Soil nutrient status under barley intercropped with poplar (*Populus deltoides*) agroforestry systems in Northern India

ABSTRACT

The present investigation was carried out to assess the soil nutrient status under five year old popular plantation. In the study, five barley varieties (BH 946, BH 959, BH 393, BH 885 and BH 902) were sown with already established poplar plantation at a 7 x 3 spacing. Soil pH and EC decreased significantly under poplar plantation than sole barley crop. A significant increase in soil organic carbon, available N, P and K were observed at all depths (0-15, 15- 30 and 30-45 cm) under poplar based agroforestry system than sole barley (devoid of trees). Poplar based agroforestry system was observed to provide exemplary effect on soil properties as compared to sole cropping. Thus, signifying that poplar based agroforestry system will also yield good returns to farmers in the long-run by improving the soil health and agricultural sustainability.

***Keywords*:** Agroforestry, soil nutrients, organic carbon, poplar, barley, sustainability

INTRODUCTION: During Green Revolution, India was able to attain food self-sufficiency, but this was achieved at a high cost. Due to the overexploitation of natural resources and the inappropriate use of chemicals, the soil, water and ecological systems deteriorated. Along with this, the continuous reduction in forests is frightening the mankind. According to the National Forest Policy (1988), one third (33.3%) of the land area should be under forest cover for a sustainable ecological balance. The country's total forest cover is 7,13,789 square kilometres, i.e., 21.71% of India's total geographical area (ISFR, 2021). Forests are of great importance to us as they furnish economic, social and environmental strength to our nation. Agroforestry represents the combination of agriculture and forestry through the integration of trees on the farmland and increased social, economic and environmental benefits. It is a wealthy, multi-functional and climatically smart agriculture alternative to control land deterioration and gain ecological balance according to the surroundings (Montes *et al.,* 2020). Agroforestry is of great importance for the North Indian states like Haryana, Punjab and Uttar Pradesh. It fosters the enrichment of soil by increasing the nitrogen fixation, efficient nutrient cycle, improving water holding capacity and drainage. The component other than crops works as an income booster and reduces the owner's dependency on one. Diversification also leads to ecological stability and sustainability. India is the first country to adopt the National Agroforestry Policy in 2014, under the Ministry of Agriculture and Farmers Welfare, Government of India. Carbon emission has become a big problem these days (Sahoo and Sahoo, 2022). Agroforestry can be a possible solution for this problem because by incorporating trees, agricultural systems can be a potential sink for enormous amounts of carbon. It act as carbon sink for improving biological diversity in the soil (Kay *et al.,* 2019). Thus, agroforestry is very promising in terms of the income, sustainability and quality of climate (Yirga, 2019). Based on the tree-crop combinations, agroforestry systems serve as both a sink and source for the minerals. It can maintain minerals like nitrogen by reducing volatile losses, biological nitrogen fixation and litter decomposition (Ram *et al.,* 2017). The trees collective biomass in the form of wood, timber, litter etc., acts as a reservoir of the nutrients and revamps the soil's infiltration rate and water holding capacity and plays an outstanding role in the structure and functioning of the ecosystem (Muchane *et al.,* 2020). Multipurpose trees (MPTs) are acquiring considerable prominence in India's agroforestry systems of arid and semi-arid regions (Raj *et al.,* 2022); poplar is one of them (Pandey *et al.,* 2020). *Populus deltoides* is a fast-growing tree species belonging to the Salicaceae family. Poplar is adopted by the farmers due to its quick growth, multi-utility wood, pruning tolerance, and minimal competition with agricultural crops grown in the association. Predominantly it is cultivated in Uttar Pradesh, Jammu and Kashmir, Punjab, Himachal Pradesh, Haryana, West Bengal, Uttrakhand, and Arunachal Pradesh. Its deep root system empowers the tree to consume considerable nutrients beneath the crop's rooting zone, thus offering less resistance to intercropped crops. Also, the addition of litter in the form of leaves from the tree enhances the organic matter in the soil and maintains soil fertility by replenishing nutrients. Thus, the main aim of the present study was to analyse the effect of poplar based agroforestry system and different barley varieties on soil chemical properties.

