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GROWTH AND YIELD OF SORGHUM UNDER WILLOW BASED AGROFORESTRY SYSTEM IN NORTHERN INDIA

K. S. AHLAWAT[1]*, ANITA KUMARI[2], DALIP KUMAR[3], KAUTILYA CHAUDHARY[4], CHHAVI SIROHI[1], SATPAL[5], SANJAY KUMAR[6] AND PAWAN KUMAR POONIA[1]

[1]Department of Forestry, [2]Department of Botany & Plant Physiology, [3]Department of Agricultural Economics, [4]Department of Soil Science, [5]Department of G&PB (Forage section)
CCS Haryana Agricultural University, Hisar-125004, India
[6]Krishi Vigyan Kendra, Kaithal, CCS HAU, Hisar
(e-mail : ahlawat19799@gmail.com)
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SUMMARY

The present study was carried out to evaluate the performance of sorghum intercropped with 3 years and 4 months old willow based agroforestry system at a spacing of 3×3 m. During the study period, the growth observations of willow tree showed considerable increase in height (6.7-7.5 m), dbh (9.9-11.1 cm) and basal diameter (12.9-14.2 cm). The growth, physiological parameters, yield attributes and green fodder yield of sorghum were recorded during the experimentation. The physiological parameters (chlorophyll, photosynthesis, transpiration and stomatal conductance) of sorghum with willow plantation and in open varied highly significantly indicating the dense shade effect of trees on agricultural crops as available per cent light intensity was considerably low under willow plantation over control. The chlorophyll content was recorded higher in willow-based agroforestry system as compared to control. The plant height, stem diameter, leaf area, fresh leaf and stem weight, TSS and green fodder yield in sorghum showed highly significant variation in willow and open (control). The fodder yield varied from 8.09 (with willow) to 44.42 (control) t/ha. The per cent yield reduction in willow plantation was 81.79 %, respectively over control. The B: C ratio (0.21) in the above experiment was also negative in willow-based agroforestry system.

Key words: Agroforestry, willow, sorghum, green fodder yield, light intensity

According to the Livestock Census of 2019, India's total livestock population has increased by 4.6% to 535.82 million over the livestock census of 2012. Livestock is the primary source of income for many subsistence farmers, serving as a safety net against crop failure. Additionally, it has a direct impact on the food security and means of subsistence for around a billion people worldwide, as well as on many more people's diets and health (Downing *et al.,* 2017). The primary cause of the low productivity of our cattle is under or malnutrition brought on by the significant differences in the nation's supply and demand for feed and fodder (Prajapati *et al.,* 2019). Due to a lack of green fodder in the summer, dairy farmers have been feeding more concentrates to their animals to maintain milk production. Sustainable cattle husbandry requires addressing the difficulties of fodder and feed resource development in the country. Fodder supply availability has decreased to about 50% of the overall requirement, from projections of over 60% in the 1990s. The total area under cultivated fodder in India is 8.4 million hectares. India, with only 2.29% of the world's land area, is home to 15% of the global livestock population. Only 4% of cultivable land is used for fodder, resulting of 35.6% shortfall in green fodder, 10.5% in dry crop left overs and 44% in concentrate feed ingredients (Singh *et al.*, 2022). The livestock population is expected to rise by 1.23%, which could lead to a further increase in the deficit (Kumar *et al.,* 2023). The option for increasing land area under fodder cultivation is very limited. The issue becomes urgent since natural pasture, grasses, and weeds become unproductive during the dry season and no crop can normally be cultivated during the dry season under rain-fed conditions. The issue may be solved by agroforestry systems made up of appropriate tree-forage-crop combinations. Numerous ecosystem services and advantages, like increased soil fertility and water retention as well as biodiversity maintenance, are also provided by incorporating trees into livestock systems (Jose and Dollinger, 2019). Through improved resource sharing efficiency between various components, the development of suitable tree-crop combinations can raise the overall productivity and soil fertility status of agroforestry systems. For livestock producers to improve fodder supplies, it will be essential to choose forage crops that are compatible under agroforestry system.

