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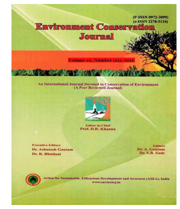

Status of soil and plant micronutrients and their uptake by barley varieties intercropped with *Populus deltoides* plantation

Ashish Kumar ✉
Department of Forestry, CCS Haryana Agricultural University, Hisar, Haryana
K. S. Ahlawat
Department of Forestry, CCS Haryana Agricultural University, Hisar, Haryana
Chhavi Sirohi
Department of Forestry, CCS Haryana Agricultural University, Hisar, Haryana
K. K. Bhardwaj
Department of Soil Science, CCS Haryana Agricultural University, Hisar, Haryana
Sushil Kumari
Department of Forestry, CCS Haryana Agricultural University, Hisar, Haryana
Charan Singh
Department of Soil Science, CCS Haryana Agricultural University, Hisar, Haryana
Ritambhara
Department of Soil Science, CCS Haryana Agricultural University, Hisar, Haryana
Sandeep Bedwal
Department of Soil Science, CCS Haryana Agricultural University, Hisar, Haryana

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ABSTRACT

In Agroforestry systems, crops grown in interspaces of tree plantations undergo different kind of interactions with the environment, consequently affecting soil fertility in different ways. In the present study, soil and plants micronutrients and their uptake by five barley varieties (BH 946, BH 959, BH 393, BH 885 and BH 902) grown under poplar plantation as well as sole crop were examined. During this investigation, a significant increase in DTPA (Diethylene triamnine penta acetic acid) extractable micronutrients (Zinc, Copper, Manganese and Iron) was observed at all depths (0-15, 15-30 and 30-45 cm) under poplar plantation than sole crop. Sole crop exhibited higher micronutrient uptake than under poplar plantations. Maximum uptake of soil micronutrients like Zn, Mn and Cu (495.5, 527.06 and 53.8 g ha^{-1}) were recorded in variety BH 946. However, variety BH 959 exhibited minimum uptake of soil micronutrients (401.85, 439.46 and 44.07 g ha^{-1}) during this study.

Introduction

The increasing pressure on the agriculture sector to meet the food requirements of the burgeoning population has led to degradation of the natural resources throughout the world. Moreover, the situation has further aggravated in the highly productive Indo-Gangetic plains of north-western India. Consequently, widespread multi-nutrient deficits have also been documented (Dwivedi *et al.,* 2006; Singh *et al.,* 2015; Shukla and Behera, 2019; Bhardwaj *et al.,* 2020). Therefore, sustainable management of these natural resources is necessary for ensuring livelihoods and environmental protection. Meanwhile, diversifying existing farming systems with suitable region-based agroforestry models has emerged as one of the powerful solutions (Dhyani and Handa, 2013). Agroforestry plays a significant role in protecting the resource base and increasing production capacity and micronutrient availability in arid and semi-arid areas (Dhyani, 2011). Agroforestry is of great importance for North Indian states like Haryana, Punjab and Uttar Pradesh. According to