MATERIALS AND METHODS

The present study was conducted in already established *Populus deltoides* plantation planted in February, 2015 at a spacing of 5 x 3 at Research area, Department of Forestry, CCS Haryana Agricultural University, Hisar. In the interspaces of the trees, five barley varieties were raised in three replications during the *rabi* season of 2019- 20. The standard package of practices as recommended by CCS HAU, Hisar was followed. The experiment is located at 29° 20' N latitude and 75° 46' E longitude at an elevation of 215 meters from the mean sea level in the semi-arid region of North-Western India. The major part of the year is dominated by prolonged hot spells. The summers are quite hot with a maximum temperature varying from 40 to 48 °C in the month of May and June, whereas; December and January are the coldest months (the lowest temperature reaches as low as 0 °C). The average annual rainfall is 350-400 mm, with 70-80% of it falling between July to September. 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). The soil samples were collected before sowing and after harvesting of barley crop for the study of various soil chemical properties (pH, EC and OC), available nutrients (N, P and K). The samples were air-dried, ground in a wooden pestle with mortar, passed through a 2 mm stainless steel sieve and stored for further analysis. The soil obtained was stored for analysis. The pH and EC (Jackson, 1973) of the soil were determined in soil: distilled water suspension (1:2). Organic carbon was analysed by using partial oxidation method (Walkley and Black, 1934). Available N was estimated using alkaline permanganate distillation method (Subbiah and Asija, 1956). Phosphorous and potassium were determined by sodium bicarbonate (Olsen *et al.,* 1954) and neutral normal ammonium acetate method, respectively. The data recorded during the research were analyzed statistically by using two factor randomized block design. Critical difference for all characters was found to compare the treatment means.

Results and Discussion

The results depicted in Fig. 1 indicate that the decrease in soil pH after harvesting of barley crop at all depths was more considerable in poplar-based agroforestry system than in sole crop (devoid of trees). It was observed that the value of pH increased significantly with the increase in soil depth. The interaction effect of depth and environment on soil pH was also significant. However, the value of pH was recorded higher in sole crop than under poplar plantation. The lowest value (7.41) of pH was observed at a depth of 0-15 cm after harvesting of barley crop under poplar-based agroforestry system. In sole crop (without trees), no change in soil pH (7.89) was observed at a depth of 30-45 cm in both the observations taken before sowing and after harvesting of barley crop. The extent of soil pH decrease was more considerable in soil present under poplar plantation than in sole crop conditions. This might be attributed to the microenvironment established by varieties and poplar roots. Additionally, when litter decomposes, more acidic behaviour is introduced into the soil (Sarkar *et al.,* (2017). The electrical conductivity (dS m^{-1}) differed significantly under both environments and soil depths before sowing and after harvesting of the barley crop (Table 1). But, the interaction between soil depth and environment was found non-significant. Furthermore, the decrease in electrical conductivity after harvesting barley varieties was more considerable in the poplar-based agroforestry system than in the sole crop (devoid of trees). The maximum reduction in soil EC was observed at a depth of 0-15 cm in both sole (devoid of trees) and under poplar based agroforestry system. However, the decrease in EC was considerable lesser in sole crop than in poplar based agroforestry system. The result indicates that soil organic carbon content varied significantly at all the depths (0-15, 15-30 and 30-45 cm) and in both environments (Table 2). The interaction effect of depth and environment was found non-significant. The maximum organic carbon content (0.46 %) was recorded under poplar plantation at a depth of 0-15 cm after harvesting of barley crop. The minimum average organic carbon content (0.24%) was observed at a depth of 30-45 cm before the sowing of the crop. Along with the advancement in the age of poplar plantation, a more significant amount of litter fall and root necromass were added to the soil, resulting in high soil organic carbon status (Singh *et al.,* 1997; Bhardwaj *et al.*, 2016). Due to shading effect of tree, there may be reduced oxidation of organic matter which contributed to higher organic carbon under poplar plantation (Devi *et al.,* 2020).

