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Soil Chemical Properties and Nutrient Dynamics under Different Legume-based Agroforestry Systems in Semi-arid Conditions of Haryana

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ABSTRACT

Background: In order to support livelihoods, enhance food security, restore ecosystem services, and reduce pressure on forests, soil fertility can be improved by utilizing alternative land-use systems, such as agroforestry.

Methods: The present study was conducted to investigate the effect of different agroforestry systems on soil chemical properties and nutrient availability (macro and micro) during different seasons in Hisar, Haryana. Different systems include Poplar (*Populus deltoides)*, Eucalyptus (*Eucalyptus tereticornis*), Melia (*Melia composita)*, Shisham (*Dalbergia sissoo*) based agroforestry system (Cowpea-Wheat) and sole cropping of Cowpea-Wheat (as control). Soil samples were collected from 0-15 and 15-30 cm of soil depth during five seasons *i.e.*, winter, spring, summer, rainy and autumn.

Result: Soil EC, SOC and available macronutrients and micronutrients were significantly affected by the depth of sampling, systems and seasons while soil pH was not significantly affected by seasons. Lower soil pH and EC was observed from agroforestry systems as compared to sole cropping. Soil Organic Carbon, availability of N, P, K and S was significantly higher under tree based systems as compared to control. Maximum DTPA extractable Mn, Zn and Cu was observed under poplar based system while highest DTPA extractable Fe was observed under Melia based system during both the years. Significantly higher SOC and nutrient availability was observed during autumn, rainy and spring seasons as compared to winter and summer seasons, while reverse trend was observed for soil pH and EC among the seasons. Soil Organic Carbon, availability of macro and micronutrients decreased with increase in soil depth. Overall, the soil chemical properties and nutrient status of soil were comparatively better under tree based systems than sole cropping of Cowpea-Wheat.

Key words: Agroforestry, Macronutrient, Micronutrient, Seasons, Soil organic carbon.

INTRODUCTION

Our capacity to meet food demands is threatened by the rapidly rising human population, the shrinking amount of cropland and the declining fertility of the soil. In the foreseeable future, managing the soil will be crucial to sustaining rising human requirements. The pressure on natural habitats, soil degradation, including the depletion of soil health, erosion and pollution of natural resources, will increase with intensive cultivation, the clearing of more forest lands for crop production and increasing cropping intensity on existing croplands. The conversion of natural ecosystems into agricultural lands, known as agricultural intensification, alters the type and quantity of organic residual input, as well as how it is distributed in the soil and accelerates the mineralization of soil organic carbon (Guo and Gifford, 2002). Additionally, the widespread degradation of the land has decreased crop output and impacted the sustainability of agriculture (Chaturvedi *et al.*, 2012). The pace of deterioration in soil fertility has accelerated with the cultivation of monocultures or exhausting crops without the addition of organic matter to the soil. In order to preserve the health of the soil and meet human requirements, it is crucial to implement a sustainable land use system.

Agroforestry is a distinctive form of land use that increases ecological and environmental advantages by combining trees with agricultural crops or livestock. It's the best scientific method for repairing degraded areas and effectively managing resources (Sileshi *et al.*, 2020). Despite the fact that the advantages that trees can offer on rural properties, such as food security, household income,

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economic stability and thermal comfort (shade), are frequently connected to their products, such as fruit, timber, or other items, trees can also improve nutrient cycling and have positive effects on soil chemical and physical properties when they are included in agricultural systems (Rodriguez *et al*., 2021). Agroforestry will be essential in the near future for providing environmental services such as phytoremediation for watershed safety, carbon sequestration for local weather change mitigation and biodiversity preservation.