Corresponding author E-mail: akansal67@gmail.com
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FSI (2021) report, Haryana's Forest and tree cover is 6.85 % of its total geographical area. Out of 6.85 %, the forest cover is 3.63 %, and the rest 3.22 % is the tree cover under the agroforestry system. Based on market demand, poplar is one of the most preferred and promoted tree species and the extensive presence of poplar in north India, especially in Haryana, Punjab, Western Uttar Pradesh and tarai regions of Uttrakhand, is an authentication of the broad acceptance of poplar by the farmers (Nandal and Dhillon, 2007). Poplar-based agroforestry systems are more profitable and commercially sustainable than many other crop rotations (Jain and Singh, 2000). Besides tree species, proper selection of understory crops exerts a considerable effect on the performance of the agroforestry system and results in increased productivity, improved soil fertility, foster land resilience, and the quality of resource use (Sharma *et al.,* 2004; Muthuri *et al.,* 2005; Jose, 2009). Poplar-based agroforestry systems serve as a sink and source for the minerals based on the tree-crop combinations. It can maintain and increase plant-available minerals like macronutrients (Bhardwaj *et al.,* 2016; Kumar *et al.,* 2017; Ram *et al.,* 2017; Sirohi and Bhangrwa, 2017) and micronutrients (Sharma *et al.,* 2021), by reducing volatile losses, adopting biological nitrogen fixation, litter and biomass decomposition. However, some researchers have found a substantial decline in nutrient availability in agroforestry systems than sole crops (Chauhan, 2012; Sharma *et al.,* 2012; Sarkar *et al.,* 2017). Moreover, because of its deciduous nature, low shading problem, and sufficient light intensity, poplar-based agroforestry is highly suitable for winter crops, i.e., barley among farmers of Northern India. Barley (*Hordeum vulgare*) belongs to the grass family Poaceae and it is world's fourth most important cereal after wheat, rice, and maize, has become an essential component of the developing countries human diet, including India. It is probably the most widely adapted cereal crop with a strong tolerance for drought, wind and salt. Its ruggedness makes it the only viable rainfed cereal crop under low input and challenging climate in many countries all over the world. It occupied an area of 0.62 million hectares in India, producing 1.59 million tonnes of grain with a productivity of 25.73 q/ha (ICAR-IIWBR, 2020). It is cultivated on 12200 hectares with a production of 44000 tons in Haryana, which ranks second in average productivity (3607 kg/ha) after Punjab (3767 kg/ha). It is used for malt and fermentation, along with its use as food and feed. It reduces blood glucose levels (glycemic index) and blood cholesterol levels in the body. Each 100 g of barley grain comprise 10.6 g protein, 2.1 g fat, 64 g carbohydrates, 50 mg calcium, 3 g crude fibres, 6 mg iron, 31 mg vitamin B1, 0.10 mg vitamin B2 and 50 µg folate. In northern India, farmers cultivate different barley varieties with poplar however, there is a dearth of information regarding micronutrients availability and their uptake in the aforementioned agroforestry system. Considering the above facts, the present experiment was planned to study the interactive effect of barley varieties under poplar (*Populus deltoides*) based agroforestry system on the availability of micronutrients in soil, plant and their uptake by different barley varieties.

Material and Methods

The present study was conducted during the *Rabi* season of 2019-20 in an already established (February, 2015) *Populus deltoides* plantation (5 × 3 m spacing) based agroforestry system at Research area in Department of Forestry, CCS Haryana Agricultural University, Hisar (29^0 10ʺ N lat.,75^0 46ʺ E long., alt. 215 m mean sea level). A subtropical climate prevails in this area with 350-400 mm average annual rainfall, most of which is received during monsoon (July to September). The temperature ranges from being minimum (0°C) in December and January, to maximum (up to 45°C) in May and June due to hot and sunny days.

In the interspaces of the trees, five barley varieties (BH 393, BH 902, BH 946, BH 885, BH 959) were sown during the first week of November 2019-20 with a row to row distance of 22.5 cm and seed rate of 86.48 kg/ha. following randomized block design with three replications during the *Rabi* season of 2019-20. However, variety BH 885 was sown at a row to row spacing of 18 cm with a seed rate of 98.84 kg/ha. In the nearby field different barley varieties were sown as sole crop (devoid of trees). For field preparation in both the systems (poplar-based agroforestry system and sole crop) two ploughings with disc harrow and one with cultivator followed by planking were given to prepare a good seed bed for sowing of barley varieties after pre-sowing irrigation. The recommended dose of fertilizers (59.30 kg/ha N and 29.65 kg/ha P) were applied in both the environments. The half amount of nitrogen and whole amount of phosphorus was applied at the time of sowing. The remaining dose of nitrogen through urea was top dressed after 1st irrigation. Three replicates of soil samples were taken randomly from the experimental field (sole crop and under poplar plantation) at different depths (0-15, 15-30 and 30-45 cm), before sowing and after harvesting of barley crop. The samples were air-dried, grounded in a wooden pestle with mortar, passed through a 2 mm stainless steel sieve and stored for further analysis. The pH and EC of the soil were determined in soil: distilled water suspension (1:2). Micronutrient content in grain and straw was determined by di-acid digestion (HNO_3 /$HClO_4$, 4:1, w/v). DTPA extractable micronutrients (Fe, Zn, Cu, Mn) in soil samples were determined with method described by Lindsay and Norvell, 1978 (0.005 M DTPA + 0.01 M $CaCl_2$ + 0.1 M TEA buffer adjusted to pH = 7.3). Statistical data was analyzed using two factor randomized block design.

