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EVALUATION OF AGRICULTURAL CROPS UNDER WILLOW BASED CROPPING SYSTEM IN SEMI-ARID ECOSYSTEM OF HARYANA

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SUMMARY

A field experiment was conducted to assess the performance of *Rabi* crops under a willow (*Salix alba*) based agroforestry system. Clonal willow seedlings were planted in February 2018 at a spacing of 3×3 m. During *Rabi* 2020-21, wheat (HD-2967) and barley (BH-393) were grown as intercrops. Tree growth parameters recorded after crop harvest showed substantial increases, with height rising from 5.4 to 6.7 m, DBH from 6.9 to 9.9 cm and basal diameter from 10.1 to 12.9 cm. Wheat grown under willow exhibited significantly reduced plant height and physiological parameters (photosynthetic rate, transpiration rate and stomatal conductance) compared to open conditions. Consequently, wheat grain yield of wheat declined from 4.97 to 2.40 t ha^{-1} (51.71% reduction), while barley yield decreased from 4.18 to 2.41 t ha^{-1} under the willow based agroforestry system (AFS). Yield attributes such as number of effective tillers, spike length, grains per spike and test weight were significantly lower in AFS compared to the sole cropping system. The benefit-cost ratio was also reduced under willow based AFS compared with the open condition. The study indicates that reduced light availability under willow significantly constrains the growth, physiology and productivity of intercrops.

Key words: *Salix alba*, light interception, physiological parameters, wheat yield and barley yield

Agroforestry systems have gained increasing attention worldwide as an effective approach to address challenges related to land degradation, climate variability and food security. In India, agroforestry has been recognized as an important strategy for achieving sustainable agricultural production, particularly in regions facing limited natural resources and environmental stress (Rizvi *et al.,* 2021). In semi-arid regions of northern India, particularly in Haryana and adjoining states, farmers traditionally cultivate agricultural crops under tree-based systems such as poplar, eucalypts and other fast-growing species. These agroforestry systems contribute significantly to rural livelihoods by providing timber, fuelwood, fodder and environmental benefits in addition to agricultural production. The adoption of tree-based farming systems also improves the resilience of agricultural landscapes by optimizing resource utilization and enhancing soil health (Kumar *et al.,* 2022). Among various tree species used in agroforestry systems, willow (*Salix alba*) has emerged as an important multipurpose tree species because of its rapid growth, coppicing ability, adaptability to diverse soil and climatic conditions and multiple economic uses. Willow species are widely cultivated in agroforestry systems due to their ability to produce large amounts of biomass within a short rotation period. The species is valued for timber, fuelwood, fodder, basketry materials and environmental protection. Additionally, willow plantations contribute to ecological sustainability by improving soil properties, reducing erosion and providing shade and shelter for crops and livestock (Rawat and Everson, 2013).

In agroforestry systems, the interaction between trees and crops plays a crucial role in determining overall productivity. These interactions may be either beneficial or competitive depending on factors such as tree spacing, canopy architecture, root distribution and crop species. Trees can positively influence crop growth through microclimate moderation, improved nutrient cycling and increased organic matter in the soil. However, competition for light, water and nutrients may also occur, particularly when trees develop dense canopies or extensive root systems. Therefore, understanding tree-crop interactions is essential for optimizing productivity and sustainability of agroforestry systems. One of the major factors influencing crop performance in tree-based systems is light availability under the tree canopy. As trees grow older, canopy expansion reduces solar radiation reaching the understory crops, thereby affecting physiological processes such as photosynthesis, transpiration and stomatal conductance. Reduced light intensity often leads to decreased crop growth and yield. Studies have shown that crops grown under willow based agroforestry systems exhibit significant variations in physiological parameters compared with crops grown under open conditions (Kumari *et al.,* 2024).

