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Research Article

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Sorghum-wheat Productivity and Soil Nutrient Status Under Eucalyptus (Eucalyptus Tereticornis) Boundary Plantation in Semi-arid Region

Chhavi Sirohi[1*], Parvinder Kumar[1], R.S. Dhillon[1], K.K. Bhardwaj[2], K.S. Ahlawat[1], A.K. Handa[3] and A. Arunachalam[3]

* Corresponding author. E-mail: chhavisirohi22dec@gmail.com

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ABSTRACT

Fast-growing trees, such as eucalyptus (Eucalyptus tereticornis), can be included into agricultural systems to offer a number of advantages over agriculture without trees. In semi-arid regions, windbreaks are typically utilized as a type of agroforestry (AF) to lower the wind speeds for sustainable agricultural production and other ecosystem services. Selecting appropriate crop to reduce competitive interactions in the tree interaction zone is crucial to the sustainability of windbreak agroforestry systems (AFS). It is recommended that well-modified tree-crop integration be established by reducing resource competition and leveraging coactions in order to increase AFS efficiency. A field experiment was carried out with the objective to assess the green fodder yield of sorghum and grain yield of wheat at varying distances (0-3 m, 3-6 m, 6-9 m, 9-12 m, 12-15 m, and 15-18 m) from tree line as affected by six year old eucalyptus boundary plantation in East-West and North-South directions (E-W tree line divide farmlands into two aspects i.e. Northern and Southern and N-S tree line divide into Eastern and western aspects). The green fodder yield of sorghum and grain yield of wheat declined significantly up to 9 and 3 m distance from eucalyptus tree line, respectively in all the four aspects during the study period. The maximum green fodder yield of sorghum and grain yield of wheat (36.2 and 3.33 t/ha) was recorded in north-south row direction of eucalyptus bund plantation. The variable influence of tree line directions on yield in different aspects might be attributed to micro-site enrichment caused by favourable environment due to shade and leaf litter addition. We also quantified the soil pH, EC, available nitrogen (N), phosphorus (P) and potassium (K) under six year old eucalyptus boundary plantation at varying distances (0-3 m, 3-6 m, 6-9 m, 9-12 m, 12-15 m, and 15-18 m) in East-West and North-South directions. The organic carbon showed a decreasing trend for SOC from 0-3m to 15-18m and higher organic carbon was recorded in western aspect followed by southern aspect. The available N, P and K also showed decreasing trends for N, Pand K from tree line to 15-18m of eucalyptus windbreaks AFS

INTRODUCTION

Agroforestry systems (AFS) have demonstrated multifaceted advantages in the fields of agriculture and forestry-related resources by assimilating land use techniques of trees and crops in various ways (Hildreth, 2008). The capability and productivity of land in terms of agricultural crops, fodder, biomass, soil fertility, timber production and ecosystem services can be enhanced by adopting AFS (Meijer et al., 2015; Nair and Toth, 2016). Agroforestry has the potential to boost farmer incomes and address environmental problems including soil erosion inefficient water usage, and biodiversity loss brought on by intensive monocultures (Smethurst *et al.*, 2017). Additionally, crops intercropped under agroforestry can be shielded from climate change-related hazards (Dupraz, 2013). In wind-

break agroforestry systems, crops are mainly affected by tree canopies partial radiation absorption and tree leaf area up to some distances from tree line (Gosme *et al.,* 2016; Dupraz *et al.,* 2018). Nevertheless, intercrop yields have drastically decreased as a result of competition for light by trees with the advancement of tree age and canopy volume (Zhang *et al.,* 2017).