In many tropical and subtropical regions, the loss of nutrients and organic matter in the soil poses an imminent threat to agricultural production and food security (Lal, 2004). Due to the depletion of nutrients and bad environmental conditions, such a fall causes a decrease in agricultural production. (Lal, 2004). Although soils are important suppliers of plant nutrients, throughout the growth season they are not always readily available due to factors like soil organic matter concentration, pH and cation-exchange capacity. Understanding nutrient availability and storage mechanisms aids in the development of appropriate nutrient management strategies for maximizing biomass production. Even though there have been numerous studies on the chemical characteristics of soil and the availability of nutrients in both tropical and temperate and forests agroforests, there are relatively few that demonstrate how the seasons and agroforesty systems affect the chemical characteristics and nutrient availability in semi-arid regions of Haryana. In order to better understand the dynamics of soil nutrients in terms of availability during various seasons and at various soil depths, the current study was done to investigate the chemical characteristics of soil and nutrient availability in agroforestry systems.

MATERIALS AND METHODS

Present study was carried out at Research Farm, Department of Forestry, Chaudhary Charan Singh Haryana Agricultural University, Hisar during 2021-22. The experimental site is located at 29°09′N latitude and 75°43′E longitude at an elevation of 215 meters above mean sea level which comes under semiarid region of north-west India. The soil is TypicUstochrept and sandy loam.

The field experiment was designed in Randomized Block Design with four replications. Four agroforestry systems including Poplar (*Populusdeltoides)*, Eucalyptus (*Eucalyptus tereticornis*), Melia (*Meliacomposita)* and Shisham (*Dalbergiasissoo*) based agroforestry system (Cowpea-Wheat) while one control with sole cropping of Cowpea-Wheat was chosen for the study.

In this experiment, the recommended packages of practices were followed separately for Poplar, Eucalyptus, Melia, Shishamand intercrops. For wheat, recommended dose of fertilizer (RDF) *i.e*. 150 kg N + 60 kg P_2O_5 + 30 kg K_2O + 25 kg $ZnSO_4$ per hectare was applied in each treatment. The whole amount of P and K and half dose of N were applied at the time of sowing. The remaining N through urea was top dressed at crown root initiation stage. Under trees 8 kg FYM was incorporated around each tree every year in the rainy season (June-July). In addition to these, under trees additional 10% dose of N was applied.

Soil samples were collected from two depths (0-15 cm and 15-30 cm) for 2 years during five seasons *i.e*., winter (Mid-November to Mid- January), spring (Mid-February to Mid-April), summer (Mid-May to Mid-June), rainy (Mid-July to Mid- August) and autumn (Mid-September to Mid-October). An auger was used to collect soil samples from four locations in each plot in a zig-zag pattern and then mixed and about 500 gm of soil was taken for analysis. The collected samples were dried in the shade, ground in a wooden pestle and mortar, sieved through a 2 mm sieve and stored in polythene bags for different chemical and nutrient analysis.

The soil samples were analyzed for chemical properties and available nutrients. The soil pH was determined in 1:2 soil-water suspensions (Jackson, 1973). Electrical conductivity (EC) was measured with an Elico conductivity meter using 1:2 soil-water suspensions after equilibrating the soil sample for one day. Organic carbon was determined by chromic acid titration method (Walkley and Black, 1934). The available N in the soil samples was determined by alkaline potassium permanganate method (Subbiah and Asija, 1956). The available phosphorus (P) was extracted with Olsen's method (Olsen *et al*., 1954) and determined on an Elico spectrometer at a wavelength of 760 nm. Available potassium was determined using neutral normal ammonium acetate method and then determined on flame photometer (Jackson, 1973). Available sulphur in soil is determined using turbidimetric method (Williams and Steinberg, 1969). Soil micronutrients were determined through the use of DTPA (Diethylentriaminepenta acetic acid) extract (1:2 Soil:DTPA). Fe, Mn, Zn and Cu were determined as per the method outlined by Lindsay and Norvell, 1978. The readings were taken on atomic absorption spectrophotometer using appropriate standards and cathode lamps.

Analysis of variance (ANOVA) was used for analyzing the data in the randomized block design. Least significant differences (LSD) at $p<0.05$ were used for multiple comparison of treatment means.

