Indian Journal of Agronomy **69** (3): 298–302 (September 2024)
DOI: 10.59797/ija.v69i3.5525

Research Paper

Poplar based agroforestry system: Symmetry to maximize productivity and optimized nutrient acquisition in fodder sorghum–wheat rotation in semiarid region of Haryana

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Received: July 2024; Revised accepted: September 2024

ABSTRACT

A field experiment was conducted during the *kharif* and *rabi* season of 2 years (2022–24) at the farm of agroforestry of Chaudhary Charan Singh Haryana Agricultural University, Hisar to evaluate the impact of different geometry of poplar on the yield and nutrient uptake of sorghum and wheat under poplar-based agroforestry systems. The experiment was laid out in a randomized block design with 3 replications. The sorghum and wheat were sown as per the treatment comprising different spacing of poplar i.e. 3 m × 3 m, 4 m × 3 m, 5 m × 3 m, 6 m × 3 m, 7 m × 3 m, 8 m × 3 m and control (sole crops without trees). The results showed that sorghum (14.02 and 14.48 t/ha) dry fodder yield and wheat grain yield (5.14 and 5.30 t/ha) and straw yield (7.17 and 7.28 t/ha) were maximum under control in 2022–23 and 2023–24, respectively. The yield of sorghum (13.62 and 15.54%), wheat grain (44.55 and 45.66%) and wheat straw (39.05 and 39.15%) were lower at 3 m × 3 m spacing compared to control in 2022–23 and 2023–24, respectively. The increase in spacing of poplar increase the yield of sorghum and wheat during both the years of study i.e. least yields at 3 m × 3 m popular spacing and highest under 8 m × 3 m spacing. However, popular based system yields of sorghum (8.01 and 8.42%), wheat grain (50.18 and 50.00%) and wheat straw (42.56 and 42.44%) were higher under 8 m × 3 m than 3 m × 3 m spacing in 2022–23 and 2023–24, respectively. Similar significant results were obtained in case of nutrient uptake N, P and K as yield of sorghum (143.9, 147.2, 18.3, 19.9 and 31.4, 29.2 kg/ha) and wheat in grain (81.8, 83.4, 13.7, 14.3 and 13.3 14.4 kg/ha) and straw (26.8, 28.4, 7.5, 8.7 and 64.2, 66.3 kg/ha) under 8 m × 3 m during 2022–23 and 2023–24, respectively. Hence, control has significant effect on the yield and nutrient uptake of crops than under agroforestry systems. While, among all the treatments of poplar-based alley crop systems, spacing of 8 × 3 m the significantly higher green forage, and grain yields and nutrient uptake.

***Key words*:** Nutrient content, Nutrient uptake, poplar spacing, Yield

The challenge of ensuring food security and achieving higher productivity from limited natural resources has led to the overexploitation and injudicious use of chemical fertilizers. This misuse has resulted in further land degradation, environmental problems, and low productivity in the semi-arid tropics of India (Gupta, 2019). Despite India being one of the leading countries in terms of animal population, with 536 million units, milk productivity remains remarkably low. One major reason for this low milk productivity is the limited availability of green fodder for livestock. The country faces an estimated 35 percent deficit in green and dry fodder due to decrease in the area under forage crops over the past 3–4 decades, as farmers have preferred cereal crops and other cash crops. This deficiency in forage availability makes livestock rearing more challenging (Sirohi *et al.,* 2022). The situation becomes critical during the dry season under rain-fed conditions when no crops can typically be grown and natural pastures, grasses, and weeds become unproductive. Farmers resort to feeding their animals with low-quality hay made from stored crop residues or travel long distances to gather green grasses or fodder (Mallikarjun *et al.,* 2018). Agroforestry systems (AFS) incorporate diverse methods of using trees and crops for the management of land, and show considerable benefits for the efficient use of agricultural and forest resources (Qiao *et al.,* 2019). Tree-based agroforestry systems are far