Several studies have investigated the performance of different crops under willow based agroforestry systems. Kumari *et al.* (2024) observed that wheat, barley, sorghum and mustard grown under willow plantations exhibited reduced photosynthetic rate, plant height and yield compared with sole cropping systems due to reduced light availability beneath the tree canopy. Similarly, Ahlawat *et al.* (2025) reported that sorghum grown under willow plantations showed significant reductions in growth parameters and fodder yield compared with open field conditions, highlighting the strong influence of tree shade on crop productivity. Despite these limitations, agroforestry systems offer several long-term advantages. Trees contribute to improved soil fertility through litter fall and nutrient recycling. The presence of trees enhances soil organic carbon and nutrient availability, thereby improving soil structure and overall soil health. Long-term studies on tree-based agroforestry systems have demonstrated improvements in soil organic carbon, nitrogen, phosphorus and potassium compared with sole cropping systems (Kumar *et al.,* 2022).

In Haryana, where agriculture is predominantly practiced under semi-arid climatic conditions, increasing pressure on land resources has necessitated the adoption of sustainable land-use systems. Agroforestry offers an effective approach to enhance land productivity while maintaining ecological balance. Fast growing tree species such as willow can be integrated with agricultural crops to develop productive and sustainable farming systems suitable for semi-arid environments. However, the success of such systems depends on the selection of compatible crops and proper management practices that minimize competition between trees and crops. Evaluation of agricultural crops under willow based cropping systems is therefore essential to identify suitable crop combinations and management practices for maximizing productivity. Understanding the growth performance, physiological responses and yield potential of crops under tree canopies can help develop efficient agroforestry models for farmers in semi-arid regions. Furthermore, quantifying the effects of tree shade and resource competition on crop productivity will contribute to designing improved tree spacing and crop management strategies.

Considering the importance of agroforestry for sustainable agriculture and the potential role of willow as a multipurpose tree species, the present study was undertaken to evaluate the performance of agricultural crops under a willow based cropping system in the semi-arid ecosystem of Haryana. The study aims to assess tree growth, light availability, crop growth parameters, physiological traits and yield attributes in order to understand the tree-crop interactions and identify suitable crop combinations for willow based agroforestry systems.

MATERIALS AND METHODS

The present study was conducted at the research farm of the Department of Forestry, Chaudhary Charan Singh Haryana Agricultural University (CCS HAU), Hisar, Haryana, located at 29°102 N latitude and 75°462 E longitude with an altitude of 215 m above mean sea level. In this experiment, clonal seedlings of willow (*Salix alba*) were planted in February 2018 at a spacing of 3×3 m in the research field. During the *Rabi* season of 2020-21, wheat (HD-2967) and barley (BH-393) were grown as intercrops under willow based agroforestry system. The crops were cultivated following the recommended package of practices prescribed by CCS HAU, Hisar. Observations on growth parameters, yield attributes and yield of the crops were recorded during the course of the study.

RESULTS AND DISCUSSION

Growth performance of willow

The growth performance of willow during July 2020 to April 2021 is presented in Table 1. The results indicated a substantial increase in the growth parameters of willow during the study period. Tree height increased from 5.4 m in July 2020 to 6.7 m in April 2021, showing an increment of 1.3 m (24.07%). Similarly, diameter at breast height (DBH) increased from 6.9 cm to 9.9 cm, representing an increase of 3.0 cm (43.48%), while basal diameter increased from 10.1 cm to 12.9 cm, recording an increment of 2.8 cm (27.72%). The continuous increase in height, DBH and basal diameter indicates the vigorous growth potential of willow under semi-arid climatic conditions. The rapid growth may be attributed to the fast-growing nature of willow species, efficient nutrient uptake and high photosynthetic efficiency. The spacing of 3×3 m likely provided adequate growing space and reduced intra-specific competition, thereby promoting better stem and canopy development. The results further suggest that the presence of intercrops did not significantly suppress the growth of willow trees during the experimental period. Similar observations were reported by Ahlawat et al. (2025) who reported that willow trees grown under agroforestry systems showed significant increments in tree height and DBH under a spacing of 3×3 m, indicating the suitability of willow for tree-crop integration systems.

Likewise, Rizvi *et al.* (2021) reported that *Salix alba* is widely adopted in agroforestry systems due to its rapid growth, high biomass production and adaptability to diverse agro-climatic conditions. The rapid growth of willow trees observed in the present study is consistent with earlier findings that willow species are capable of producing high biomass within short rotation periods, making them suitable for agroforestry systems aimed at increasing land productivity.

