions. Among the spacings under agroforestry, 8×3 m recorded the highest grain yield (3.83 t ha^{-1}) followed by 7×3 m (3.29 t ha^{-1}) and 6 3 m (3.11 t ha^{-1}). Among the wheat varieties, HD-2967 produced the highest grain yield (3.41 t ha^{-1}) followed by WH-1105 (3.16 t ha^{-1}) and WH-711 (3.14 t ha^{-1}). The maximum grain yield (4.10 t ha^{-1}) was recorded in HD-2967 under 8×3 m spacing. A similar trend was observed for straw yield, which ranged from 2.87 t ha^{-1} under 3×3 m spacing to 5.75 t ha^{-1} under control. The highest straw yield among agroforestry treatments was recorded under 8×3 m spacing (4.22 t ha^{-1}). The percentage reduction in grain yield over control was highest under 3×3 m spacing, where reductions of 50.21%, 45.04% and 41.64% were observed in WH-1105, WH-711 and HD-2967, respectively. The reduction in yield under closer spacing may be attributed to higher competition for light, moisture and nutrients between poplar trees and wheat crop. Xu *et al.* (2016) reported that delayed canopy senescence positively influences grain filling and wheat productivity, especially under moderate light reduction (approximately 12% PAR) occurring after the anthesis stage.

Table 6: Grains/ear head and test weight of wheat varieties under different poplar spacings

Spacing (m)	Grains/ear head				Test weight (g)			
	Variety			Mean	Variety			Mean
	WH-1105	HD-2967	WH-711		WH-1105	HD-2967	WH-711	
3 × 3	34.6	36.5	35.7	35.6	36.8	39.6	38.2	38.2
4× 3	36.0	38.8	37.3	37.4	37.8	41.0	40.0	39.6
5× 3	37.6	40.2	38.9	38.9	39.8	42.7	41.9	41.5
6 × 3	38.6	41.5	40.0	40.0	41.5	44.3	42.9	42.9
7 × 3	39.0	41.8	40.4	40.4	42.5	44.7	43.6	43.6
8 × 3	40.5	43.7	42.3	42.2	44.1	46.6	45.1	45.3
Control	50.5	47.4	46.4	48.1	49.6	47.5	46.6	47.9
Mean	39.5	41.4	40.1		41.7	43.8	42.6	
C.D. at 5%	Variety: 1.35 Spacing: 2.13 Variety × Spacing: NS				Variety: 1.50 Spacing: 2.16 Variety × Spacing: NS			

Table 7: Grain and straw yield of wheat varieties under different poplar spacings

Spacing (m)	Grain yield (t/ha)				Straw yield (t/ha)			
	Variety			Mean	Variety			Mean
	WH-1105	HD-2967	WH-711		WH-1105	HD-2967	WH-711	
3 × 3	2.30	2.55	2.33	2.39	2.71	3.07	2.84	2.87
4× 3	2.61	2.90	2.63	2.71	3.08	3.48	3.22	3.26
5× 3	2.78	3.12	2.83	2.91	3.27	3.72	3.44	3.48
6 × 3	2.98	3.33	3.02	3.11	3.50	3.95	3.72	3.72
7 × 3	3.16	3.52	3.19	3.29	3.75	4.15	3.92	3.94
8 × 3	3.66	4.10	3.72	3.83	4.07	4.42	4.18	4.22
Control	4.62	4.37	4.24	4.41	5.60	5.86	5.79	5.75
Mean	3.16	3.41	3.14		3.71	4.09	3.87	
C.D. at 5%	Variety: 0.011 Spacing: 0.017 Variety × Spacing: 0.029				Variety: 0.025 Spacing: 0.038 Variety × Spacing: NS			

Similarly, previous studies have indicated that when photosynthetically active radiation (PAR) is reduced by 40-60%, wheat yield may decline by 25-80% compared with full sunlight conditions (Artru *et al.,* 2017; Lakshmanakumar *et al.,* 2013). Tree-crop competition in agroforestry systems significantly affects the productivity of intercropped winter wheat, with yield reductions ranging from 15 to 65% relative to control conditions, depending on tree age (Chauhan *et al.,* 2012). Overall, the results of the present investigation indicate that wider poplar spacing (8×3 m) is more suitable for wheat cultivation, particularly for the variety HD-2967, which exhibited superior growth and yield performance under agroforestry conditions. The results of the present study are in agreement with several studies conducted in silvoarable systems, which reported that yield reductions were primarily due to decreased light availability near tree rows, while water competition was not considered a major limiting factor (Reynolds *et al.,* 2007; Carrier *et al.,* 2019; Mantino *et al.,* 2019).