Based on a part of Ph.D. Scholar of the first author submitted to Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana in 2024 (unpublished)

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more economically feasible and environmentally friendly than mono-cropping systems. Agroforestry systems provide benefits such as improved water quality, biodiversity, reduced soil erosion, increased aesthetic value, carbon sequestration, and mitigation of climate change (Gurmessa *et al*., 2021). Agroforestry is regarded as a cure the ills of intensive agriculture. It prevents land degradation and increases site production through interactions among trees, soil, and crops, restoring soil fertility. Effective agroforestry systems rely heavily on tree spacing and shape (Rizvi *et al.,* 2020). Poplar is India's most effective industrial agroforestry tree species, with annual yield ranging from 10 to 30 m^3/hectare. A poplar-based agroforestry unit is a huge success in irrigated parts of northern India. This approach is practical and more economically successful than several other harvest rotations in India (Sirohi and Bangarwa, 2017). Selecting suitable forage and cereal crops that can be integrated with poplar crucial for enhancing feed supplies for livestock producers and economic yield for farmers. Sorghum (*Sorghum bicolor*) and wheat (*Triticum aestivum* L.) crop rotations can fulfill the fodder needs of livestock and productivity as well as address protein deficiency issues (Kumar *et al.,* 2012a, 2012b). However, further research is required to determine the best management practices for these crop rotations under poplar trees. To maintain intercrop productivity and maximize returns, adopting appropriate spacing for tree species is crucial in any agroforestry system since intensive agriculture methods have a worsening effect on soil fertility. Farmers can opt for agroforestry systems that not only replenish soil but also help to preserve crop output. The spacing between and within tree rows was a key factor influencing intercrop productivity (Handa *et al.,* 2019). Ensuring the ongoing intercrop productivity and optimizing returns necessitates adopting appropriate spacing for tree species in any agroforestry system. The arrangement between and within tree rows stands out as a critical factor influencing intercrop productivity (Chaturvedi *et al.,* 2016). Wider spacing between tree rows led to higher productivity of intercrops compared to narrow spacing. However, soil fertility increased more with narrow spacing, particularly close to the tree base rather than farther away. This study aimed to investigate the effect of poplar spacing on forage production and wheat productivity to identify suitable poplar-forage crop combinations in sorghum-wheat cropping system to enhance both fodder and grain yield.

MATERIALS AND METHODS

The field experiment was conducted during *kharif* and *Rabi* season of 2022–23 and 2023–24 at Research Farm of Forestry (29°10′N; 75°43′E), CCSHAU, Hisar. The experiment was laid-out in a Randomized block design with 3 replications. The treatments consisted of 7 spacing of poplar transplanted in 2017. The poplar (clone G-3) was planted at different spacing of 3 m × 3 m, 4 m × 3 m, 5 m × 3 m, 6 m × 3 m, 7 m × 3 m, 8 m × 3 m and control (sole crop without tree). Sorghum-wheat rotation was taken under the different geometry of poplar. The gross plot size for each treatment varied based on the tree spacing and increased from 81 m^2 in 3 m × 3 m to 216 m^2 in 8 m × 3 m and spacing 5 m × 4 m was grown as control (devoid of trees) during their respective seasons. Sorghum 'HJ-541' was sown during first week of June, while wheat (DWB 187) was sown during first week of November in 2022–2023. Recommended dose of fertilizers were applied to the crops as per the recommendation of package and practice of CCSHAU. Similar, procedure was followed during 2023–24. Within each experimental unit, crop data were recorded from all spacings, randomly placed 1 m × 1 m quadrates. After being sun-dried for 4–5 days, the grains were accurately weighed and expressed as tonnes/hectare, as delineated by Rana *et al.* (2014).

Nutrient content and uptake: Nitrogen (N), phosphorus (P) potassium (K) and micronutrients (Fe, Cu, Zn and Mn) content were estimated by modified kjeldahl method (Prasad *et al.,* 2006), vanado-molybdo-phosphoric acid yellow color method (Jackson, 1973), flame photometer method (Jackson, 1973) and DTPA extractable (Lindsey and Norvell, 1978) respectively. Nutrient uptake was calculated by multiplying nutrient content with fodder and wheat yields.

