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PHYSIOLOGICAL RESPONSES OF FIELD CROPS UNDER WILLOW BASED AGROFORESTRY SYSTEM

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SUMMARY

The present work was conducted to study the effect of willow (*Salix alba*) based agroforestry system (AFS) on physiological and yield responses of different crops. Sorghum (*Sorghum bicolor*), wheat (*Triticum aestivum*), barley (*Hordeum vulgare*) and mustard (*Brassica juncea*) were sown in their respective seasons with willow intercropping (5-year old willow based agroforestry system with a spacing of 3m×3m) and without willow intercropping *i.e.* as sole crop in open fields. Willow growth parameters, including basal diameter (14.35 cm) and DBH (12.19 cm) were recorded during the study. Observations were recorded on growth, physiological traits, yield attributes and economics of the intercropped species compared to their respective sole crop under willow based AFS. A significant reduction in photosynthetic rate, plant height and yield parameters was observed in all the above crops with willow-based AFS compared to open-field sole cropping system. Fodder yield in sorghum ranged from 5.41 t/ha (with willow) to 40.90 t/ha (sole crop control) whereas grain yield of wheat and barley ranged from 1.76 t/ha (with willow) and 4.33 t/ha (open field), and 0.74 t/ha (with willow) and 3.91 t/ha (open field) respectively. However, mustard seed yield ranged 0.99 t/ha (with willow) to 1.88 t/ha (sole crop).

Key words: Agroforestry, barley, grain yield, green fodder, sorghum, mustard, wheat, willow

Increasing crop yield is one of agriculture's main objectives. It needs to be accomplished in a changing climate using environmentally friendly approaches that limit future detrimental effects of agriculture on the ecosystem while minimising the impact of climate change on crop development (Burgess *et al*., 2022). Livestock constitute a vital component of the rural economy, comparable to agriculture. India is having about 20% of world's livestock population with only 4.4% of the cultivated area under fodder production (Singh *et al*., 2021), resulting in undernourished livestock that fail to achieve optimal productivity. According to IGFRI vision 2050, there is deficiency of green fodder (35.6%), dry fodder (10.95%) and concentrate feed material (44%). To address this shortage, the adoption of agroforestry systems and the integration of multipurpose trees into existing farming practices appear promising.

Agroforestry is the practice of growing woody perennials trees along with crops, forages or animals on the same piece of land for the purpose of producing wood, fuel, or other agricultural products and promoting more efficient utilization of resources. In order to optimize maximum advantages, agroforestry system includes carefully pairing of crops and or animals with trees to get sustainable land use system (Schaffer *et al*., 2019). Many of the sustainable development goals could benefit from multiple cropping systems, such as SDG2- aims to end hunger; SDG13- addresses climate change; and SDG15- aims to improve life on land, especially by restoring degraded land and soil, including areas vulnerable to desertification, severe drought, and floods. In agroforestry systems trees can also improve water and nutrient use efficiency as they have better developed root system. Agroforestry system provides radiation protection, more soil organic carbon, activity of beneficial soil organisms. Tree roots can trap water and nutrients that are seeping down the soil profile under the crop rooting zone and help weather the bedrock or saprolite layers that are inaccessible to crops. They can also reduce evaporation through temperature and wind reduction (Lin, 2010).

Furthermore, hydraulic lift is a mechanism by which plants with deep roots may raise or transfer water to the top layers (Bayala and Prieto, 2020).

Willow (*Salix* L.) is one of the feasible alternative to traditional land use strategy for preserving or enhancing soil quality and achieving sustained biological output within an irrigated agricultural system. It belongs to the *Salicaceae* family; encompass a diverse group of dioecious trees and shrubs. The genus comprises 450-520 species distributed predominantly across the Northern Hemisphere. In India, there are about 33 Salix species, mostly categorized as shrubs, with notable exceptions such as *Salix alba, S. babylonica, S. daphnoids, S. fragilis, S. elegas,* and *S. tetrasperma.* Willow incorporation in agricultural fields can improve water quality by drastically reducing nitrate leachate levels, hence enhancing soil health and nutrient availability. Furthermore, willow buffers placed strategically can boost wheat output by reducing nutrient loss and increasing nutrient recovery. Tree species contribute a significant amount of litter fall, which impacts wheat crop development and production as it decomposes. Wheat and mustard intercropping are an ancient technique used mostly in northern India for stability and the need for both grains and oil.