RESULTS AND DISCUSSION

Effect of different legume-based agroforestry systems on soil chemical properties

Soil pH and EC

Among seasons, soil pH varied non-significantly and was highest during summer season and least in rainy season while significantly affected by systems and soil depth (Table 1). In agroforestry systems, it varied signiûcantly from 7.87 to 8.23, being highest under cultivated system and least under Poplar+Cowpea-Wheatsystem during 2021. During 2021 and 2022, pH was significantly 1.6 and 1.7% lower in surface soil (0-15 cm) as compared to sub-surface soil (15-30 cm). Under sole cropping of Cowpea-Wheat, soil

EC was significantly higher by 35.7, 11.8, 29.5 and 21.3% during 2021 as compared to Poplar, Eucalyptus, Melia and Sisham based agroforestry systems, respectively. Soil EC decreased with increase in soil depth and among the seasons highest pH (8.08) and EC (8.05 dS/m) was observed under summer season during both the years. No interaction was found significant during both the years. Buildup and eventual breakdown of organic matter, releases organic acids so, the soil pH and EC under tree cover are reduced. Kaur *et al*. (2020) showed that soil pH was highest in fallow site (8.02) and lowest in the site having poplar plantations for 30 years (7.77). Singh *et al*. (2021) also observed lower soil pH under agroforestry systems. The leaching of base cations (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) and salts down the soil profile and drainage into streams cause lower soil pH and EC during the period of rainfall.

Soil organic carbon

During 2021, Poplar, Eucalyptus, Melia and Sisham based agroforestry systems had significantly 38.1, 19.1, 31.0 and 28.6% greater soil organic carbon (SOC), than control (sole cropping), respectively (Table 1). Among the seasons, least SOC was observed during summer season (0.47 and 0.47%) and the highest SOC was observed during autumn season (0.55 and 0.57%) in 2021 and 2022, respectively. These findings were also supported by earlier workers Kaur and Bhat (2017); Bhople and Sharma (2020). Increased carbon addition through litterfall, rhizodepositions and increased root biomass addition, notably in poplar, may be responsible for the significantly higher organic carbon in tree-based systems. The high amount of OC in the rainy and autumn seasons was caused by the high moisture content in these seasons, which promotes the microbial population's growth. Bhople *et al.* observed that soil organic carbon in farm forest, horticulture and cropland was significantly higher by 10.0, 14.0 and 7.1% in post rainy season than the prerainy season in 0-15 cm of soil depth, respectively.

Effect of different legume-based agroforestry systems on availability of macronutrients

Available nitrogen

The available nitrogen content was significantly higher in the surface soils (0-15 cm) and gradually declines with the depth (Table 2). During the 2021 and 2022, available nitrogen decreased in order Poplar+Cowpea-Wheat (199.9 and 203.7 kg ha^{-1})>Melia+Cowpea-Wheat (187.1 and 190.2 kg ha^{-1})> Sisham+Cowpea-Wheat (180.8 and 184.3 kg ha^{-1})> Eucalyptus+Cowpea-Wheat (177.2 and 178.9 kg ha^{-1})> Cowpea-Wheat (152.2 and 154.0 kg ha^{-1}), respectively. Highest available nitrogen was observed during autumn season (192.4 and 194.8 mg kg^{-1}) and least under summer season (163.0 and 165.5 kg ha^{-1}) in 2021 and 2022, respectively. The availability of nitrogen in tree-based systems improves as a result of the consistent input of litterfall or organic matter and the positive relationship between SOC and available nitrogen. Huo *et al*. (2017) showed that afforestation practices significantly increased the soil bioavailable N as compared to control.

Available phosphorus

The data illustrated in Table 2 reported that available phosphorus during 2021 and 2022 in soil ranged from 14.6 to 17.1 kg ha^{-1} and 14.9 to 17.5 kg ha^{-1} in surface and sub-surface soil layers, respectively. During 2021 and 2022, available P was significantly 47.2 and 51.2% higher under Poplar+Cowpea-Wheat as compared to sole cropping of

Table 1: Effect of soil depth, agroforestry systems and seasons on soil chemical properties in surface and sub-surface during 2021 and 2022.