Results and Discussion

It is evident from the results (Table 1) that the values of zinc varied significantly between different soil depths and environments in both the observations taken before sowing and after harvesting of different barley varieties. Along with an increase in the soil depth, the average value of zinc decreased significantly from the maximum at 0-15 cm to minimum at 30-45 cm in both the observations taken before sowing and after harvesting (0.87 and 0.43 mg/kg, respectively). The average value of copper was significantly higher (Table 1) at the surface layer (0-15 cm) before sowing (0.70 mg/kg) and after harvesting (0.71 mg/kg) of different varieties of barley, while it was significantly lower (0.46 mg/kg) at a soil depth of 30-45 cm. Before sowing of barley varieties, it was observed that the average value of manganese concentration was significantly higher at the surface layer i.e., 0-15 cm (4.21 mg/kg) followed by 15-30 cm (2.89 mg/kg), and it was significantly lower at 30-45 cm (2.26 mg/kg). A similar pattern was observed after harvesting of barley varieties. During this study, it was found that the average iron was significantly higher (Table 1) under poplar-based agroforestry system than that of open conditions (devoid of trees). The maximum concentration of iron was observed at a depth of 0-15 cm (6.81 mg/kg) under poplar based agroforestry system and minimum at a soil depth of 30-45 cm (3.22 mg/kg) under open conditions.

After harvesting of barley varieties, the average Fe concentration was significantly higher at the surface layer i.e., 0-15 cm (6.07 mg/kg) followed by 15-30 cm (5.00 mg/kg), and significantly lower at soil depth of 30-45 cm (4.25 mg/kg). The interaction effect of depth and environment was found significant for Zn and Cu but found non-significant for Mn and Fe. The micronutrients available in poplar-based agroforestry system before sowing and after harvesting of different varieties of barley were significantly higher than the sole crop (devoid of tree). Furthermore, the availability of micronutrients decreased along with an increase in depth, and the maximum amount of micronutrients were available in the surface layer (0-15 cm). It could be possible that the more quantity of micronutrients (Zn, Cu, Mn and Fe) in the surface layer (0-15 cm) is attributed to the presence of more organic matter. Second, via litter fall and root biomass, the tree absorbs nutrients from the deeper layer of soil (30-45 cm) and transfers them to the surface layer. A similar results were also observed earlier by Sarkar *et al.* (2020) and Sharma *et al.* (2021). Additionally, they observed that as a result of tree litter fall and increased C (carbon) input in the form of root biomass, exudates, and above ground biomass under tree plantation, the supply of organic matter increased and stimulated microbial growth, which enhanced micronutrient availability under agroforestry systems. The primary factor influencing the vertical distribution and accumulation of nutrients under different agroforestry systems is nutrient cycling, with human disturbances and leaching as the minor contributors (Jobbage and Jackson, 2001). These results are in agreement with the findings of Campanha *et al.* (2007), Singh and Sharma (2007), Jiang *et al.* (2009) and Khanmirzaei *et al.* (2011). They performed multiple trials in various regions of the globe and concluded that the explanation for these changes is the soil's microclimatological

Table 1: Effect of environment on DTPA extractable zinc, copper, manganese and iron (mg/kg) concentration at different depths before sowing and after harvesting of barley varieties.