Wheat (*Triticum aestivum* L.), a member of the *Poaceae* family, is a primary staple crop widely consumed worldwide, providing significant calories and protein to global populations. India, with the largest cultivated area, ranks second globally in wheat production after China. Mustard (*Brassica juncea*), a prominent oilseed crop in the *Cruciferae* family, is only second to peanuts in terms of significance among oilseed crops. The average productivity of rapeseed mustard in India stands at 1145 kg/ha, necessitating an increase to 2562 kg/ha by 2030 to ensure self-reliance in edible oil (DRMR, 2011). Barley (*Hordeum vulgare* L.) is a significant crop utilized extensively as livestock feed and in the production of malt for brewing and distilling industries. Barley is cultivated globally due to its adaptability and versatility in various environmental conditions (Ko *et al*., 2019). Sorghum (*Sorghum bicolor*) is a significant cereal crop serving as a primary food staple for many Asian populations. It ranks fifth among the world's most important cereals, following maize, wheat, rice, and barley (Yahaya *et al*., 2023). Researchers have highlighted sorghum's suitability for enhancing global food security due to its ability to thrive in high salinity environments, withstand biotic and abiotic stresses, and undergo dormancy during adverse environmental conditions. Global reports exist for several strains of sorghum, including grain, sweet, and forage sorghum (used for animal feed), and the purpose of cultivation extends from human consumption to the production of animal feed.

There is a significant imbalance between fodder supply and demand due to the diverse range of forage crops grown across different seasons and regions, often on degraded or marginal lands with minimal inputs. This shortage of high-quality fodder is exacerbated by a growing animal population, leading to reduced livestock productivity. It is observed that the yields of C_3 plants, such as winter wheat and winter barley, in intercropping systems have typically been the same as those in monocrop systems, sometimes even exceeding under drought conditions. Intercropping is one approach to boost production per unit area of land with scarce resources. Due to its many advantages, intercropping with agroforestry is still a popular technique. In light of potential yield increases, more effective solar energy usage, and improved land management that yields larger returns, intercropping study has recently been sparked to better understand the viability of the system (Chavda *et al*., 2023). Intercropping protects against disasters and promotes economic output *via* optimal use of natural resources. This study focuses on evaluating the physiological responses of sorghum, wheat, barley, and mustard under a willow-based agroforestry system, emphasizing growth, physiological parameters, yield attributes, and economic viability.

MATERIALS AND METHODS

The research work was conducted at the field research area of the Department of Forestry at CCS Haryana Agricultural University Hisar, located at 29°10' N latitude and 75°46' E longitude, at an altitude of 215.2 meters above mean sea level. Clonal seedlings of willow (*Salix alba*) were planted in February 2018 at a spacing of 3×3m in the experimental field. During the *Kharif* season of June 2022, Sorghum (HJ 541) was sown, followed by the sowing of wheat (HD 2967), barley (BH 393), and mustard (RH 30) during the *Rabi* season of 2022-23. The study assessed the growth, physiological parameters, yield attributes, and final yield of these different crops under a willow-based agroforestry system compared to a control setup without willow trees. The chlorophyll content was measured by using the 'SPAD 502 plus' equipment, measure the leaf's absorbance in two wavelength regions: red at 600-700 nm and blue at 400-500 nm. Leaf area was measured using CI-202 portable laser leaf area meter. To measure the photosynthetic rate (µmole CO_2 $m^{-2}s^{-1}$), transpiration rate (mmole H_2O $m^{-2}s^{-1}$), and stomatal conductance (mmole H_2O $m^{-2}s^{-1}$), an infrared gas analyzer (IRGA LCi-SD, ADC Biosciences) was used. The flag/third leaf from the top was placed within the assimilation chamber and adjusted in position to obtain the maximum PAR. Data was statistically analysed by Independent sample t-test to determine significant difference between treatments.