Soil properties

The soil chemical properties of the experimental field are presented in Table 2. The soil was non- saline, low in organic carbon and available nitrogen, medium in available P and K. The soil at 0-15 cm depth had a pH of 7.21, indicating neutral to slightly alkaline soil reaction, which is considered favourable for the growth of most agricultural crops. The electrical conductivity (EC) of the soil was 0.49 dS m^{-1}, indicating that the soil was non-saline and suitable for crop cultivation. The organic carbon content was recorded as 0.38%, which falls under the low fertility category, indicating low organic matter content in the soil. Similarly, the available nitrogen content was 134.8 kg ha^{-1}, which is considered low. However, the available phosphorus (12.3 kg ha^{-1}) and available potassium (290.1 kg ha^{-1}) were recorded in the medium fertility range, suggesting moderate availability of these nutrients for crop growth. Low organic carbon and nitrogen levels are commonly observed in soils of semi-arid regions due to high temperatures and rapid decomposition of organic matter. However, agroforestry systems have been reported to improve soil fertility through litter fall, root turnover and enhanced nutrient cycling.

In tree-based systems, leaf litter deposition and root biomass contribute to increased soil organic

TABLE 1
Growth performance of willow during July, 2020 -April, 2021

Tree spacing (m)	Tree height (m)		DBH (cm)		Basal diameter (cm)	
	July, 2020	April, 2021	July, 2020	April, 2021	July, 2020	April, 2021
3×3	5.4	6.7	6.9	9.9	10.1	12.9

TABLE 2
Soil chemical properties of the experimental field

Depth (cm)	pH	$EC_{1:2}$ (dS/m)	OC (%)	Available nutrients(kg/ha)		
				N	P	K
0-15	7.21	0.49	0.38	134.8	12.3	290.1

carbon and nutrient availability over time. Similar findings were reported by Kumar *et al.* (2022) who observed that agroforestry systems significantly improved soil organic carbon and nutrient status compared with sole cropping systems due to improved nutrient recycling and organic matter accumulation. These results are in agreement with the findings of Sirohi and Bangrwa (2017), who reported enhanced availability of soil nutrients under poplar based cropping systems. Likewise, Sirohi *et al.* (2022b) also observed significantly higher availability of nitrogen (N), phosphorus (P) and potassium (K) in poplar windbreak agroforestry systems as compared to sole cropping systems. Similarly, Ahlawat *et al.* (2025) reported that willow based agroforestry systems improved soil properties through increased litter deposition and biological activity in the soil profile. The results of the present study therefore indicate that although the initial soil fertility status of the experimental field was low in organic carbon and nitrogen, integration of trees with crops in agroforestry systems may improve soil health and nutrient availability over time.

Light intensity under willow based agroforestry system

The availability of solar radiation plays a crucial role in determining the growth and productivity of crops grown under agroforestry systems. The per cent light intensity available to crops under the willow based agroforestry system compared with open conditions during October, 2020 to April, 2021 is presented in Table 3. The results revealed considerable variation in light availability under the willow canopy during different months and times of the day. The mean light intensity ranged from 34.31% in November 2020 to 49.15% in February 2021 compared with open conditions. Among the months studied, February recorded the highest mean light availability (49.15%), followed by January (47.28%), whereas the lowest mean light intensity was observed in November (34.31%). The diurnal pattern of light intensity indicated that maximum light availability occurred during mid-day hours (1 PM) in all months, while relatively lower light availability was observed during early morning (7 AM) and late evening (5 PM). For instance, in February 2021, the light intensity increased from 44.79% at 7 AM to 54.68% at 1 PM, followed by a decline to 48.18% at 5 PM. Similar trends were observed during other months, indicating that canopy shading effects were less pronounced during mid-day due to the higher solar angle.