Nutrient (mg/kg)	Before harvesting				After harvesting		
	Soil depth (cm)	**Under tree**	**Sole crop**	**Mean**	**Under tree**	**Sole crop**	**Mean**
Zn	**0-15**	0.94	0.76	0.85	0.96	0.77	0.87
	15-30	0.75	0.54	0.65	0.77	0.55	0.66
	30-45	0.52	0.33	0.43	0.53	0.33	0.43
	Mean	0.74	0.54		0.75	0.55	
	CD at 5 %	Depth = 0.03 Environment = 0.02 Depth x Environment = NS			Depth = 0.03 Environment = 0.02 Depth x Environment = NS		
Cu	**0-15**	0.74	0.65	0.70	0.76	0.66	0.71
	15-30	0.68	0.57	0.63	0.69	0.57	0.63
	30-45	0.52	0.40	0.46	0.52	0.40	0.46
	Mean	0.65	0.54		0.66	0.54	
	CD at 5 %	Depth = 0.02 Environment = 0.02 Depth x Environment = NS			Depth = 0.03 Environment = 0.02 Depth x Environment = NS		
Mn	**0-15**	4.80	3.61	4.21	4.88	3.62	4.25
	15-30	3.32	2.45	2.89	3.36	2.44	2.90
	30-45	2.63	1.89	2.26	2.65	1.89	2.27
	Mean	3.58	2.65		3.63	2.65	
	CD at 5 %	Depth = 0.07 Environment = 0.06 Depth x Environment = 0.10			Depth = 0.08 Environment = 0.07 Depth x Environment = 0.12		
Fe	**0-15**	6.81	5.15	5.98	6.94	5.19	6.07
	15-30	5.83	4.09	4.96	5.88	4.11	5.00
	30-45	5.24	3.22	4.23	5.27	3.22	4.25
	Mean	5.96	4.15		6.03	4.17	
	CD at 5 %	Depth = 0.13 Environment = 0.11 Depth x Environment =0.18			Depth = 0.14 Environment = 0.12 Depth x Environment = NS		

amerlioration as a result of litter fall and organic matter addition. The data presented in Table 2 pertains to Zn, Cu, Mn and Fe content in grain and straw of different barley varieties grown under poplar-based agroforestry system and in open conditions (devoid of trees). Significant variation was observed neither in Zn, Cu, Mn and Fe content in grain and straw among different barley varieties and environments nor the interaction of variety and environment was found significant. It is evident from the Table 3 that the concentration of micronutrients in grain varied significantly among different barley varieties and environments (sole crop and under poplar plantation). However, the interaction effect of variety and environment was found non-significant. Zn and Cu uptake of variety BH 946 were found significantly higher than all the other varieties except BH 393, which was statistically at par. The other varieties were in the following order: BH 902 > BH 885 > BH 959. The uptake of zinc and copper was significantly lower in variety BH 959 (210.92 and 23.23 g/ha, respectively). A slight shuffle in the positions was observed in the uptake of Mn and Fe. The manganese and iron uptake were significantly higher in variety BH 946 (259.18 and 376.46 g/ha, respectively). The other varieties were in the following order: BH 393 > BH 902 > BH 885.

Similar to that of grain, the micronutrient uptake by straw also varied significantly among different varieties as well as in environments. But their interaction effect was found non-significant. The zinc uptake of variety BH 902 (233.15 g/ha) was significantly higher than all the other varieties. The

Table 2: Effect of environment on micronutrients (Zn, Cu, Mn and Fe) content in grain and straw of barley varieties (mg/kg).