CONCLUSION

The present study demonstrated that poplar spacing significantly influences light availability, growth, and productivity of wheat varieties under poplar based agroforestry systems in the semi-arid conditions of Haryana. Wider spacing (8×3 m) improved tree diameter and enhanced light penetration to the understory crops, thereby reducing competition between trees and crops. Among the different spacings, 8×3 m spacing provided the most favorable conditions for wheat growth and yield, while closer spacing (3×3 m) resulted in substantial reductions due to increased competition for light, moisture, and nutrients. Wheat variety HD-2967 consistently exhibited superior growth, yield attributes, and grain yield compared with WH-1105 and WH-711 under all spacings. The results indicate that integration of HD-2967 with poplar planted at 8×3 m spacing is a suitable option for sustaining wheat productivity in poplar based agroforestry systems of semi-arid Haryana. These findings highlight the importance of appropriate tree spacing and crop variety selection for optimizing productivity and sustainability of agroforestry systems.

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REFERENCES

Artru, S., Garre, S., Dupraz, C., Hiel, M., Blitz-Frayret, C., & Lassois, L. (2017). Impact of spatio-temporal shade dynamics on wheat growth and yield: Perspectives for temperate agroforestry. *European Journal of Agronomy, 82*, 60–70.

Carrier, M., Gonzales, F. A. R., Cogliastro, A., Olivier, A., Vanasse, A., & Rivest, D. (2019). Light availability, weed cover and crop yields in second generation temperate tree-based intercropping systems. *Field Crops Research, 239*, 30–37.

Chauhan, S. K., Brar, M. S., & Sharma, R. (2012). Performance of poplar and its effect on wheat yield under agroforestry system. *Caspian Journal of Environmental Sciences, 10*(1), 53–60.

Chauhan, S. K., Sharma, R., & Dhillon, W. S. (2011). Poplar based agroforestry systems for enhancing crop productivity and resource use efficiency. *Indian Journal of Agroforestry, 13*(2), 37–42.

Dhillon, R. S., Bangarwa, K. S., Beniwal, R. S., Bhardwaj, K. K., Handa, A. K., Kumari, S., Chavan, S. B., Rizvi, R. H., Sirohi, C., & Sheokand, R. N. (2017). Effect of spacing on crop yield and soil nutrient status under poplar based agroforestry system. *Indian Journal of Agroforestry, 19*(1), 42–47.

Dufur, L., Metay, A., Talbot, G., & Dupraz, C. (2013). Assessing light competition for cereal production in temperate agroforestry systems using experimentation and crop modelling. *Journal of Agronomy and Crop Science, 199*, 217–227.

Dupraz, C., Liagre, F., Talbot, G., & Lawson, G. (2019). Agroforestry systems and light interception dynamics in tree–crop interactions. *Agriculture, Ecosystems and Environment, 265*, 111–121.

Eichhorn, M. P., Paris, P., Herzog, F., Incoll, L. D., Liagre, F., Mantzanas, K., Mayus, M., Moreno, G., Papanastasis, V. P., Pilbeam, D. J., Pisanelli, A., & Dupraz, C. (2006). Silvoarable systems in Europe—Past, present and future prospects. *Agroforestry Systems, 67*, 29–50.

Gandhi, J. N., & Dhiman, R. C. (2010). Performance of wheat intercropped under different tree spacings of *Populus deltoides* plantation. *Indian Journal of Agroforestry, 12*(2), 41–48.

Kaur, N., Singh, B., & Gill, R. I. S. (2010). Agro-techniques for increasing productivity of wheat (*Triticum aestivum* L.) under poplar (*Populus deltoides*) plantation. *Indian Journal of Agronomy, 55*(1), 68–74.

Kumar, A., Gupta, N., Singh, B., & Chaturvedi, O. P. (2019). Productivity and carbon sequestration potential of poplar based agroforestry systems in north-western India. *Forest Ecology and Management, 448*, 87–92.