	Soil pH		EC (dS m^{-1})		SOC (%)	
	2021	2022	2021	2022	2021	2022
			Soil depth			
0-15 cm	7.95	7.92	0.57	0.54	0.61	0.63
15-30 cm	8.08	8.06	0.40	0.39	0.42	0.44
CD@5%	0.11	0.13	0.01	0.01	0.01	0.01
			Agroforestry systems			
Poplar+Cowpea-Wheat	7.87	7.84	0.43	0.40	0.58	0.61
Eucalyptus+Cowpea-Wheat	8.12	8.09	0.51	0.50	0.50	0.51
Melia+Cowpea-Wheat	7.90	7.89	0.45	0.42	0.55	0.56
Sisham+Cowpea-Wheat	7.96	7.91	0.46	0.45	0.54	0.54
Cowpea-Wheat	8.23	8.21	0.57	0.56	0.42	0.42
CD@5%	0.18	0.21	0.01	0.02	0.02	0.02
			Seasons			
Winter	8.01	7.99	0.48	0.46	0.50	0.51
Spring	8.04	8.02	0.50	0.48	0.53	0.54
Summer	8.08	8.05	0.52	0.5	0.47	0.47
Rainy	7.97	7.93	0.46	0.43	0.53	0.55
Autumn	7.98	7.95	0.47	0.45	0.55	0.57
CD@5%	NS	NS	0.01	0.02	0.02	0.02

Cowpea-Wheat, respectively. Available P was significantly higher by 1.52, 1.14, 1.69 and 1.09 times under autumn season as compared to winter, spring, summer and rainy season during 2021, respectively. The considerable annual input of organic matter through litter fall, which releases organic acids during decomposition, was the cause of the greater availability of P in agroforestry systems. By lowering the binding of metal ions to phosphate by chelation and for exchange sites on the surface of organic matter, these improve the release of P (El-Baruni and Olsen, 1979). Yang *et al*. (2018) discovered that soils beneath forests contained more phosphorus than barren ground. Autumn had the highest amount of soil available P which may be because of more organic matter addition and break down during this season because more moisture was available during this season.

Available potassium

Availability of potassium was significantly affected by soil depth, agroforestry systems and different seasons (Table 2). Available K was highest under Melia+Cowpea-Wheat (294.9 and 298.3 kg ha^{-1}) followed by Poplar+Cowpea-Wheat (272.4 and 274.0 kg ha^{-1}) and least under Cowpea-Wheat sole cropping (238.8 and 240.0 kg ha^{-1}) during 2021 and 2022, respectively. Under spring, rainy and autumn seasons available K was significantly 1.09, 1.11 and 1.12 times higher as compared to summer season during 2021. These result were similar with Sharma *et al*. (2022); Dhaliwal *et al*. (2019). Higher availability of K in agroforestry systems was caused by the decomposition of organically bound forms, recycling of nutrients and the solubilization of its insoluble forms found in soil minerals by the byproducts of organic decomposition (Lal *et al*., 1998).

Available sulphur

Available S during 2021 and 2022 was significantly affected by soil depth, systems and seasons (Table 2). During 2021, available sulphur under Poplar (112.9 kg ha^{-1}), Eucalyptus (96.3 kg ha^{-1}), Melia (110.9 kg ha^{-1}) and Sisham (99.2 kg ha^{-1}) based agroforestry system was significantly higher in comparison with control (83.2 kg ha^{-1}), respectively. Available S during both the years was found highest for rainy season followed by autumn and least under summer season, respectively. Higher availability of sulphur under trees based systems is due to better recycling of nutrients by addition of organic matter through litterfall.