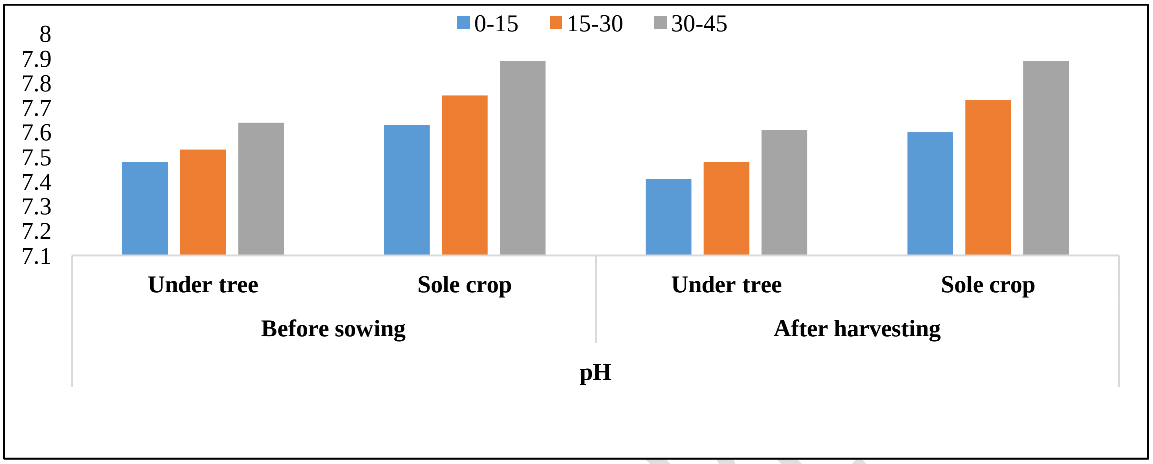

Fig. 1: Effect of environment on soil pH at different depths before sowing and after harvesting of barley varieties

Table 1: Effect of environment on electrical conductivity (dS m^{-1}) at different depths before sowing and after harvesting of barley varieties

Soil depth (cm)	Electrical conductivity (ds m^{-1})					
	Before sowing			After harvesting		
	Under tree	Sole crop	Mean	Under tree	Sole crop	Mean
0-15	0.38	0.43	0.41	0.36	0.42	0.39
15-30	0.40	0.46	0.43	0.38	0.45	0.42
30-45	0.44	0.52	0.48	0.43	0.52	0.48
Mean	0.41	0.47		0.39	0.46	
CD at 5 %	Depth = 0.019 Environment = 0.016 Depth x Environment = NS			Depth = 0.020 Environment = 0.016 Depth x Environment = NS		

Table 2: Effect of environment on soil organic carbon (%) at different depths before sowing and after harvesting of barley varieties

Soil depth (cm)	Organic carbon (%)					
	Before sowing			After harvesting		
	Under tree	Sole crop	Mean	Under tree	Sole crop	Mean
0-15	0.43	0.38	0.41	0.46	0.39	0.43

15-30	0.32	0.31	0.32	0.34	0.32	0.33
30-45	0.24	0.24	0.24	0.25	0.24	0.25
Mean	0.33	0.31		0.35	0.32	
CD at 5 %	Depth = 0.014 Environment = 0.017 Depth x Environment = NS			Depth = 0.013 Environment = 0.015 Depth x Environment = NS		