The reduction in light intensity under trees compared with open conditions can be attributed to canopy development, leaf area index and crown architecture of willow trees. During winter months (December-February), partial leaf fall and lower canopy density may allow relatively higher penetration of sunlight, which explains the higher light intensity recorded during January and February. In contrast, during October and November, denser foliage and canopy overlap may have reduced solar radiation reaching the understory crops. Similar observations were reported by Sirohi *et al.* (2022) who studied tree-crop interactions under poplar based agroforestry systems and reported that light availability under tree canopies varied significantly with season. The authors reported that light intensity under agroforestry systems generally ranged between 30-60% of open conditions, which significantly influenced crop growth and productivity. Likewise, Chavan *et al.* (2023) reported that reduced light availability under tree based systems significantly influenced crop photosynthesis and growth parameters due to shading effects. Their study demonstrated that canopy architecture and tree density play an important role in regulating the amount of solar radiation reaching the understory crops. Similar findings were also reported by Jose *et al.* (2021) in

TABLE 3

Per cent light intensity available under willow based agroforestry system over control during October, 2020- April, 2021

Month	Per cent light available to crop under willow based agroforestry system over control						
	7 AM	9 AM	11 AM	1 PM	3 PM	5 PM	Mean
October, 2020	31.42	32.82	35.64	39.15	36.18	33.84	34.84
November, 2020	31.15	32.15	34.49	39.70	35.19	33.15	34.31
December, 2020	37.62	39.15	42.64	46.59	42.94	40.18	41.52
January, 2021	42.89	44.68	47.69	52.64	49.64	46.15	47.28
February, 2021	44.79	46.89	49.15	54.68	51.18	48.18	49.15
March, 2021	38.62	40.15	43.13	47.89	44.68	41.64	42.69
April, 2021	35.12	37.94	40.15	45.16	41.54	38.14	39.68

agroforestry systems where light availability under tree canopies varied significantly depending on canopy structure and seasonal variations. The authors reported that light interception by trees is one of the major factors determining crop performance in agroforestry systems. The results of the present study therefore indicate that willow based agroforestry systems significantly influence light availability to understory crops.

Crop growth studies of wheat and barley

Plant height of wheat and barley

The plant height of wheat and barley recorded under willow based agroforestry system and open conditions (control) is presented in Table 4 and 8. The results indicated significant variation in plant height between agroforestry system and sole cropping system at all growth stages. At 30 days after sowing (DAS), wheat grown under willow recorded a plant height of 24.31 cm, which was considerably lower than the plant height recorded under the control (32.57 cm). Similarly, at 60 DAS, wheat plants under the willow system attained a height of 45.21 cm, whereas the plants grown under open conditions recorded 64.65 cm. At 90 DAS, plant height under willow was 64.97 cm, while the control recorded 87.59 cm. At 120 DAS, wheat under willow attained 71.65 cm, whereas under open conditions plant height reached 94.58 cm, indicating substantial suppression of plant growth under the tree canopy.

At harvest, the plant height under willow was 71.72 cm, compared with 95.75 cm under the control. The reduction in plant height under the tree canopy can be primarily attributed to reduced light availability due to shading by the willow trees. In the present study, the reduced plant height of wheat under willow

TABLE 4

Plant height (cm) at different time intervals in wheat under willow based agroforestry system and control (devoid of tree)

Treatment	Plant height (cm)				At harvest
	30 DAS	60 DAS	90 DAS	120 DAS	
With Willow #	24.31	45.21	64.97	71.65	71.72
Control (Devoid of tree)	32.57	64.65	87.59	94.58	95.75
t-value	13.89**	16.84**	14.08**	13.23**	13.77**

**Significant at 0.01 per cent level of P, # Willow planted at a spacing of 3×3 m.

TABLE 5

Physiological parameters in wheat under willow based agroforestry system and control (devoid of tree)

Treatment	Chlorophyll (CCI)	Photosynthesis rate (μ mol CO_2 m^{-2} s^{-1})	Transpiration rate (m mol H_2O m^{-2} s^{-1})	Stomatal conductance (mol m^{-2} s^{-1})
		After 7 days of anthesis		
With Willow #	30.4	10.11	4.67	0.21
Control (Devoid of tree)	23.7	15.87	9.27	0.42
t-value	12.35**	20.80**	28.06**	24.74**