The retention of nutrients by the litter layer is crucial inagroforestry systems and the amount of litter that falls to the ground plays a vital role in the transport of nutrients from plants to soil. Across all land uses, the amount of available N, P, K and S generally decreased with soil depth. N, P, K and S were more abundant in the top layer of soil (0-15 cm) than at subsequent depths. The significant increase in these nutrients' concentrations in the surface layer was attributed to increased absorption, scavenging from deeper soil layers, and return to the soil top through litter fall.

Effect of different legume-based agroforestry systems on DTPA extractable micronutrients

There was a significant variation in micronutrient status for soil depth, systems and seasons whereas, no significant variations were observed in case of depth, systems and

Table 2: Effect of soil depth, agroforestry systems and seasons on soil available nitrogen, phosphorus, potassium and sulphur (kg ha^{-1}) in surface and sub-surface during 2021 and 2022.

	Avl. nitrogen		Avl. phosphorus		Avl. potassium		Avl. sulphur	
	2021	2022	2021	2022	2021	2022	2021	2022
Soil depth								
0-15 cm	185.1	188.5	17.1	17.5	298.1	300.4	107.8	110.4
15-30 cm	173.8	175.9	14.6	14.9	233.2	235.9	93.1	95.0
CD@5%	4.1	4.1	0.4	0.4	6.6	6.2	2.9	2.7
Agroforestry systems								
Poplar+Cowpea-Wheat	199.9	203.7	18.1	18.9	272.4	274.0	112.7	115.4
Eucalyptus+Cowpea-Wheat	177.2	178.9	15.6	15.8	253.5	257.4	96.3	98.9
Melia+Cowpea-Wheat	187.1	190.2	17.4	17.6	294.9	298.3	110.9	114.1
Sisham+Cowpea-Wheat	180.8	184.3	16.0	16.3	268.5	271.1	99.2	100.8
Cowpea-Wheat	152.2	154.0	12.3	12.5	238.8	240.0	83.2	84.3
CD@5%	6.4	6.2	0.7	0.7	10.3	9.8	4.6	4.3
Seasons								
Winter	168.8	172.1	12.9	13.1	252.2	254.5	92.2	92.3
Spring	185.3	187.7	17.2	17.4	270.4	274.6	104.1	106.2
Summer	163.0	165.5	11.6	12.0	249.0	250.6	89.2	90.0
Rainy	187.7	191.0	18.0	18.4	277.1	278.7	107.3	110.3
Autumn	192.4	194.8	19.6	20.3	279.4	282.4	109.3	114.7
CD@5%	6.4	6.2	0.7	0.7	10.3	9.8	4.6	4.3

Table 3: Effect of soil depth, agroforestry systems and seasons on soil DTPA extractable micronutrients (mg kg^{-1}) in surface and sub-surface soil during 2021 and 2022.

	Iron		Manganese		Zinc		Copper	
	2021	2022	2021	2022	2021	2022	2021	2022
				Soil depth				
0-15 cm	9.92	10.13	12.61	13.21	1.77	1.79	1.01	1.02
15-30 cm	8.52	8.64	9.97	10.10	1.66	1.68	0.80	0.81
CD@5%	0.28	0.28	0.33	0.31	0.05	0.05	0.03	0.03
				Agroforestry systems				
Poplar+Cowpea-Wheat	10.25	10.43	13.37	13.54	1.99	2.01	1.11	1.13
Eucalyptus+Cowpea-Wheat	8.87	9.15	11.16	11.39	1.73	1.75	0.92	0.96
Melia+Cowpea-Wheat	11.08	11.19	11.24	12.47	1.89	1.93	1.03	1.04
Sisham+Cowpea-Wheat	9.02	9.16	10.98	11.10	1.78	1.80	0.85	0.83
Cowpea-Wheat	6.90	7.01	9.71	9.79	1.17	1.18	0.61	0.62
CD@5%	0.45	0.45	0.52	0.47	0.08	0.08	0.04	0.04
				Seasons				
Winter	7.89	8.15	0.80	10.15	1.54	1.56	0.78	0.80
Spring	9.68	9.62	0.97	12.43	1.79	1.82	0.95	0.97
Summer	7.59	7.61	0.75	9.7	1.48	1.5	0.75	0.75
Rainy	10.08	10.52	1.01	12.8	1.86	1.88	0.99	1.01
Autumn	10.86	11.02	1.05	13.19	1.89	1.91	1.05	1.05
CD@5%	0.45	0.45	0.52	0.47	0.08	0.08	0.04	0.04