The average available soil nitrogen was significantly higher under poplar plantation than in sole crop (devoid of trees) in both the observations taken before sowing and after harvesting of barley crop. However, the interaction effect of depth and environment was found non-significant. The average available nitrogen found at a depth of 0-15 cm in both the observations taken before sowing and after harvesting of barley varieties (124.71 and 127.15 kg ha^{-1}, respectively) was significantly higher than all the other depths. Moreover, along with an increase in depth, the amount of average available nitrogen reduced significantly. The average available nitrogen was recorded minimum (93.98 kg ha^{-1}) at a depth of 30-45 cm in the samples collected for the analysis before sowing of barley crop (Table 3). The results further revealed that average available phosphorus (12.48 and 13.22 kg ha^{-1}, respectively) in the soil was significantly higher under a poplar-based agroforestry system than in the sole crop (devoid of trees) in both the observations taken before sowing and after harvesting of barley crop. The interaction effect of depth and environment was found significant in the soil samples taken before the sowing of the crop. However, it was found non-significant in samples collected after the barley crop was harvested. Available phosphorus (14.55 kg ha^{-1}) was significantly higher at a depth of 0-15 cm in a poplar-based agroforestry system than at all the other depths and open conditions (without trees) in soil samples collected before sowing. Moreover, along with an increase in depth, the amount of available phosphorus (kg ha^{-1}) reduced significantly. While in soil samples collected after the harvesting of barley crop, the average available phosphorus (13.65 kg ha^{-1}) was significantly higher at a depth of 0-15 cm than at all the other depths (Table 4). The reason for higher phosphorus under agroforestry might be the organic acids supplied during the breakdown of residue, increase the phosphorus release by curtailing the binding of metal ions with phosphate group via chelation effect and by challenging for exchange sites (El-Baruni and Olsen, 1979). However, due to the low temperature, the release of nutrients through litter fall breakdown would be reduced over the winter, but a rise in ambient temperature in the month of March–April may enhance the availability of phosphorus. The organic decomposition process releases the organic phosphorus and converts the insoluble phosphorus into the soluble one (Lal *et al.,* 2000; Sirohi and Bangarwa, 2017; Bhardwaj *et al.,* 2016). It is evident from fig. 2 that the average available potassium (kg ha^{-1}) in the soil was significantly higher under poplar plantation than in sole crop (devoid of trees) in both the observations taken before sowing and after harvesting of barley crop. However, the interaction effect of depth and environment was found non-significant. The average available potassium observed at a depth of 0-15 cm in both pre-sowing and post-harvest observations of soil samples (295.84 and 298.23 kg ha^{-1}, respectively) was significantly higher than the average available potassium observed at all other depths (15-30 and 30-45 cm). Moreover, along with an increase in depth, the amount of average available potassium reduced significantly. The average available potassium (235.20 kg ha^{-1}) was recorded minimum at a depth of 30-45 cm in the samples collected for the analysis before sowing of barley crop. All the macronutrients were observed increasing from their initial values after the harvesting of barley crop. However, the increase in the amount of nutrients was higher at a depth of 0-15 cm than that of 15-30 and 30-45 cm depth. This might be due to the mineralization of macronutrients from leaf fall, finer roots and the divulgence of nutrients from the soil reservoirs. A significant increase in above mentioned parameters indicated that there was higher organic matter buildup, which acts as labile pool of nutrients for microorganisms, crops and plants which was also indicated by the increase in amount of available N, P and K. The impact of agroforestry on soil fertility in terms of higher organic matter content, total nitrogen, phosphorus and potassium in the top soil was also reported by Kaushal *et al.* 2016.

Table 3: Effect of environment on available nitrogen (kg ha^{-1}) at different depths before sowing and after harvesting of barley varieties

	Available nitrogen (kg ha^{-1})

Soil depth (cm)	Before sowing			After harvesting		
	Under tree	Sole crop	Mean	Under tree	Sole crop	Mean
0-15	134.26	115.15	124.71	138.44	115.85	127.15
15-30	122.68	100.76	111.72	125.36	101.57	113.47
30-45	106.05	81.45	93.98	107.15	81.87	94.51
Mean	121.15	99.12		123.65	99.76	
CD at 5 %	Depth = 2.53 Environment = 2.07 Depth x Environment = NS			Depth = 2.80 Environment = 2.30 Depth x Environment = NS		

Table 4: Effect of environment on available phosphorus (kg ha^{-1}) at different depths before sowing and after harvesting of barley varieties

Soil depth (cm)	Available phosphorus (kg ha^{-1})					
	Before sowing			After harvesting		
	Under tree	Sole crop	Mean	Under tree	Sole crop	Mean
0-15	14.55	11.46	13.01	15.45	10.85	13.65
15-30	12.04	9.15	10.60	12.82	9.46	11.14
30-45	10.85	8.45	9.65	11.39	8.55	9.97
Mean	12.48	9.69		13.22	9.95	
CD at 5 %	Depth = 0.18 Environment = 0.15 Depth x Environment = 0.25			Depth = 0.36 Environment = 0.30 Depth x Environment = NS		