Nutrient (mg/kg)	Grain				Straw		
	Variety	**Under tree**	**Sole crop**	**Mean**	**Under tree**	**Sole crop**	**Mean**
Zn	**BH 946**	65.0	64.0	64.5	36.0	35.0	35.5
	BH 959	64.0	64.0	64.0	35.0	34.0	34.5
	BH 393	65.0	65.0	65.0	35.0	35.0	35.0
	BH 885	65.0	64.0	64.5	35.0	34.0	34.5
	BH 902	66.0	65.0	65.5	38.0	36.0	37.0
	Mean	65.0	64.4		35.8	34.8	
	CD at 5 %	Variety = NS Environment = NS Variety x Environment = NS			Variety = NS Environment = NS Variety x Environment = NS		
Cu	**BH 946**	7.31	7.22	7.27	3.71	3.61	3.66
	BH 959	7.11	7.00	7.06	3.81	3.72	3.77
	BH 393	7.42	7.31	7.36	3.61	3.50	3.55
	BH 885	7.11	7.08	7.09	3.71	3.60	3.65
	BH 902	7.21	7.11	7.16	3.81	3.71	3.76
	Mean	7.23	7.14		3.73	3.63	
	CD at 5 %	Variety = NS Environment = NS Variety x Environment = NS			Variety = NS Environment = NS Variety x Environment = NS		
Mn	**BH 946**	59.47	58.88	59.17	44.90	44.31	44.60
	BH 959	57.72	57.13	57.43	45.46	44.89	45.18
	BH 393	58.31	58.30	58.30	44.31	43.73	44.02
	BH 885	57.73	57.70	57.71	44.89	43.71	44.31
	BH 902	58.30	57.72	58.01	45.47	44.88	45.18
	Mean	58.30	57.95		45.01	44.31	
	CD at 5 %	Variety = NS Environment = NS Variety x Environment = NS			Variety = NS Environment = NS Variety x Environment = NS		
Fe	**BH 946**	87.0	85.0	86.0	278	276	277
	BH 959	84.0	84.0	84.0	276	275	276
	BH 393	85.0	83.0	84.0	272	270	271
	BH 885	85.0	84.0	84.5	274	273	274
	BH 902	86.0	85.0	85.5	280	276	278
	Mean	85.4	84.2		276	274	
	CD at 5 %	Variety = NS Environment = NS Variety x Environment = NS			Variety = NS Environment = NS Variety x Environment = NS		

Table 3. Effect of environment on micronutrient (Zn, Cu, Mn and Fe) uptake (g/ha) by grain and straw of barley varieties.

Micronutrient (g/ha)	Variety	Grain			Straw		
		Under tree	Sole crop	Mean	Under tree	Sole crop	Mean
Zn	**BH 946**	261.30	303.57	282.44	193.68	232.42	213.05
	BH 959	182.40	239.45	210.92	164.59	217.26	190.92
	BH 393	243.32	290.55	266.93	162.46	212.77	187.62
	BH 885	206.27	257.70	231.98	163.57	212.20	187.88
	BH 902	236.28	284.70	260.49	210.86	255.44	233.15
	Mean	225.91	275.19		179.0	226.0	
	CD at 5 %	Variety = 19.51 Environment = 12.34 Variety x Environment = NS			Variety = 16.57 Environment = 10.48 Variety x Environment = NS		
Cu	**BH 946**	29.39	34.25	31.82	19.96	23.97	21.97
	BH 959	20.26	26.19	23.23	17.92	23.77	20.85
	BH 393	27.78	32.68	30.23	16.76	21.28	19.02
	BH 885	22.56	28.50	25.53	17.34	22.47	19.91
	BH 902	25.81	31.14	28.48	21.14	26.32	23.73
	Mean	25.16	30.55		18.62	23.56	
	CD at 5 %	Variety = 2.17 Environment = 1.37 Variety x Environment = NS			Variety = 1.71 Environment = 1.03 Variety x Environment = NS		
Mn	**BH 946**	239.07	279.29	259.18	241.51	294.25	267.88
	BH 959	164.50	213.75	189.13	213.82	286.85	250.34
	BH 393	218.23	260.60	239.42	205.68	265.84	235.76
	BH 885	183.17	232.41	207.79	209.79	272.93	241.36
	BH 902	208.71	252.81	230.76	252.31	318.52	285.42
	Mean	202.74	247.77		224.62	287.68	
	CD at 5 %	Variety = 17.50 Environment = 11.08 Variety x Environment = NS			Variety = 20.71 Environment = 13.10 Variety x Environment = NS		
Fe	**BH 946**	349.74	403.18	376.46	1495.64	1832.82	1664.23
	BH 959	239.40	314.28	276.84	1297.89	1757.25	1527.57
	BH 393	318.18	371.01	344.60	1262.55	1641.38	1451.97
	BH 885	269.73	338.26	304.00	1280.49	1703.84	1492.17
	BH 902	307.88	372.30	340.09	1553.72	1958.39	1756.06
	Mean	296.99	359.81		1378.06	1778.74	
	CD at 5 %	Variety = 17.50 Environment = 11.08 Variety x Environment = NS			Variety = 127.34 Environment = 80.54 Variety x Environment = NS		