N uptake (kg/ha) in grain/straw = [% N in grain/straw × grain/straw yield (kg/ha)]

Analysis of variance was performed using the GLM procedures of the statistical analysis system (SAS Institute, Cary, NC) for randomized block design. The differences between treatment means were compared using a LSD test at $P<0.05$ (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Productivity of fodder sorghum and wheat

The results revealed that sorghum (14.02 and 14.48 t/ha) dry fodder yield and wheat grain (5.14 and 5.30 t/ha) and straw yield (7.17 and 7.28 t/ha) was significantly higher under the control (sole crops) than other poplar-based intercropping in 2022–23 and 2023–24, respectively in sorghum wheat cropping system (Table 1). The yield of both crops decreased with increased tree density. The sorghum dry fodder yield in sole crop was 8% higher than the yield at 3 m × 3 m spacing in 2022–23, and this difference increased to 8.4% in 2023–24. Similar results were obtained for wheat crop for both the years. The wheat grain and straw yields were higher under sole crop which was 33.3,

Table 1. Effect of different geometry of poplar on yield of sorghum and wheat under poplar based agroforestry system in 2022–23 and 2023–24

Treatment	Sorghum dry fodder yield (t/ha)		Wheat grain yield (t/ha)		Wheat straw yield (t/ha)	
	2022–23	2023–24	2022–23	2023–24	2022–23	2023–24
Poplar spacing (m)						
3 × 3	12.11±0.39	12.23±0.45	2.85±0.52	2.88±0.53	4.37±0.43	4.43±0.45
4 × 3	12.15±2.68	12.27±2.71	3.33±1.16	3.35±1.18	5.01±0.80	5.08±0.81
5 × 3	12.39±3.00	12.51±3.04	3.59±1.35	3.61±1.37	5.36±0.93	5.43±0.95
6 × 3	12.53±3.10	12.66±3.15	3.76±1.44	3.77±1.45	5.54±0.99	5.61±1.01
7 × 3	12.92±3.04	13.08±3.09	4.12±1.45	4.25±1.46	6.03±1.01	6.11±1.03
8 × 3	13.08±2.80	13.26±2.86	4.28±1.36	4.32±1.37	6.23±0.95	6.31±0.97
Control	14.02±2.32	14.48±2.39	5.14±1.15	5.30±1.17	7.17±0.83	7.28±0.85
CD (P=0.05)	1.04	1.20	0.42	0.43	0.65	0.67

34.2% and 29.8, 29.9% than 3 m × 3 m in 2022–23 and 2023–24, respectively. This could be due to shade by the trees, which results in crops receiving reduced light intensity, restricting growth and decreasing agricultural output. Similar findings were corroborated by Sirohi *et al*. (2020) and Lamerre (2017), who showed higher intercrop yields with wider spacing compared to close spacing. Wider spacing leads to increased photosynthetic activity and crop development, resulting in higher productivity. Devi *et al.* (2020) and Meena *et al.* (2023) also detected a drop in light intensity in poplar-based agroforestry systems compared to solo cropping systems, resulting in a fall in intercrop yields.

Nutrient Acquisition

The nutrient uptake of sorghum was significantly affected, more nutrients were acquisitioned under control than poplar based intercropping system (Figs. 1 and 2). The N, P, K, Fe, Cu, Zn and Mn uptake of sorghum was 3.12 and 5.53%, 1.30 and 4.43%, 1.30 and 4.43%, 2.41 and 4.15%, 8.47 and 10.89%, 10.26 and 12.24%, 13.03 and 15.59%, 11.70 and 13.77% higher in control than the 3 m × 3 m spacing of poplar in 2022–23 and 2023–24, respectively. Under poplar-based system, the highest uptake was observed in 8 m × 3 m spacing for macro and micro nutrients and then decreased with increased tree density during both years. The uptake of macro and micro nutrients increases from 2022–23 to 2023–24 in both polar-based intercropping and solitary cropping. Similar findings were previously found by Sharma *et al.,* (2012), that the N, P, and K content and uptake by wheat crop decreased considerably under a poplar-based agroforestry system when compared to the control (without trees). They also discovered low quantities of N, P, and K, and their uptake in wheat plants, along the tree line and then increased with distance away from the tree line.