RESULTS AND DISCUSSION

Growth parameters of tree and soil properties

Growth parameters of the 5-year-old willow (*Salix alba*) were recorded during April, 2023 showed 12.19 cm DBH and 14.35 cm as basal diameter. The soil characteristics of the experimental field indicated non-saline conditions, low levels of organic carbon and available nitrogen (N) with moderate level of phosphorus (P) and potassium (K). Significantly higher concentrations of N (136.1 mg/kg), P (13.1 mg/kg), and K (294.1 mg/kg) were observed under a willow agroforestry system compared to monoculture cropping. The soil electrical conductivity (EC) measured at a 1:2 ratio was 0.41 dS/m, pH was 7.76, and organic carbon content was 0.42%. These findings are consistent with results reported by Sirohi *et al.* (2022b) under a poplar wind break agroforestry system compared to sole cropping.

Physiological responses of crops

Chlorophyll content, photosynthesis rate, transpiration rate, and stomatal conductance studied at 40 DAS in sorghum, 7 days after anthesis in wheat and barley and at 50% flowering in mustard crop differed significantly between plots with willow plantation and open plots (sole crop). Overall, most physiological parameters were higher in the control (sole crop) compared to the willow-based agroforestry system, except for chlorophyll content, which was higher in the agroforestry system (Table 1).

In sorghum chlorophyll content observed at 40 DAS was 11.6 in open conditions while 21.84 under tree shade conditions. Similarly higher chlorophyll content was recorded in wheat, barley and mustard under tree shade conditions as compared to sole crop *i.e.* open conditions. The higher chlorophyll content observed under the agroforestry system can be attributed to the development of larger light-harvesting complexes under reduced light conditions. This adaptation allows the plant to efficiently capture light energy, thereby increasing chlorophyll pigment

TABLE 1

Physiological parameters of different crops under willow based agroforestry system and control condition (devoid of trees)

Treatment	Chlorophyll (CCI)	Photosynthesis rate (µmol $CO_2m^{-2}s^{-1}$)	Transpiration rate (mmol $H_2Om^{-2}s^{-1}$)	Stomatal conductance ($molm^{-2}s^{-1}$)
		Physiological parameters of sorghum at 40 DAS		
With Willow#	21.84	4.27	1.81	0.05
Control (Without tree)	11.60	10.26	4.53	0.14
t-value	25.24**	42.69**	39.18**	45.12**
		Physiological parameters of wheat (After 7 days of anthesis)		
With Willow#	31.96	7.28	2.12	0.16
Control (Without tree)	22.85	13.39	6.19	0.29
t-value	7.55**	13.87**	21.36**	12.05**
		Physiological parameters of barley (After 7 days of anthesis)		
With Willow#	31.15	4.66	1.97	0.08
Control (Without tree)	22.39	7.87	3.74	0.14
t-value	8.79**	14.10**	11.66**	6.63**
		Physiological parameters of mustard (50% flowering)		
With Willow #	24.09	5.33	1.63	0.06
Control (Without tree)	17.80	10.71	3.84	0.26
t-value	5.80**	12.00**	9.96**	13.26**