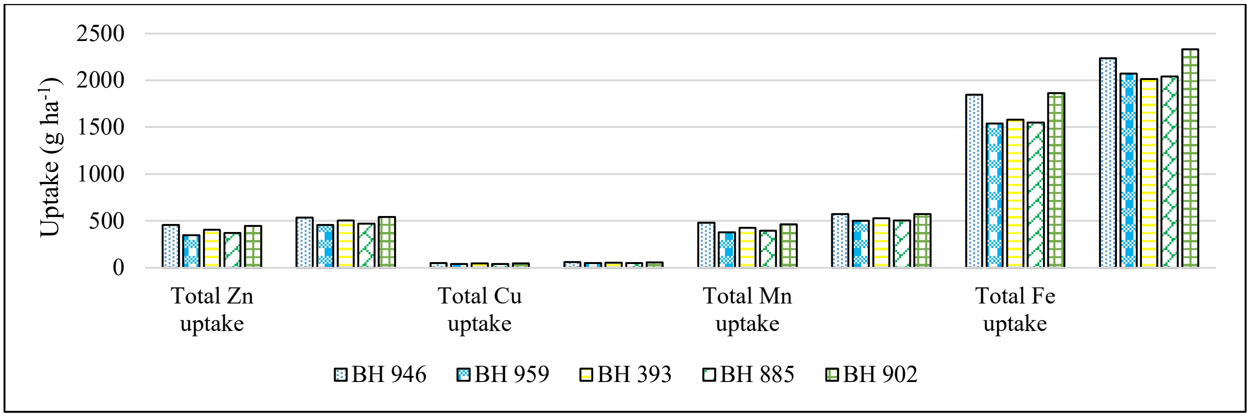

Figure 1: Total micronutrients uptake (g/ha) by five barley varieties.

difference in zinc uptake of varieties BH 959, BH 885 and BH 393 were statistically at par. Variety BH 902 (23.73 g/ha) was significantly higher than all the other varieties in copper uptake. It was closely followed by BH 946 (21.97 g/ha) and BH 959 (20.85 g/ha). A considerable change in positions was observed in manganese and iron uptake. The Mn and Fe uptake of variety BH 902 (285.42 and 1756.06 g/ha, respectively) was significantly higher than all the other varieties except BH 946 (267.88 and 1664.23 g/ha, respectively), which was statistically at par. The total micronutrient (Zn, Cu, Fe and Mn) uptake by barley varieties grown in open conditions (devoid of trees) was significantly higher than grown under poplar plantation. These results are in line with that of Dhillon (1992) and Gill *et al.* (2009) who found that wheat crop nutrient uptake was lower near the eucalypts tree. Thus, the significant reduction in nutrient uptake by barley varieties with poplar plantation than sole crops can be assigned to the intense competition for moisture and nutrients between poplar trees and the barley crop. Additionally, it was noticed that the uptake of total micronutrients (Zn, Cu, Mn and Fe) differed significantly among barley varieties (Fig. 1). On the other hand, the interaction effect of variety and environment was found non-significant. The total uptake of zinc and copper was significantly higher in BH 946 (495.49 and 53.79 g/ha, respectively). It was found to be statistically at par with variety BH 902 (493.64 and 52.21 g/ha, respectively). Variety BH 946 (527.06 g/ha) was observed significantly higher than all the other varieties in total Mn uptake except BH 902 (516.18 g/ha), as it was statistically at par. The maximum iron uptake was observed in variety BH 902 (2096.15 g/ha). It was closely followed by variety BH 946 (2040.69). The other varieties were as follows: BH 959 (1804.41 g/ha), BH 393 (1796.56 g/ha), and it was minimum in variety BH 885 (1796.16 g/ha).

In our experiment, photosynthetic rate, transpiration rate and stomatal conductance were observed maximum in BH 946 and minimum in BH 959 in both the environments and stages (At flag leaf and 10 days after anthesis). Furthermore, it was observed that the photosynthetic rate, transpiration rate and stomatal conductance were significantly higher in sole barley crop than under poplar plantation.