Eucalyptus is the most common agroforestry species utilized as the main tool to improve farmer's livelihoods in northern regions. It has a high potential for productivity because to its ease of adaptation to soil and climate conditions (Flumignan *et al.,* 2023). Eucalyptus is often grown as a forest, but when combined with crops and pastures, it can impact the production environment, perhaps leading to benefits for agricultural sustainability. This species is a great source of charcoal, hardboard, particle board pulpwood, and firewood. Out of about 170 species, varieties, and provenances tested in India, *Eucalyptus tereticornis* has proven to be the most notable and preferred species (Bhatia, 1984). India has implemented a number of eucalyptus based agroforestry models with different crop combinations and spacings as well as boundary plantation (Kulkarni, 2014).

A significant gap exists between the supply and demand for fodder because of the variety of forage crops grown in different seasons and geographical areas, as well as the production of forage with low inputs on marginal and degraded land (Ghosh *et al.,* 2016). Lack of timely access to agricultural inputs like fertilizers and irrigation, as well as limited cultivable land for fodder crops, are important challenges for increasing fodder yield (Meena *et al.,* 2018). Therefore, there is a significant challenge to utilize the

available scarce land wisely to produce the necessary fodders for the animals. 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.

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. 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 (Khalili *et al.,* 2023). 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).

Another most important food crop cultivated in an agroforestry system in the states of North India is wheat (*Triticum aestivum* L.). In parts of the central and eastern regions of M.P., Chhattisgarh, and W.B., as well as Uttarakhand, Punjab, Haryana, U.P. and Bihar, wheat is commonly intercropped with eucalyptus, poplar and other fast-growing short rotation tree species during the *Rabi* season (November-April). The technology for producing wheat on the Indo- Gangetic plains is well established, although it may need some improvement in mixed land-use systems like agroforestry, particularly in the area where wheat is grown along with boundary plantation of fast growing tree species. Keeping in view, the present investigation was carried out with the objectives to assess the green fodder yield of sorghum and wheat productivity under eucalyptus boundary plantation in semi-arid region of Haryana.

2. MATERIALS AND METHODS

Experimental site

The study was conducted in the experimental farm of Forestry Department at CCS Haryana Agricultural University in Hisar, Haryana, which is located at an elevation of 215.2 meters above mean sea level (290 09' N latitude and 750 43' E longitude). A total of 317.5 mm of rainfall was recorded during July-March against long term mean rainfall of 410.6 mm during this period. During the Kharif season (July-October), merely 274.4 mm rainfall was received. However, in June and August months 113.6 mm rainfall was recorded; consequently the *Kharif* crops yield was poor. Due to the frequent western disturbances during the winter season, a few amount of rain fall was received. The summer months are very hot with maximum temperature ranging from 39.5oC in May whereas, December and January are the coldest months. Eucalyptus trees were planted during 2015 at a distance of 2m. The experiment was laid out in factorial randomized block design with three replications.

Growth of Eucalyptus

Eucalyptus planted in East-West direction has attained

22.4 cm DBH and 19.6 m height at the age of 6 years. However, eucalyptus planted in North-South direction has attained DBH of 20.1 cm and height of

Table 1

2 5 2

17.2 m. The growth performance of eucalyptus planted in North- South direction was comparatively deprived due to availability of uneven soil salinity in the field.

Soil sampling to determine soil nutrient status

The soil nutrient status of eucalyptus trees planted in East-West and North-South directions were quantified (E-W tree line divide farmlands into two aspects *i.e.* Northern and Southern and N-S tree line divide into Eastern and western aspects) at various distances (0-3 m, 3-6 m, 6-9 m, 9-12 m, 12-15 m, and 15-18 m) from tree line. Before the sowing of wheat crop, the soil samples were collected in three replications for soil pH, EC, soil organic carbon (%), accessible nitrogen (N; kg ha-1), phosphorous (P; kg ha-1), and potassium (K; kg ha-1) at a depth of 0-15 cm. The air-dried soil samples were pulverized and sieved through a 2 mm sieve before being kept for further analysis. In a soil:distilled water suspension (1:2), the pH and EC of the soil were measured. The percentage of organic carbon was calculated using the partial oxidation method (Walkley and Black, 1934). Available N was determined using the alkaline permanganate method (Subbiah and Asija, 1956), available P was determined using the sodium bicarbonate method (Olsen *et al.,* 1954), and available K was determined using the neutral normal ammonium acetate method (Jakson, 1973).