The nutrient uptake by wheat grain and straw was observed significantly higher under sole cropping (control) than poplar based agroforestry system (Figs. 3-4). The nutrient uptake by wheat grain for N, P, K, Fe, Cu, Zn and Mn ranged from 97.14–56.15 kg/ha, 13.70–10.26 kg/ha, 13.27–9.98 kg/ha, 206.78–120.64 g/ha, 36.03–22.23 g/ha, 129.11–82.34 g/ha and 127.37–73.47 g/ha in 2021. While

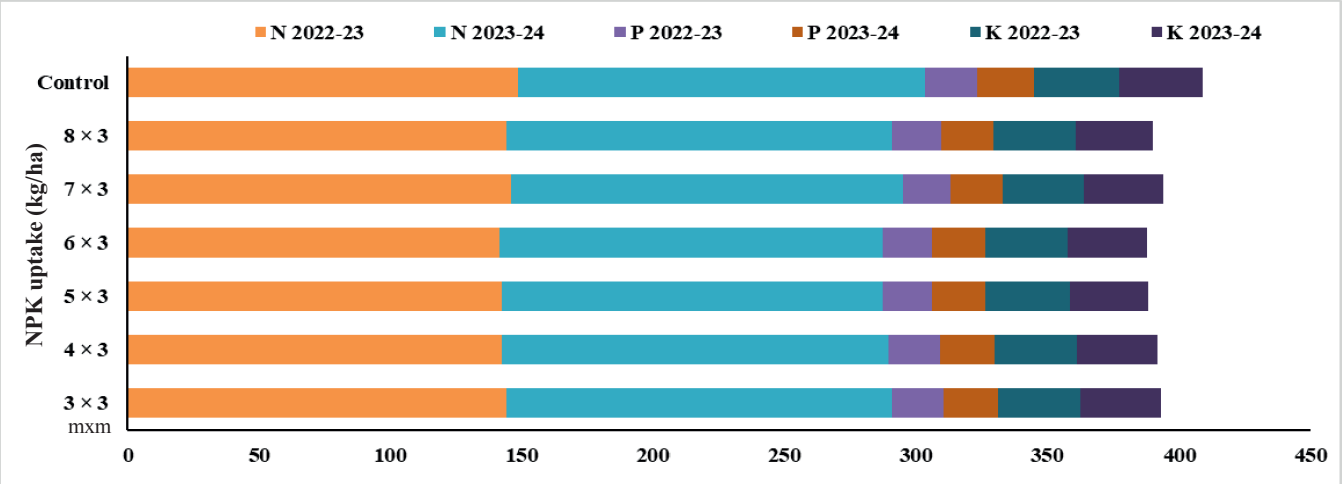

Fig. 1. Effect of plant spacing on poplar based agroforestry system on NKP uptake in fodder sorghum