Willow (*Salix alba*) is a deciduous tree known for their fast growth and adaptability, this species thrive in a variety of habitats, from wetland areas and riverbanks to drylands. They are characterized by slender, flexible branches, narrow leaves, and a tendency to grow rapidly, making them an ideal species for various land-use systems. Willows are well-suited for agroforestry due to their fast growth, resilience to a variety of soil types, and ability to thrive in areas with wet conditions, such as riparian zones or floodplains (Mola-Yudego, 2010). Systems of short-rotation agroforestry have promise for producing woody biomass and crops in an affordable and ecologically responsible manner (Rivest *et al.*, 2022). Willow-based systems can offer farmers diverse income sources through biomass production for renewable energy, timber for crafts, and non-timber forest products like willow baskets. By incorporating willows into the farming systems, farmers can diversify their operations, increase sustainability, and mitigate the environmental impacts of traditional agriculture. It represents a sustainable approach to farming, balancing productivity with conservation, and contributing to the broader goal of environmental stewardship.

Sorghum (*Sorghum bicolor*) ranks fifth among cereals in terms of production capacity with an annual production of about 64 million metric tons (Stefan, 2015). This crop is highly resistant to drought, making it a suitable option for addressing global warming and the decrease in maize cultivation due to fallow areas induced by climate change. Due to it's ability to meet 70% of the daily calorie requirement, its usage as a staple meal has significantly expanded across both the African and Asian continents (Tenywa *et al.*, 2018). Owing to its diverse range of uses, sorghum's commercial worth is currently at its highest point (Duff *et al.*, 2019). Commercial agriculture has four primary sectors; ethanol production, animal feedstock as a cover crop (Mesbah *et al.*, 2019), and food product formulations (Rashwan *et al.*, 2021). Sorghum is a perfect crop to solve global food security since it can grow in high salinity conditions withstand biotic and abiotic challenges and become dormant in unfavorable environmental conditions (Labuschagne, 2018). Sorghum is generally cultivated in nutrient-poor soils in frequently drought-prone areas, it offers food and fodder security through risk aversion on sustainable basis. There is a significant disparity in fodder availability and demand due to the variety of forage crops grown in different seasons and areas, as well as the production of forage with little inputs on degraded and marginal land (Ghosh *et al.*, 2016). This can be achieved by adopting suitable cropping systems, incorporating fodder crops in food and cash crop-based cropping systems on a rotational basis and producing fodder on degraded lands through fodder-based agroforestry system. Due to high salinization and an increase in degraded land, agroforestry systems comprised of the right tree-forage cover can be the best solution. Keeping in view, the present study was planned to study the effect of salix based AFS on growth and yield of sorghum in semi-arid ecosystem in Haryana.

MATERIALS AND METHODS

The present study was conducted at research area of the Department of Forestry, CCS Haryana Agricultural University, Hisar (29°10′ N lat., 75°46′ E long., alt. 215 m msl). In this study, the seedlings of willow (*Salix alba*) were planted during February, 2018 at 3×3 m spacing in research field. During *Kharif* season, 2021 Sorghum (HJ 541) was sown. The standard package of practices as recommended by CCS HAU, Hisar was followed. The growth, physiological parameters, yield attributes and green fodder yield of sorghum were recorded during the experimentation period. The chlorophyll content and leaf area were measured by using the 'SPAD 502 plus' and CI-202 portable laser leaf area meter, respectively. An infrared gas analyzer (IRGA LCi-SD, ADC Bioscience) was used to measure the photosynthetic rate, transpiration rate and stomatal conductance rate.

RESULTS AND DISCUSSION

Tree growth parameters of willow and soil properties

During the growing period of willow tree the data presented in Table 1 showed considerable increase in height (6.7-7.5 m), dbh (9.9-11.1 cm) and basal diameter (12.9-14.2 cm). Similar findings were also reported by Bhat *et al.* (2019) who studied the impact of intercropping maize and sorghum on the growth (height and girth) of *Salix alba* trees prior to sowing the intercrops and after harvesting of intercrops. The results showed that before sowing of maize as intercrop, *Salix alba* exhibited 4.65 m height and 13.92 cm girth and after harvesting of maize crop it attained 5.18 m height and 14.80 cm girth with an increment of 11.40% and 6.35% in tree height and girth under salix based agroforestry system. However, *Salix alba* + sorghum representing a 10.72% and 7.78% increase in tree height and girth. *Salix alba* alone had an increase of 14.02% and 8.06% in tree height and girth. The results showed that *Salix alba* trees grown without intercrops exhibited the largest percentage increase in height and girth. The superior growth in the control, where *Salix alba* was planted alone, was likely due to the absence of competition for resources, allowing the trees to thrive unimpeded (Ahmad *et al.,* 2017; Bhaskar *et al.,* 2019). The tree growth data suggested that agroforestry systems can lead to improved production values per unit area, which aligns with the findings of previous researchers (Anusha *et al.,* 2015; Blanc *et al.,* 2019; Brown *et al.,* 2018).