Green fodder yield of sorghum and grain yield of wheat

Sorghum variety (HJ 541) was sown during the second fortnight of June 2021 in East-West and North-South directions at different distances from the eucalyptus tree line (0-3 m, 3-6 m, 6-9 m, 9-12 m, 12-15 m, and 15-18 m). Recommended dose of fertilizers according to the package of practices of CCS HAU, Hisar was applied for sorghum crop. The plants harvested from each quadrant of one-meter square area from each plot were then weighed to record the green fodder yield.

In the first week of November 2021, the wheat variety (WH-1105) was sown in East-West and North-South directions at different distances from the eucalyptus tree line (0-3 m, 3-6 m, 6-9 m, 9-12 m, 12-15 m, and 15-18 m). The rows were spaced for sowing of wheat

22.4

cm apart, and the seed rate was 100 kg ha-1. For the wheat crop, the prescribed dosage of fertilizer (N: 150 kg ha-1, P O : 60 kg ha-1, and K O: 60 kg ha-1) were applied. Half of the N and the full amounts of P and K were applied at the time of sowing. The top dressing was applied with the remaining N via urea during the crown root initiation stage of wheat. Data for the wheat crop was recorded at different distances from eucalyptus tree line (0-3 m, 3-6 m, 6-9 m, 9-12 m, 12- 15 m and 15-18 m). The net plots were harvested in order to obtain wheat grain yield.

3. RESULTS AND DISCUSSION

Organic carbon and available N, P and K

The soil chemical properties observed at different distances (0-3 m, 3-6 m, 6-9 m, 9-12 m, 12-15 m and 15-18 m) from tree line of eucalyptus planted in East-West and North-South directions which formed Eastern, Western, Northern and Southern aspects (Figure 1). The soil pH and EC showed increasing trend from 0-3 m to 15-18 m in all the aspects of East- West and North-South planted eucalyptus. The lesser EC and pH was recorded from 0-3 m from tree line in all the aspects as well as tree species under study. However, the organic carbon showed decreasing trend from tree line to 15-18 m and higher organic carbon was recorded in western aspect followed by southern aspect of eucalyptus may be due to higher biomass production in western aspect. The available N, P and K also showed decreasing trend from tree line to 15-18

m. However, available N was recorded higher in eastern aspect due to availability of more sun light and thereby more photosynthesis and physiological activities. Available P and K were found higher in western aspect closely followed by southern aspect in both the tree species. Reduced pH was associated with increased accessible P under eucalyptus, which encouraged the release of organic acids and improved phosphorus solubility. These findings are in line with the results of Bhardwaj *et al.* (2017), who quantified that how tree-based agroforestry systems improve soil enrichment by adding litter, recycling root biomass, and lowering the oxidation of organic matter.

One of the key elements in intercropping research is nutrient capture. More favorable microclimatic conditions beneath trees, which result in higher soil moisture and favorable soil temperature, as well as nutrients released through leaf litter, in situ root decomposition, and higher microbial activity, have all been identified as contributing factors to the improvement of soil fertility under agroforestry systems (Patel *et al.,* 2010).