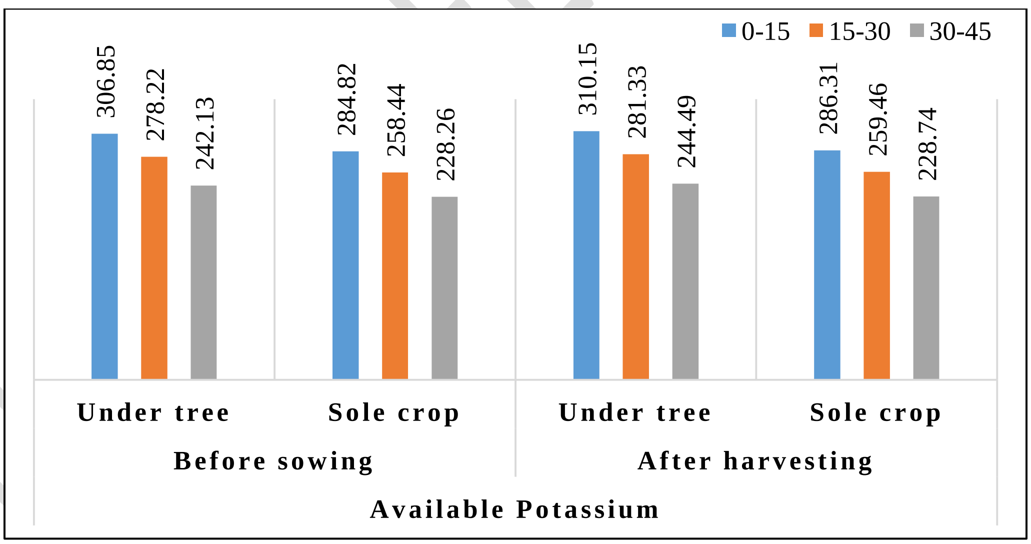

Fig. 2: Available potassium status (kg ha^{-1}) at different depths under poplar based agroforestry and sole barley

The N, P and K content (%) in grain and straw of different barley varieties grown under poplar-based agroforestry system and in open conditions (devoid of trees). It was observed that there was a non-significant variation in N, P and K content in grain and straw among different barley varieties and environments. Moreover, the interaction of variety and environment was also found non- significant (Fig. 3).