**Significant at 0.01 per cent level of P, # Willow planted at a spacing of 3m×3 m.

TABLE 6

Yield and yield attributes of wheat under willow based agroforestry system and control (devoid of tree)

Treatment	Number of effective tillers (m^{-2})	Maturity days (No.)	Length of spike (cm)	Number of grains/spike (No.)	Test weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)	B:C ratio
With Willow#	207.45	149.57	9.57	27.56	28.87	2.40	3.10	5.50	0.76
Control (Devoid of tree)	312.57	140.27	11.97	40.88	41.67	4.97	6.41	11.38	1.57
t-value	19.13**	12.77**	10.79**	18.86**	19.45**	30.41**	29.67**	37.32**	

**Significant at 0.01 per cent level of P, # Willow planted at a spacing of 3m×3 m.

TABLE 7
Physiological parameters in barley under willow based agroforestry system and control (devoid of tree)

Treatment	Chlorophyll (CCI)	Photosynthesis rate (μ mol CO_2 m^{-2} s^{-1})	Transpiration rate (m mol H_2O m^{-2} s^{-1})	Stomatal conductance (mol m^{-2} s^{-1})
		After 7 days of anthesis		
With Willow#	29.9	5.78	2.39	0.10
Control (Devoid of tree)	22.8	8.41	4.15	0.17
t-value	12.23**	17.02**	23.21**	22.47**

**Significant at 0.01 per cent level of P, # Willow planted at a spacing of 3m×3 m.

TABLE 8
Growth, yield and yield attributes of barley under willow based agroforestry system and control (devoid of tree)

Treatment	Plant height at harvest (cm)	Number of effective tillers (m^{-2})	Maturity days (No.)	Length of spike (cm)	No. of grains/ spike (No.)	Test weight (g)	Grain yield (t/ha)	Straw yield (t/h)	Biological yield (t/ha)	B:C ratio
With Willow #	87.98	256.58	129.37	6.12	36.54	34.54	2.41	3.42	5.83	0.73
Control (Devoid of tree)	110.58	352.87	124.67	7.48	47.54	41.44	4.18	5.52	9.70	1.26
t-value	10.69**	14.62**	1.73*	11.87**	15.69**	11.51**	28.35**	26.29**	36.49**	

**Significant at 0.01 per cent level of P, # Willow planted at a spacing of 3m×3 m.

trees may be attributed to decreased light penetration, competition for nutrients and moisture, and changes in microclimatic conditions under the tree canopy. Similar findings were reported by Sirohi *et al.* (2022), who observed significantly reduced plant height of wheat under poplar based agroforestry systems compared with open conditions due to shading effects and tree-crop competition. Likewise, Kumar *et al.* (2022) reported that wheat grown under agroforestry systems recorded significantly lower plant height compared with sole cropping systems due to reduced light interception and competition for resources under tree canopies. Similarly, Jose *et al.* (2021) highlighted that shading is one of the major factors influencing crop growth in agroforestry systems and that reduced photosynthetically active radiation under tree canopies leads to decreased plant height and biomass production. The results of the present study therefore indicate that the willow canopy significantly reduced light availability to wheat plants, which in turn affected plant growth at different stages of development. However, agroforestry systems still provide long-term ecological and economic benefits through tree biomass production, improved soil fertility and diversified farm income.

Barley grown under willow based agroforestry system attained a height of 87.98 cm, whereas plants grown under the control (devoid of trees) recorded a significantly higher plant height of 110.58 cm. Similar findings were reported by Sirohi *et al.* (2021), who observed significant reductions in barley growth parameters when grown under eucalypts based agroforestry systems in the semi-arid region of Haryana. Their study reported that tree canopies significantly influenced crop growth due to shading and resource competition.