Conclusion

The remarkable change for available micronutrients under *Populus deltoides* based agroforestry system over sole barley crop (devoid of trees) was observed. Micronutrients (Zn, Cu, Mn and Fe) content increased significantly under poplar plantation than sole barley crop at all soil depths. The present study concludes that barley varieties BH 946 and BH 902 could be attributed to having better uptake efficiency of the micronutrients than rest of other varieties. The micronutrients (Zn, Cu, Mn and Fe) uptake by grain was found maximum in BH 946 followed by BH 393, BH 902, BH 885 and minimum in BH 959. The micronutrients uptake by straw was found higher in variety BH 902 than all the other varieties. However, uptake of micronutrients was higher under sole barley than intercropped with poplar-based agroforestry system.

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Conflict of interest
The authors declare that they have no conflict of interest.

References
Bhardwaj, K.K., Dhillon, R.S., Godara, A.S., Bangarwa, K.S., Sushil, K. & Sheokand, R.N. (2016). Effect of different spacings of poplar based agroforestry system on soil chemical properties and nutrient status in North-West India. *Indian Journal of Ecology*, *43*(1): 312317.

Bhardwaj, S., Khanna, D. R., Ruhela, M., Bhutiani, R., Bhardwaj, R., & Ahamad, F. (2020). Assessment of the soil quality of Haridwar Uttarakhand India: A comparative study. *Environment Conservation Journal*, *21*(3), 155-164.

Campanha, M.M., Santos, R.H.S., Freitas, G.B., Martinez, H.E.P., Jaramillo, B.C. & Garcia, S.L. (2007). Comparative analysis of litter and soil characteristics under coffee (*Coffea arabica* L.) crop in agroforestry and monoculture systems. *Revista Arvore, 31*(5): 805-812.

Chauhan, S.K. (2012). Performance of poplar (*Populus deltoids* Bartr.) and its effect on wheat yield under agroforestry system in irrigated agro-ecosystem, India. *Caspian Journal of Environmental Sciences*, *10*(1): 53-60.

Dhillon, M. S. (1992). Quantification and mitigation of yield losses in wheat due to boundary plantation of eucalyptus [Ph.D. thesis], Department of Agronomy, College of Agriculture, Punjab Agricultural University, Ludhiana, India.

Dhyani, S.K. (2011). Agroforestry interventions in India: Focus on environmental services and livelihood security. *Indian Journal of Agroforestry*, *13*(2): 1-9.

Dhyani, S.K. & Handa, A.K. (2013). Area under agroforestry in India: An assessment for present status and future perspective. *Indian Journal of Agroforestry*, *15*(1): 1-11.

Dwivedi, B.S., Singh, D., Chonkkar, P.K., Sahoo, R.N., Sharma, S.K. & Tiwari, K.N. (2006). Soil fertility evaluation-A potential tool for balanced use of fertilizers. IARI, New Delhi and PPI/PPIC-India programme, Gurgaon. pp. 1-60.

Gill, R. I. S., Singh, B. & Kaur, N. (2009). Productivity and nutrient uptake of newly released wheat varieties at different sowing times under poplar plantation in North-Western India. *Agroforestry Systems, 76*(3): 579–590.

ICAR-IIWBR. (2020). Director's report of AICRP on wheat and barley 2019-20, Ed: G.P. Singh. ICAR- Indian Institute of Wheat and Barley Research, Karnal, Haryana, India. pp.76.

India State of Forest Report (2021). Forest Survey of India, Ministry of Environment and Forests, released by Ministry of Environment Forest and Climate change.

Jain, S.K. & Singh, P. (2000). Economic analysis of industrial agroforestry: poplar (*Populus deltoides*) in Uttar Pradesh (India). *Agroforestry systems*, *49*(3): 255-273.

Jiang, Y., Zhang, Y.G., Zhou, D., Qin, Y. & Liang, W.J. (2009). Profile distribution of micronutrients in an aquic brown soil as affected by land use. *Plant Soil Environment, 55*(11): 468-476.