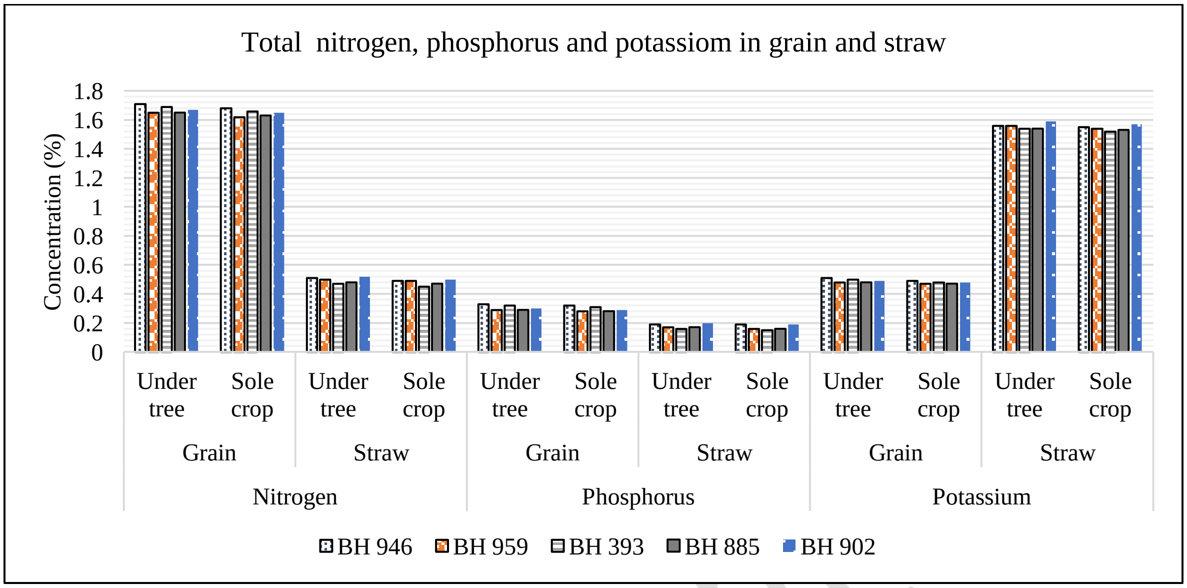

Fig. 3: Total nitrogen, phosphorus and potassium content in grain and straw of barley varieties intercropped with poplar and sole crop

It is evident from Table 5 that N, P & K uptake by grain differed significantly among varieties and environments. However, the interaction effect of variety and environment was found non-significant. N, P and K uptake of variety BH 946 (74.22, 14.22 and 21.87 kg ha^{-1}, respectively) was observed significantly higher than all the other varieties followed by BH 393, BH 902 and BH 885. The N, P and K uptake was minimum in BH 959 (53.82, 9.38 and 15.63 kg ha^{-1}, respectively).

Table 5: Effect of environment on N, P and K uptake (kg ha^{-1}) by grain and straw of barley varieties

Nutrient uptake (kg ha^{-1})	Variety	Grain			Straw		
		Under tree	Sole crop	Mean	Under tree	Sole crop	Mean
Nitrogen	BH 946	68.74	79.69	74.22	27.44	32.54	29.99
	BH 959	47.03	60.61	53.82	23.51	31.31	27.41
	BH 393	63.26	74.20	68.73	21.82	27.36	24.59
	BH 885	52.36	65.63	59.00	22.43	29.33	25.88
	BH 902	59.79	77.27	68.53	28.85	35.48	32.17
	Mean	58.24	71.48		24.81	31.20	
	CD at 5 %	Variety = 5.01 Environment = 3.17 Variety x Environment = NS			Variety = 2.30 Environment = 1.45 Variety x Environment = NS		
	BH 946	13.27	15.18	14.22	10.22	12.62	11.42

Phosphorus	**BH 959**	8.27	10.48	9.38	7.99	10.22	9.11
	BH 393	11.98	13.86	12.92	7.43	9.12	8.28
	BH 885	9.20	11.27	10.24	7.94	9.99	8.97
	BH 902	10.74	12.70	11.72	11.10	13.48	12.29
	Mean	10.69	12.70		8.94	11.09	
	CD at 5 %	Variety = 0.92 Environment = 0.58 Variety x Environment = NS			Variety = 0.85 Environment = 0.53 Variety x Environment = NS		
Potassium	**BH 946**	20.50	23.24	21.87	83.93	102.94	93.44
	BH 959	13.68	17.58	15.63	73.36	98.41	85.89
	BH 393	18.72	21.46	20.09	71.48	92.40	81.94
	BH 885	15.23	18.92	17.08	71.97	95.49	83.73
	BH 902	17.54	21.02	19.28	88.23	111.40	99.82
	Mean	17.13	20.44		77.79	100.13	
	CD at 5 %	Variety = 1.47 Environment = 0.93 Variety x Environment = NS			Variety = 7.20 Environment = 4.56 Variety x Environment = NS		

Conclusion

A remarkable change in soil chemical properties was observed under *Populus deltoides* based agroforestry system over sole barley crop (devoid of trees). The reduction in soil pH and EC was more considerable under poplar trees than in sole crop. The soil organic carbon significantly improved under poplar based agroforestry system. Available soil N, P and K increased significantly under poplar plantation than sole barley crop in all soil depths (0-15, 15-30 and 30-45 cm). The N, P and K uptake by grain of variety BH 946 was maximum followed by BH 393, BH 902, BH 885 and BH 959. However, the N, P and K uptake by straw was maximum in variety BH 902 followed by BH 946, BH 959, BH 885 and minimum in BH 393. Therefore, this study concludes that improvement in soil chemical properties depicts significant impact of the agroforestry system as compared to sole cropping.