Physiological parameters of wheat and barley under willow based agroforestry system

The physiological parameters of wheat and barley recorded seven days after anthesis under willow based agroforestry system and open field conditions (control) are presented in Table 5 and 7. Significant variations were observed between the two growing conditions for chlorophyll content, photosynthetic rate, transpiration rate and stomatal conductance. In wheat, chlorophyll content was higher under willow plantation (30.4 CCI) compared with open conditions (23.7 CCI). Similarly, in barley, chlorophyll content was also significantly higher under willow canopy (29.9 CCI) than in open conditions (22.8 CCI). However, photosynthesis rate, transpiration rate and stomatal conductance were significantly higher in open conditions for both the crops. In wheat crop, photosynthetic rate decreased from 15.87 μmol $CO_2 m^{-2} s^{-1}$ in open conditions to 10.11 μmol CO_2 m^{-2} s^{-1} under willow canopy. Similarly, transpiration rate declined from 9.27 to 4.67 mmol H_2O m^{-2} s^{-1}, while stomatal conductance decreased from 0.42 to 0.21 mol m^{-2} s^{-1}. A similar trend was observed in barley where photosynthesis rate decreased from 8.41 to 5.78 µmol $CO_2 m^{-2}$ s^{-1} under willow canopy. Transpiration rate and stomatal conductance were also significantly reduced under tree canopy with t-values of 23.21 and 22.47, respectively.

Reduced radiation under tree canopy directly affects stomatal conductance and photosynthetic efficiency in C_3 crops like wheat and barley. Similar findings were reported by Cozzi *et al.* (2019) who observed that cereal crops grown under shaded agroforestry conditions showed lower photosynthetic rates but increased chlorophyll concentration as a physiological adaptation to shade. Similar reductions in physiological activities of wheat grown under tree canopies were reported by Jatav *et al.* (2025) in a shisham based agroforestry system, where wheat grown under tree shade exhibited lower photosynthetic efficiency and yield compared with open conditions.

Yield and yield attributes of wheat and barley

Yield attributes and yield of wheat and barley under willow based agroforestry system and open conditions are presented in Table 6 and 8. All yield parameters showed significant variation between treatments. In wheat crop, the number of effective tillers decreased significantly under willow plantation (207.45 m^{-2}) compared with open conditions (312.57 m^{-2}). Spike length, number of grains per spike and test weight were also significantly reduced under tree canopy with t-values of 10.79, 18.86 and 19.45, respectively. Consequently, grain yield decreased from 4.97 t ha^{-1} under open conditions to 2.40 t ha^{-1} under willow plantation, representing a yield reduction of 51.71 %. Straw yield and biological yield also exhibited the similar trends. In barley, the number of effective tillers was significantly higher under open conditions (352.87 m^{-2}) than under willow based AFS (256.58 m^{-2}). Grain yield varied from 2.41 t ha^{-1} under willow to 4.18 t ha^{-1} in open conditions, indicating a yield reduction of 29.53 % under tree canopy.

Similar results have been reported by Sirohi *et al.* (2022a) observed significant reductions in yield under tree based agroforestry systems due to competition for light, water and nutrients between trees and crops. They reported that cereal yield reduction under agroforestry may vary from 20% to 60% depending on tree species and canopy density. Furthermore, Artru *et al.* (2017) and Yang *et al.* (2019) emphasized that shading from trees reduces solar radiation interception by crops, resulting in reduced tiller formation and grain filling in cereals grown in agroforestry systems.

Economic analysis also revealed higher profitability under open conditions. The benefit-cost ratio ranged from 0.76 to 1.57 in wheat and 0.73 to 1.26 in barley, indicating that cereal cultivation alone was more profitable under open conditions compared with agroforestry conditions at the existing tree spacing (3×3 m). However, agroforestry systems may provide long-term economic and ecological benefits through timber production, carbon sequestration and improved soil fertility

CONCLUSION

The study demonstrated that willow based agroforestry systems significantly influence the growth, physiology and productivity of *Rabi* crops by modifying the microenvironment, particularly light availability under the canopy. Wheat and barley grown under willow canopy showed variations in plant height, physiological parameters and yield attributes compared to crops grown in open conditions. Although grain yield of both crops was comparatively lower under willow based agroforestry system, the system offers opportunities for integrating tree and crop production on the same land. The findings suggest that appropriate management practices, such as wider spacing, regular pruning, and the use of shade-tolerant crop varieties, can enhance intercrop performance, making willow based agroforestry a sustainable and viable land use option.

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