Lakshmanakumar, P., Bana, O. P. S., & Guru, S. K. (2013). Physiological basis of yield variability in wheat (*Triticum aestivum* L.) under varying degree of shade. *Indian Journal of Plant Physiology, 18*, 164–168.

Mantino, A., Volpi, I., Micci, M., Pecchioni, G., Bosco, S., Dragoni, F., Mele, M., & Ragaglini, G. (2019). Effect of tree presence and soil characteristics on soybean yield and quality in an innovative alley-cropping system. *Agronomy, 10*, 52.

Neto, A. S., Panozzo, A., Piotto, S., Mezzalira, G., Furlan, L., & Vamerali, T. (2024). Screening old and modern wheat varieties for shading tolerance within a specialized poplar plantation for agroforestry farming systems implementation. *Agroforestry Systems, 98*, 2765–2783. https://doi.org/10.1007/s10457-024-00956-1

Piotto, S., Panozzo, A., Pasqualotto, G., Carraro, V., Barion, G., Mezzalira, G., Furlan, L., Moore, S. S., & Vamerali, T. (2024). Phenology and radial growth of poplars in wide alley agroforestry systems and the effect on yield of annual intercrops in the first four years of tree age. *Agriculture, Ecosystems and Environment, 361*, 108814. https://doi.org/10.1016/j.agee.2023.108814

Reisner, Y., de Filippi, R., Herzog, F., & Palma, J. (2007). Target regions for silvoarable agroforestry in Europe. *Ecological Engineering, 29*, 401–418.

Reynolds, P. E., Simpson, J. A., Thevathasan, V. N., & Gordon, A. M. (2007). Effects of tree competition on corn and soybean photosynthesis, growth and yield in a temperate tree-based agroforestry intercropping system in southern Ontario, Canada. *Ecological Engineering, 29*, 362–371.

Singh, B., Gill, R. I. S., & Kaur, N. (2022). Performance of poplar plantation under different nutrient levels in an agroforestry system. *Indian Forester, 148*(5), 487–494.

Sirohi, C., Bangarwa, K. S., Dhillon, R. S., Chavan, S. B., & Handa, A. K. (2022b). Productivity of wheat (*Triticum aestivum* L.) and soil fertility with poplar (*Populus deltoides*) agroforestry system in the semi-arid ecosystem of Haryana, India. *Current Science, 122*(9), 1072–1080.

Sirohi, C., Dhillon, R. S., Chavan, S. B., Handa, A. K., Balyan, P., Bhardwaj, K. K., Kumari, S., & Ahlawat, K. S. (2022a). Development of poplar-based alley crop system for fodder production and soil improvements in semi-arid tropics. *Agroforestry Systems, 96*, 731–745. https://doi.org/10.1007/s10457-022-00735-w

Sirohi, C., Dhillon, R. S., Handa, A. K., Kumar, P., Bhardwaj, K. K., Kumari, S., Ahlawat, K. S., & Chavan, S. B. (2020). Promising wheat cultivars for poplar (*Populus deltoides* Bartr. ex Marsh.) based agroforestry system in semi-arid ecosystem of northern India. *Indian Journal of Agroforestry, 22*(1), 31–37.

Sirohi, C., Kumar, P., Dhillon, R. S., Bhardwaj, K. K., Kumari, S., & Ahlawat, K. S. (2022). Response of nitrogen levels on growth and yield attributes of wheat varieties under poplar based agroforestry system in northern India. *Indian Journal of Agroforestry, 24*(2), 71–75.

Smith, J., Pearce, B. D., & Wolfe, M. S. (2013). A European perspective for developing modern agroforestry systems. *Biomass and Bioenergy, 54*, 1–10.

Swieter, A., Langhof, M., Lamerre, J., & Greef, J. M. (2021). Light availability and crop performance in agroforestry systems with poplar trees. *Agriculture, Ecosystems and Environment, 314*, 107503.

Torralba, M., Fagerholm, N., Burgess, P. J., Moreno, G., & Plieninger, T. (2016). Do European agroforestry systems enhance biodiversity and ecosystem services? *Agroforestry Systems, 90*, 759–773.

Xu, C. L., Tao, H. B., Wang, P., & Wang, Z. L. (2016). Slight shading after anthesis increases photosynthetic productivity and grain yield of winter wheat (*Triticum aestivum* L.) due to delayed leaf senescence. *Journal of Integrative Agriculture, 15*, 63–75.

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