The soil 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. These findings are also supported by Sirohi and Bangrwa (2017) who found higher available nutrient status under a poplar-based cropping system, and similarly, Sirohi *et al.* (2022ab) observed significantly higher availability of N, P, and K content under a poplar windbreak as well as different spacings of poplar based agroforestry system compared to a sole crop.

TABLE 2
Soil chemical properties of the experimental field (October, 2021)

pH	EC (dS/m) (1:2)	OC (%)	Available nutrients (kg/ha)		
			N	P	K
7.86	0.42	0.40	135.6	12.8	290.7

Growth, physiological and green fodder yield of sorghum

The growth, physiological parameters, yield attributes and green fodder yield of sorghum were recorded during the study period. The physiological parameters (chlorophyll, photosynthesis, transpiration and stomatal conductance) of *kharif* (sorghum) with willow plantation and in open varied highly significantly indicating the dense shade effect of trees on agricultural crops as available per cent light intensity was considerably low under willow plantation over control (Table 3).

Different physiological parameters of sorghum were higher under control (sole crop) as compared to willow plantation except chlorophyll content. The chlorophyll content was recorded higher in willow-based agroforestry system as compared to control (Table 4).

The plant height, stem diameter, leaf area, fresh leaf and stem weight, TSS and green fodder yield (Table 5) in sorghum showed highly significant variation in willow and open (control).

The present findings are consistent with the current results of Dai *et al.* (2021) reported that intercropped alfalfa exhibited significantly lower physiological parameters (leaf area index, leaf-stem ratio, growth rate) than sole-cropped alfalfa. The percentages of crude protein (CP) and crude fat (CF) in intercropped alfalfa were 17.78% and 12.33% higher, respectively, than in sole-cropped alfalfa. Singh *et al.* (2016) studied that PAR was lower than under open conditions where turmeric crop (Punjab haldi 1) was sown under nine-year-old plantations of three different tree species *i.e., Ailanthus excelsa* (2415.2 $\mu molm^{-2}s^{-1}$), *Gmelina arborea* (2512.3 $\mu molm^{-2}s^{-1}$), *Eucalyptus tereticornis* (2596.6 $\mu molm^{-2}s^{-1}$) and control (2712.4 $\mu molm^{-2}s^{-1}$).

Results showed that the fodder yield varied from 8.09 (with willow) to 44.42 (control) t/ha. The per cent yield reduction in willow plantation was 81.79 %, respectively over control. The B: C ratio (0.21) in the above experiment was also negative in willow-based agroforestry system. The present findings are consistent with the current results of Bhat *et al.* (2019) who studied that fodder crops (sorghum and maize) grown as sole crops had considerably higher yields

TABLE 1
Growth performance of willow during April, 2021-April, 2022

Tree spacing (m)	Tree height (m)		DBH(cm)		Basal diameter (cm)	
	April, 2021	April, 2022	April, 2021	April, 2022	April, 2021	April, 2022
3x3	6.7	7.5	9.9	11.1	12.9	14.2

TABLE 3

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

Month	Per cent light available to crop under willow-based agroforestry system over control						
	7AM	9AM	11AM	1PM	3PM	5PM	Mean
May, 2021	34.89	37.25	39.87	44.97	41.21	37.64	39.31
June, 2021	34.21	36.57	38.75	44.23	40.97	37.21	38.66
July, 2021	33.68	36.01	38.16	43.84	40.24	36.56	38.08
August, 2021	32.21	34.49	36.64	42.21	38.85	35.25	36.61
September, 2021	30.17	31.99	34.39	40.00	35.45	33.40	34.23
October, 2021	28.66	29.76	32.60	38.46	34.22	31.55	32.54

TABLE 4

Physiological parameters of different crops under willow-based agroforestry system and control (devoid of tree)

Treatment	Physiological parameters of sorghum at 40 DAS			
	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})
With Willow #	21.51	4.98	1.98	0.05
Control (Devoid of tree)	11.53	10.97	4.64	0.13
t-value	19.47**	25.76**	21.50**	14.04**