season interaction (Table 3). During 2021, soils under Poplar+Cowpea-Wheat, Eucalyptus+Cowpea-Wheat, Melia+Cowpea-Wheat and Sisham+Cowpea-Wheat had 1.49, 1.29, 1.61 and 1.31 times higher DTPA extractable Fe, respectively, than sole cropping of Cowpea-Wheat (Table 3). During 2022, DTPA extractable Fe ranged from 11.19 to 9.71 mg kg^{-1} soil being highest under Melia+Cowpea-Wheat and least under control. In Poplar+Cowpea-Wheat (13.37 and 13.54 mg kg^{-1}), Eucalyptus+Cowpea-Wheat (11.16 and 11.39 mg kg^{-1}), Melia+Cowpea-Wheat (11.24 and 12.47 mg kg^{-1}), Sisham+Cowpea-Wheat (10.98 and 11.10 mg kg^{-1}) and Cowpea-Wheat (9.71 and 9.79 mg kg^{-1}) DTPA extractable Mn was significantly higher as compared to sole cropping during 2021 and 2022, respectively. The Poplar (1.99 and 1.11 mg kg^{-1}), Eucalyptus (1.73 and 0.92 mg kg^{-1}), Melia (1.89 and 1.03 mg kg^{-1}) and Sisham (1.78 and 0.85 mg kg^{-1}) based agroforestry system soils had significantly more DTPA extractable Zn and Cu than sole cropping (1.17 and 0.61 mg kg^{-1}) during 2021, respectively. DTPA extractable Fe, Mn, Zn and Cu was significantly 16.4, 26.5, 6.60 and 26.3% higher in surface soil as compared to sub-surface soil layer, respectively. In autumn season DTPA extractable Fe, Mn, Zn and Cu was significantly higher as compared to winter and summer seasons. Kumar *et al*. (2017) reported that the contents of available Fe, Mn, Zn and Cu were 15, 31, 101 and 86% higher under tree species in comparison to control. Similar results were obtained previously by Tesfahunegn (2013) in Northern Ethiopia and observed that Zn and Fe were highest in those land use systems which were less disturbed like native forests, grasslands, *Sesbania* and *Leucena* plantations as compared to disturbed systems like cultivated and pasture lands. Bhople and Sharma (2020) and Dhaliwal *et al.* (2019) also concluded the similar findings.

As micronutrients bond to soil organic matter and become more readily available, the trend in micronutrient content was remarkably similar to the trend in SOC content. Additionally improving soil aeration, high soil organic matter shields micronutrients from oxidation, precipitation and supply chelating agents, enhancing micronutrient availability. Due to extensive cultivation, ongoing nutrient removal and soil disturbances brought on by various management practices, the content under cultivated systems was lower than that under agroforestry systems (Mandal *et al.*, 2018).

CONCLUSION

The results of the present study concluded that different agroforestry systems and seasons have significant impact on soil chemical properties and nutrient availability. Poplar and Melia based agroforestry systems were found most suitable for improving soil organic carbon and increased the availability of soil macro and micronutrients as compared to other agroforestry based systems and sole cropping of cowpea-wheat due to more and faster decomposition of litter fall.Among different seasons autumn, rainy and spring seasons has higher values for soil organic carbon and nutrient availability while lower values for soil pH and electrical conductivity as compared to winter and summer season. So, adoption of tree based systems can be a better sustainable option for improving soil fertility as compared to sole cropping system.

Conflict of interest

All authors declared that there is no conflict of interest.

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