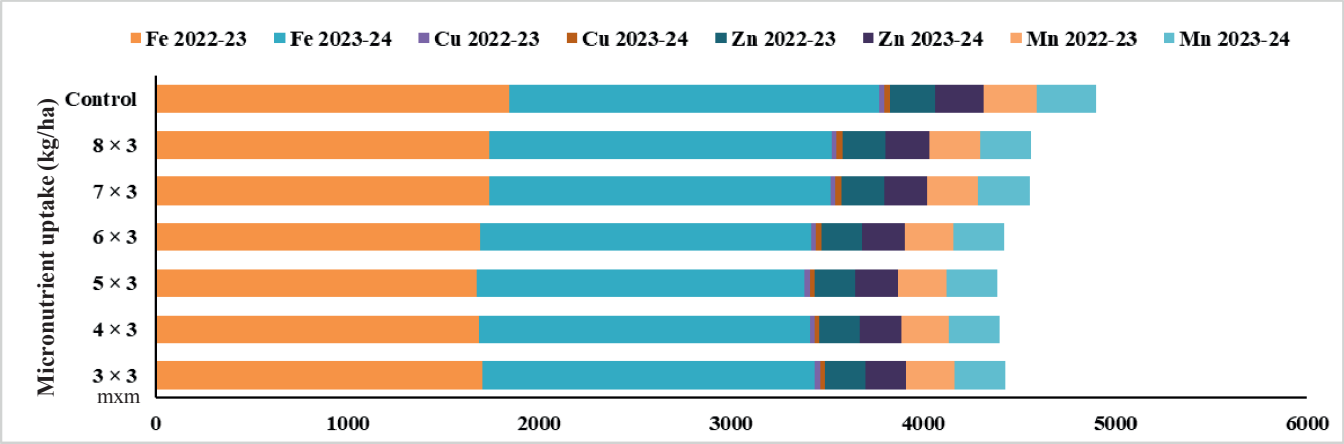

Fig. 2. Effect of plant spacing on poplar-based agroforestry system on Fe, Cu, Zn and Mn uptake in fodder sorghum

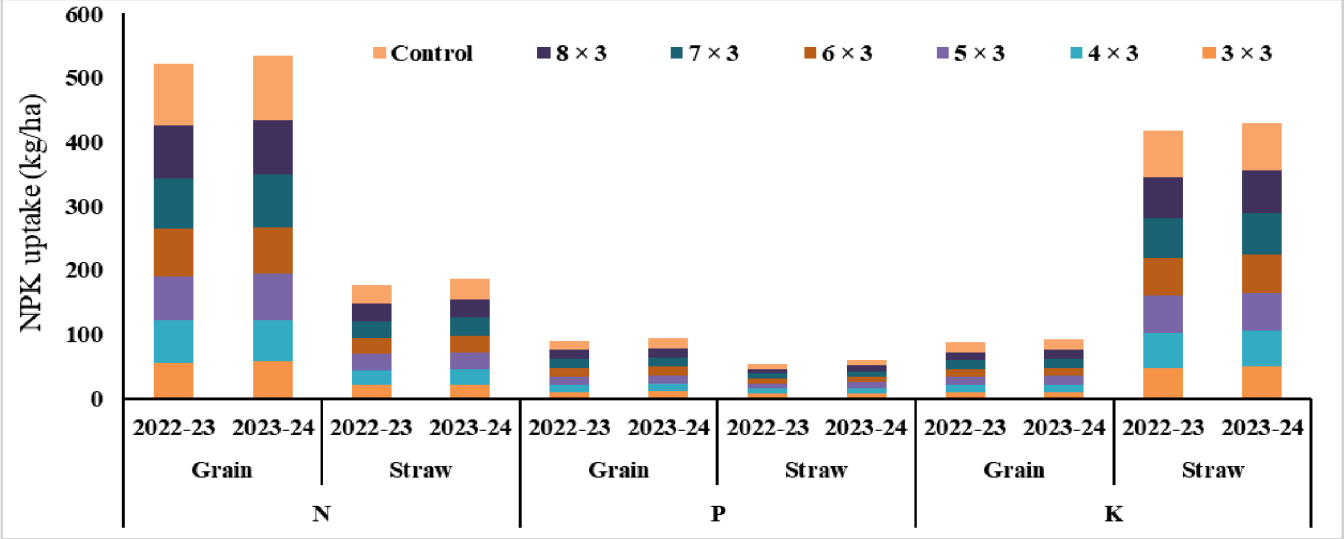

Fig. 3. Effect of plant spacing on poplar-based agroforestry system on NPK uptake by grain and straw in wheat