**Significant at 0.01 per cent level of P.

TABLE 5

Growth and yield parameters of sorghum under willow-based agroforestry system and control (devoid of tree) at harvest

Treatment	Plant height (cm)	Stem diameter (mm)	Leaf area/ plant (cm^2)	Fresh leaf weight/plant (gm)	Fresh stemx weight/plant (gm)	TSS	Fodder yield (t/ha)	B:C ratio
With Willow#	74.36	4.96	885.97	20.68	62.33	2.59	8.09	0.21
Control (Devoid of tree)	261.24	15.80	2412.84	161.24	342.65	7.28	44.42	1.14
t-value	36.31**	33.88**	44.78**	46.22**	45.36**	35.95**	44.50**	-

**Significant at 0.01 per cent level of P.

than those grown as intercrops with *Salix alba*. They stated that the highest reduction in yield was recorded in *Salix alba* + sorghum followed by *Salix alba* + maize when comparing the yield of sole crops with their corresponding intercrops. Dar *et al.* (2018) reported that the reduction in green fodder yield of intercrops due to the competition for growing resources like moisture, nutrients and radiant energy under *Salix alba* based agroforestry system. Similar findings were also reported by Sirohi *et al.* (2022a) who found that the overall yield reduction ranged from 10 to 22 per cent in the sorghum-berseem crop rotation and 10 to 56 per cent in the cowpea-berseem crop rotation under different spacings of (3×3 m, 4×3 m, 5×3 m, 6×3 m, 7×3 m, and 8×3 m) poplar based agroforestry system as compared to control.

According to Chauhan *et al.* (2009), after three years of poplar growth, light intensity dropped in poplar-based agroforestry systems as compared to sole crop/open field, which reduced the yield of intercrop. Further, Rivest *et al.* (2022) reported that the forage yield within the windbreak (0-50 m from the willow strip) was 44% greater than that in the control plots. The alley cropping system had significant negative (-12%, June, 2020) and positive (+13%, September, 2021) effects on forage yield, may be as a result of temporal variation in climatic conditions. As a result of the decreased light intensity under trees the yield drop was also observed in maize and sorghum (Bayala *et al*., 2015). Gaafar *et al.* (2006) found that intercropping in 6-year-old *Acacia senegal* trees (266 and 433 trees ha^{-1}) significantly reduced the yield of sorghum and karkadeh (*Hibiscus sabdariffa*). They stated that this drop in yields of sorghum and karkadeh due to the competition for water between crop and tree roots. These findings, however, are in contrast to those of Fadl (2013), who reported significant increases in the yields of sorghum, karkadeh, and sesame when intercropping with 11-year-old *Acacia senegal* trees, and Raddad *et al.* (2006), who found no significant effect on sorghum yields when intercropping with *A. senegal*.

A considerable decrease in forage yield was linked to significantly low availability of light (57% reduction in PAR at 2.4 m) and soil water at the willow-crop interface (Gamble *et al.,* 2019). They reported that green fodder yield of forage crop increased by 623 kg DM ha^{-1} for every 2100 µmol m^{-2} s^{-1} increase in PAR and by 1038 kg DM ha^{-1} for every 20 kPa increase in average daily water potential. A marginal impact of woody strips on the fodder yield in the vicinity during the first three years of the willow based agroforestry was also noted by Ehret *et al.* (2018). The marginally beneficial benefits of trees on agricultural yields observed close to tree rows may intensify and turn into a negative effect as the trees get older and start to compete with crops for water and light. Similar findings were also reported by Chavan *et al.* (2024) who observed that the green biomass of dhaincha was significantly reduced by the presence of moderate to dense shadow, which was caused by different eucalyptus plant geometries. The closer spacing of eucalyptus (3×3m) showed that the maximum yield reduction (24.75%) in green biomass of dhaincha, whereas the boundary plantation showed the least yield reduction (2% - 6%). This could be because of low light intensity intercepts which slow down the rate of photosynthesis, have a direct impact on crop growth rate, reproductive, and ripening stages, and ultimately result in a reduction in yield (Luna *et al.,* 2009).

CONCLUSION

The study showed that the green fodder yield of sorghum significantly affected under willow based agroforestry system. Overall, the study offered insightful information about the potential of sorghum intercropped with willow based agroforestry systems, which will help to diversify the land use systems in semi-arid regions toward more sustainability.

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