Peichl *et al.* (2006) have already studied that the addition of litter from leaf fall, twigs, and the breakdown

of tree fine roots may be the cause of increased SOC build-up close to the tree line. When poplar trees were planted in a row north-south along the farm boundary, the amount of accessible N, P, and K increased significantly from 0-3 m (near the poplar tree base) to 3-6 m. Sirohi and Bangarwa (2017) have noted a similar trend in an agroforestry system based on poplar. The north-south direction of the poplar windbreak has a major effect on the soil organic carbon, which decreases with increasing the distance from the poplar tree (Sirohi *et al.,* 2022b). They found that the western side of the north-south poplar windbreak had significantly greater amounts of organic carbon (0.74% and 0.72%) than the eastern side (0.70% and 0.68%) up to 4 meters away from the poplar tree line. The soil OC (32.4%), available N (35.9%), P (51.1%), and K (11.5%) increased at the highest rates under a six-year-old poplar-based agroforestry system (Kaur and Singh, 2022). According to Sirohi *et al.* (2022a) significant variations in available nutrients (ha-1) and soil organic carbon (SOC) were noted under different treatments of poplar-based alley cropping system with the advancement of tree age.

The most important factors that are compromised in a tree-based intercropping system are the physicochemical characteristics of the soil, primarily during the period after disturbances like weeding, plowing, and other cultural operations. In order to reorganize ecological development on a sustainable basis, the tree-based intercropping system increases soil nutrients and total biomass throughout this time (Bargali *et al.,* 2009). The results highlight how agroforestry systems can enhance soil health by boosting organic matter content and maximizing soil characteristics for sequestering carbon (Salunkhe *et al.,* 2023).

Performance of Sorghum and Wheat crop

It is evident from the data presented in Table 1 and 2 that there was a significant reduction in green fodder yield of sorghum and grain yield of wheat as sown in East-West and North-South bund planted eucalyptus under different distances from tree line. The green fodder yield of sorghum and grain yield of wheat

declined significantly up to 9 and 3 m distance from eucalyptus tree line, respectively in all the four aspects during the period of study. On an average, the maximum green fodder yield of sorghum and grain yield of wheat (36.2 and 3.33 t/ha) was recorded in north-south row direction of eucalyptus bund plantation. The results showed that the addition of leaf litter and shade created a favorable microsite environment, which in turn led to a varying influence of wind break orientations on crop output in all the aspects. Our findings showed that, in addition to eucalyptus wind break, the main parameters influencing the impact of tree canopy on green fodder yield of sorghum and wheat yield are tree row orientation and distance from tree base (0-3 m, 3-6 m, 6-9 m, 9-12 m, 12-15 m and 15-18 m). Similar findings were also reported by Chavan *et al.* (2024) who studied that the maximum grain yield of barley (2.59 Mg ha−1) was observed in the north-south direction in comparison to the east-west direction (2.42 Mg ha−1) of Eucalyptus boundary plantation. Observations of barley crops under eight years of eucalyptus boundary plantation showed that crop growth was negatively impacted up to six meters from tree line, but the crop growth was improved with the increasing distance from tree line in all four aspects of East-West and North-South row direction. The maximum green fodder yield of sorghum and grain production in wheat was recorded in western aspect because of greater solar radiation availability which led to stronger photosynthetic activity, vigorous plant development, and higher productivity.

Similar finding was also reported by Mantino *et al.* (2023) who studied that the sorghum grain yield in 2018 varied between 63.76 g DM m−2 in the West and

263.73 g DM m−2 in the Mid-west (73%).While the range of variation was more constrained in 2019, with

426.56 g DM m−2 in the West and 536.68 g DM m−2 in the Mid-east, respectively (21%). These findings demonstrate that the above-ground biomass and yield of sorghum reduced significantly near the tree row, although this did not happen in areas with less competition for resources. The impact of trees on sorghum yield has been documented by Berenji and Dahlberg's (2004) who reported that the grain yield of sorghum was declined upto 79% under poor physicochemical conditions.

Deng *et al.* (2017) demonstrated that the grain yield decreased when the improved variety of sorghum was sown in South Sudan beneath the canopy of acacia trees. Similar to our findings, Righi and Foltran (2018) found that the production was less in a native variety of broomcorn produced in Tie (Brazil) when the distance between trees increased. This suggests that a slight

decrease in the amount of light radiation accessible improves agronomic performance. Our results indicate that the performance of sorghum and wheat was similarly affected with regard to the East-West and North-South row directions of eucalyptus boundary plantation. According to earlier research, nutrient competition and soil moisture loss may have an impact on the fodder yield of sorghum grown in agroforestry systems (Gao *et al.,* 2013; Gagné *et al.,* 2022).