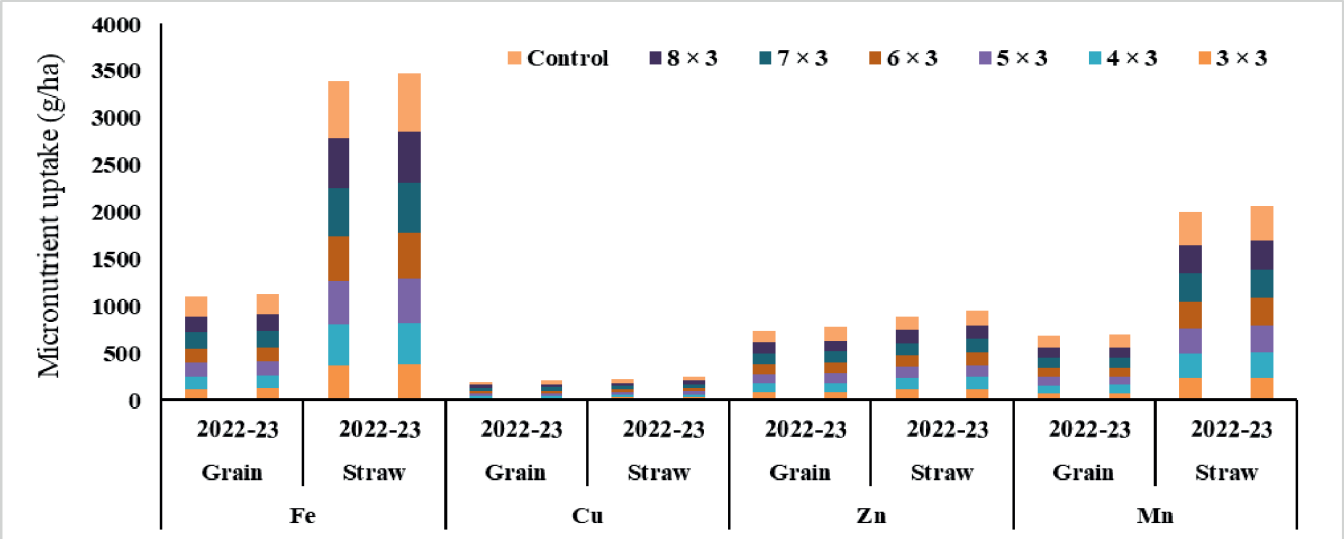

Fig. 4. Effect of plant spacing on poplar-based agroforestry system on Fe, Cu, Zn and Mn uptake by grain and straw in wheat

the nutrient uptake of wheat straw for N, P, K, Fe, Cu, Zn and Mn ranged from 29.40–20.98 kg/ha, 7.89–6.99 kg/ha, 72.42-48.07 kg/ha, 610.96–357.47 g/ha, 37.36–25.70 g/ha, 146.63–108.68 g/ha and 344.16–232.09 g/ha in 2021. The uptake of nutrients by wheat grain and straw increased from 2022–23 to 2023–24. Among the poplar-based system the highest nutrient uptake in wheat grain and straw was recorded at 8 m × 3 m spacing, which further decreased from 8 m × 3 m to 3 m × 3 m poplar spacing during both years of experiment. The wider geometries had higher uptake of macro and micro nutrients than the closer spacing of polar trees during both years. Similar were the findings of Devi *et al.* (2020) and Meena *et al.* (2023).

Thus, study concluded that among the poplar-based agroforestry system widest tree spacing treatment (8 × 3 m) yielded the highest forage output of sorghum and grain and straw yield of wheat in two year of crop rotations. Uptake of macro-and micro-nutrient in sorghum–wheat rotation under the widest spacing (8 × 3 m) was the most productive compared to other tree spacing. Intercropping sorghum-wheat with poplar can help bridge the gap between the demand and supply of green forage and economic yield in semi-arid regions, promoting a more sustainable and productive land use system integrated with livestock.

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