** Significant at 0.01 per cent level of P, # spacing of 3 m × 3 m between willow trees.

concentration and total chlorophyll content. These findings align with previous research by Ahmed *et al.* (2020), who studied the influence of different *acacia* species on sorghum growth and physiological processes. Noor *et al.* (2024) reported a significant reduction in chlorophyll a content while increase in total chlorophyll and chlorophyll b content in bermudagrass in shaded environment. This increment in total chlorophyll content under shade condition may be due to conversion of chlorophyll a to chlorophyll b, which resulted in subsequently decrease in ratio of chlorophyll a/b (Wang *et al.,* 2022). Further reduction in photosynthetic, transpiration and stomatal conductance in all above studied crops was observed under willow-based agroforestry system as compared to sole crop (open condition) (Table 1) The reduction in gas exchange parameters of crops under shaded conditions may attributed due limited light quantum which leads to reduced leaf temperature, stomatal restrictions, lower stomatal conductance, decreased intercellular CO_2 concentration and reduction in photosynthesis. Similarly, reduction in photosynthesis under shade condition was observed by Yang *et al.* (2019) in forage crops and Wan *et al.* (2020) in *Paeonia* species.

Growth and yield of crops

In sorghum, significant variations were observed in plant height, leaf area, and green fodder yield between plots with willow trees and open control plots (Table 2). Green fodder yield ranged from 5.41 t/ha in the willow-based agroforestry system to 40.90 t/ha in the control, resulting in a substantial yield reduction of 86.77% in the willow plantation compared to the control. The Benefit-Cost (B: C) ratio in the experiment was 0.14, indicating a negative economic return in the willow-based agroforestry system. These findings are consistent with those of Birhane *et al.* (2018), who observed a 22% increase in aboveground biomass of sorghum under F. *albida* canopy compared to control plots. Dos Santos *et al.* (2023) reported lower forage biomass in SS46 (46.15% woody cover) as compared to SS30 (30% woody cover) and SS18 (17.64% woody cover) in the study of tropical garsses grown under nine silvopastoral system arranged in a strips of Caatinga vegetation trees.

In wheat, plant height showed significant differences between willow and open plots. This pattern was similarly observed for yield attributes such as grain yield and straw yield (Table 3). Grain yield ranged from 1.76 t/ha in the willow plantation to 4.33 t/ha in the open control, resulting in a yield reduction of 59.45% in the willow plantation compared to the control. The Benefit-Cost (B: C) ratio varied from 0.61 in plots with willow to 1.49 in control plots, indicating economic viability was better in the open control. Similarly, significant variations were observed in

TABLE 2

Growth, yield traits and economic performance of sorghum at harvest under a willow based agroforestry system and control condition (devoid of trees)

Treatment	Plant height (cm)	Leaf area (cm^2)/plant	Fodder yield (t/ha)	B:C ratio
With Willow#	52.29	756.83	5.41	0.14
Control (Without tree)	245.69	2368.22	40.90	1.08
t-value	56.40**	37.78**	58.31**	-

**Significant at 0.01 per cent level of P, # spacing of 3×3 m between willow trees.

TABLE 3

Growth, yield traits and economic performance of wheat under a willow-based agroforestry system and control condition (devoid of trees)

Treatment	Plant height (cm) at harvest	Number of effective tillers (m^{-2})	Number of grains/spikes (No.)	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)	B:C ratio
With Willow#	45.61	108.55	14.50	1.76	2.37	4.13	0.61
Control (Without tree)	88.15	274.25	33.85	4.33	5.67	10.00	1.49
t-value	29.73**	38.25**	32.64**	38.15**	33.88**	48.09**	-

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

physiological parameters, plant height, leaf area, fresh weight of leaf and stem, and green fodder yield of sorghum and barley crops under kadam plantation compared to sole crop conditions, as reported by Ahlawat *et al.* (2024).

Similar trends were observed in yield attributes, grain yield, and straw yield of barley (Table 4). Grain yield ranged from 0.74 t/ha in plots with willow trees to 3.91 t/ha in open control plots, indicating a significant yield reduction of 81.16% in the willow plantation compared to the control. The reduction in barley yield in the willow plantation was partly attributed to damage caused by birds. The B: C ratio varied from 0.26 in plots with willow to 1.28 in control plots, reflecting varying economic returns between the two systems.

The plant height of mustard varied from 121.72 cm in plots with willow trees to 174.78 cm in open control plots. Seed yield ranged from 0.99 t/ha in plots with willow to 1.88 t/ha in sole crop conditions, reflecting a significant yield reduction of 47.39% in the willow plantation compared to the control. Similar patterns were observed for stover yield and biological yield of mustard (Table 5). The B:C ratio varied from 0.87 to 1.66, indicating varying economic returns between plots with willow and open control.