References

Bhardwaj KK, Dhillon RS, Godara AS, Bangarwa KS, Sushil K, Sheokand RN. Effect of different spacings of poplar based agroforestry system on soil chemical properties and nutrient status in North-West India. Indian Journal of Ecology, 2016; 43(1): 312- 317.

Devi S, Bhardwaj KK, Dahiya G, Sharma MK, Verma AK, Louhar G. Effect of agri-silvi-horticultural system on soil chemical properties and available nutrients at different depths in Haryana. Range Management and Agroforestry, 2020; 41(2): 267-275.

El-Baruni B, Olsen SR. Effect of manure on solubility of phosphorus in calcareous soils. Soil Science, 1979; 128(4): 219-225.

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

Jackson ML. Soil chemical analysis. Prentice Hall of India, Pvt. Ltd., New Delhi, 1973; 498p.

Kaushal R, Verma A, Mehta H, Mandal D, Tomar JMS, Jana C, Chaturvedi OP. Soil quality under *Grewia optiva* based agroforestry systems in western sub-Himalaya. Range Management and Agroforestry, 2016; (1): 50-55.

Kay S, Rega C, Moreno G, den Herder M., Palma JH, Borek R, Herzog F. Agroforestry creates carbon sinks whilst enhancing the environment in agricultural landscapes in Europe. Land use policy, 2019; 83: 581-593.

Lal JK, Mishra B, Sarkar AK. Effect of plant residues incorporation on specific microbial groups and availability of some plant nutrients in soil. Journal of the Indian society of soil science, 2000; 48(1): 67-71.

Montes O, Uribe M, Castro R, Villanueva C, Pérez M, Lara A. Policy forum: Proposal of a Mexican precision agroforestry policy. Forest Policy and Economics, 2020; 119: 102292.

Muchane MN, Sileshi GW, Gripenberg S, Jonsson M, Pumarino L, Barrios E. Agroforestry boosts soil health in the humid and sub-humid tropics: A meta-analysis. Agriculture, Ecosystems and Environment, 2020; 295: 106899.

Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soils by extraction with sodium bi-carbonate. United States Department of Agriculture Circular, 1954; 939p.

Pandey A, Kumar D, Dhawan VK. Growth assessment of poplar clones developed by FRI, at Saharanpur, Uttar Pradesh and Hoshiarpur, Punjab. Journal of Pharmacognosy and Phytochemistry, 2020; 9(1): 1735-1738.

Raj A, Jhariya MK, Banerjee A, Meena RS, Nema S, Khan N, Pradhan G. Agroforestry a model for ecological sustainability. In Natural Resources Conservation and Advances for Sustainability, 2022; 289-307.

Ram A, Dev I, Uthappa AR, Kumar D, Kumar N, Chaturvedi OP, Meena BP. Reactive nitrogen in agroforestry systems of India. The Indian nitrogen assessment, 2017; 207- 218.

Sahoo M, Sahoo J. Effects of renewable and non-renewable energy consumption on CO_2 emissions in India: empirical evidence from disaggregated data analysis. Journal of Public Affairs, 2022; 22(1): e2307.

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

Singh G, Singh NT, Dagar JC, Singh H, Sharma VP. An evaluation of agriculture, forestry and agroforestry practices in a moderately alkali soil in north-western India. Agroforestry systems, 1997; 37(3): 279-295.

Sirohi C, Bangarwa KS. Effect of different spacings of poplar-based agroforestry system on soil chemical properties and nutrient status in Haryana, India. Current Science, 2017; 113(7): 1403-1407.

Subbiah BV, Asija GL. A rapid procedure for the estimation of the available nitrogen in soils. Current Science, 1956; 25: 259-260.

Walkley A, Black IA. An examination degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science, 1934; 37: 29-37.

Yirga SA. Agroforestry for sustainable agriculture and climate change: A Review. International Journal of Environmental Sciences & Natural Resources, 2019; 19(5): 127-137.