Table 2: Effect of row direction and distance from the tree row of bund planted eucalyptus on green fodder yield (t/ha) of sorghum

Distance from tree row (m)	East-West Row			North-South Row		
	Northern aspect	Southern aspect	Mean	Eastern aspect	Western aspect	Mean
0-3	23.1	26.1	24.6	27.1	29.1	28.1
3-6	25.2	28.4	26.8	29.2	31.2	30.2
6-9	29.5	31.7	30.6	33.4	34.8	34.1
9-12	35.1	37.8	36.5	38.1	40.9	39.5
12-15	37.2	41.2	39.2	41.3	42.8	42.1
15-18	38.6	41.8	40.2	42.8	44.0	43.4
Mean	31.5	34.5		35.3	37.1	
CD at 5%	Aspect : 3.20			Aspect : 3.36		
	Distance: 4.11			Distance: 4.14		
	Aspect × Distance : NS			Aspect × Distance : NS		

Table 3: Effect of row direction and distance from the tree row of bund planted eucalyptus on grain yield (t/ha) of wheat

Distance from tree row (m)	East-West Row			North-South Row		
	Northern aspect	Southern aspect	Mean	Eastern aspect	Western aspect	Mean
0-3	2.58	2.66	2.62	2.7	2.82	2.76
3-6	2.73	2.88	2.81	2.88	2.95	2.92
6-9	2.95	3.01	2.98	3.05	3.1	3.08
9-12	3.02	3.15	3.09	3.25	3.35	3.30
12-15	3.81	3.9	3.86	3.64	3.81	3.73
15-18	3.99	4.11	4.05	4.15	4.27	4.21
Mean	3.18	3.29		3.28	3.38	
CD at 5%	Aspect : 0.14			Aspect : 0.13		
	Distance: 0.23			Distance: 0.25		
	Aspect × Distance : 0.37			Aspect × Distance : 0.40		

Chavan *et al.* (2022) studied that the green fodder biomass of sorghum and the wheat grain yields noticeably reduced from 7.04 to 83.64% and 9.04 to 54.4% at the age from 2nd year to the 8th year rotation of poplar boundary plantation at 3 m distance from tree line compared with the sole crop control. The intense competition for light and moisture in the soil near to tree line significantly lowers the productivity of crops.

They found that crop yield of sorghum and wheat at 9 m distance from the tree line was reduced by 41.2% and 19.1%, respectively during in *Kharif* and *Rabi* season. The more reduction in crop yield near the tree line might be attributed due the competition for light, water, and nutrients or unsprayed crop margins, which lower photosynthetically active radiation (PAR) and rainfall interception as compared to sole crop (Sudmeyer *et al.*, 2007).

4. CONCLUSION

The soil physical-chemical characteristics (SOC, available N, P, and K) had improved at the age of six-years eucalyptus boundary plantation in East-West and North-South directions at various distances (0-3 m, 3-6 m, 6-9 m, 9-12 m, 12-15 m, and 15-18 m) from the tree line. Up to 6 meters from eucalyptus tree line, the effect was most noticeable at 0-3 meters (close to the tree base), which made it perfect for boosting soil fertility by accumulating leaf litter. Wheat crop yield was significantly impacted by the presence of mature, fast- growing eucalyptus boundary plantations close to the tree line (0-3 m from the tree base) than the increasing distances from tree line. However, the yield reduction was found to be higher in sorghum as compared to wheat crop. The effect of eucalyptus boundary plantation was more pronounced on green fodder yield of sorghum up to 9 m distance from tree line.

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