Several studies have demonstrated that the primary factor for the intercrop's reduced output in agroforestry systems-where plant development is unrestricted by nutrients or water-is competition for light. Light intensity has various impacts on grain production at different development phases. This reduction in yield can be attributed to various factors such as root interference, above- and below-ground competition, and shading effects. Qiao *et al.* (2021) reported that the canopy of walnut trees reduced photosynthetically active radiation reaching the understory, resulting in decreased photosynthetic rates of intercropped wheat. This reduction contributed to decreased grain yield, spike number, grains per spike, and thousand-grain weight. Similar observations are recorded by Mohsin and Mohsin (2021), who noted significant decreases in yield parameters such as secondary branches per plant, siliqua per plant, and test weight of wheat and mustard under Eucalyptus and Poplar compared to open field conditions (crop grown without trees). Additionally, Mantino *et al.* (2023) studied the impact of poplar rows in an alley-cropping system on the productivity of soybeans and sorghum over a two-year rotation. They observed variations in light availability affecting the growth rates of two-year poplar rows in soybean-sorghum and sorghum-soybean rotations. At the tree-crop interface, there was a marked reduction of up to 74% in above-ground biomass, grain yield, and crop residue.

In the present study the B:C ratio varied from

TABLE 4

Growth, yield traits and economic performance of barely under a willow-based agroforestry system and control condition (devoid of trees)

Treatment	Plant height at harvest (cm)	Number of effective tillers (m^{-2})	Grain yield (t/ha)	Straw yield (t/h)	Biological yield (t/ha)	B:C ratio
With Willow#	38.09	51.50	0.74	1.25	1.99	0.26
Control (Without tree)	101.15	294.40	3.91	5.01	8.92	1.28
t-value	39.98**	56.12**	55.58**	39.27**	49.16**	-

**Significant at 0.01 per cent level of P, # spacing of 3×3 m between willow trees.

TABLE 5

Growth, yield traits and economic performance of mustard under a willow-based agroforestry system and control condition (devoid of trees)

Treatment	Plant height at harvest (cm)	Number of siliqua/plant (No.)	Seed yield (t/ha)	Stover yield (t/h)	Biological yield (t/ha)	B:C ratio
With Willow#	121.72	180.70	0.99	1.54	2.53	0.87
Control (Without tree)	174.78	303.20	1.88	2.93	4.81	1.66
t-value	17.02**	27.28**	28.45**	19.22**	31.38**	-

**Significant at 0.01 per cent level of P, # spacing of 3×3 m between willow trees.

0.14 - 1.08 (sorghum), 0.61 -1.49 (wheat), 0.26-1.28 (barely) and 0.87-1.66 (mustard) with willow based agroforestry system and control plots respectively, highlighting economic considerations between the different cropping systems. Significant increase in green fodder production was reported by Sirohi *et al.* (2022a), under a poplar-based agroforestry system as the spacing between rows increased from 3 to 8 meters. Similarly, Chavan *et al.* (2022) also reported decline ranged from 10% to 60% in green fodder biomass for *Kharif* crop (sorghum) and from 7.2% to 29.5% for *Rabi* crop (wheat) at distances up to nine meters from the poplar tree line. They concluded that wider spacing (8×3m) resulted in the highest green fodder yields thus intercropping sorghum-wheat rotations in an East-West poplar boundary plantation may generated higher farm incomes compared to traditional agricultural methods but increasing tree density can led to a reduction of 10% to 22% in the sorghum-berseem intercropping system.

CONCLUSION

Fodder yield of sorghum, wheat, barley and mustard was notably lower in the presence of a willow-based agroforestry system compared to the control. Agroforestry system can enable to land use system diversification towards more sustainable systems, thereby reduce the gap between demand and supply of fodder.

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