Jobbage, E.G. & Jackson, R.B. (2001). The distribution of soil nutrients with depth: Global patterns and the imprint of plants. *Biogeochemistry, 53*: 51-77.

Jose, S. (2009). Agroforestry for ecosystem services and environmental benefits: An overview. *Agroforestry systems*, *76*(1): 1-10.

Khanmirzaei, A., Kowsar, S.A. & Sameni, A.M. (2011). Changes of selected soil properties in a flood water-irrigated eucalyptus plantation in the Gareh Bygone Plain, Iran. *Arid Land Research and Management*, *25*: 38-54.

Kumar, M., Kumar, P., Tewari, J.C. & Pandey, C.B. (2017). Changes in soil fertility under multipurpose tree species in Thar Desert of Rajasthan. *Range Management and Agroforestry*, *38*: 274-279.

Lindsay, W. L. & Norvell, W. A. (1978). Development of a DTPA soil test for zinc, iron, manganese, and copper 1. *Soil Science Society of America Journal*, *42*(3): 421-428.

Muthuri, C.W., Ong, C.K., Black, C.R., Ngumi, V.W. & Mati, B.M. (2005). Tree and crop productivity in *Grevillea*, *Alnus* and *Paulownia*-based agroforestry systems in semi-arid Kenya. *Forest Ecology and Management*, *212*(1-3): 23-39.

Nandal, D.P.S. & Dhillon, A. (2007). Allelopathic effect of poplar (*Populus deltoides* Bartr. Ex Marsh): an assessment on the response of wheat varieties under laboratory and field conditions. *Indian Journal of Agroforestry*, *9*(2): 125-127.

Ram, A., Dev, I., Uthappa, A.R., Kumar, D., Kumar, N., Chaturvedi, O.P. & Meena, B.P. (2017). 14- Reactive nitrogen in agroforestry systems of India. *The Indian nitrogen assessment,* pp. 207-218.

Sarkar, P.K., Das, B. & Bhatt, B. (2017). Bakain (*Melia azedarach*): a promising agroforestry species for improving livelihood of farmers of eastern plateau and hill region of India. *The Bioscan*, *12*(2): 1095-1100.

Sarkar, S., Das, D.K. & Singh, A. (2020). Soil micronutrients status of different agroforestry systems in north Bihar. *Journal of Pharmacognosy and Phytochemistry*, *9*(5): 355-358.

Sharma, N.K., Singh, R.J. & Kumar, K. (2012). Dry matter accumulation and nutrient uptake by wheat (*Triticum aestivum* L.) under poplar (*Populus deltoides*) based agroforestry system. *International Scholarly Research Notices*, *2012*: 1-7.

Sharma, P., Rai, S.C., Sharma, R. & Sharma, E. (2004). Effects of land-use change on soil microbial C, N and P in a Himalayan watershed. *Pedobiologia*, *48*(1): 83-92.

Sharma, S., Singh, P., Angmo, P. & Dhaliwal, S.S. (2021). Micro-nutrient pools and their mobility in relation to land-use system in a cold high altitude Himalayan mountainous region. *Agroforestry Systems*, *95*(8): 1395-1412.

Shukla, A.K. & Behra, S.K. (2019). All India coordinated research project on micro-and secondary nutrients and pollutant elements in soils and plants: research achievements and future thrusts. *Indian Journal of Fertilizers, 15*: 522-543.

Singh, B. & Sharma, K.N. (2007). Tree growth and nutrient status of soil in a poplar (*Populus deltoides* Bartr.)-based agroforestry system in Punjab, India. *Agroforestry Systems*, *70*(2): 125-134.

Singh, V.K., Dwivedi, B.S., Shukla, A.K., Kumar, V., Gangwar, B., Rani, M., Singh, S.K. & Mishra, R.P. (2015). Status of available sulfur in soils of north-western Indo-Gangetic plain and western Himalayan region and responses of rice and wheat to applied sulfur in farmer's fields. *Agricultural Research, 4*: 76-92.

Sirohi, C., & Bangarwa, K.S. (2017). Effect of different spacings of poplar-based agroforestry system on soil chemical properties and nutrient status in Haryana, India. *Current Science*, *113*(7): 1403-140

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