Range Management and Agroforestry 45 (2) : 203-210, 2024
ISSN 0971-2070 (Print); 2249-5231 (Online)
https://doi.org/10.59515/rma.2024.v45.i2.03

Research article

Influence of *Prosopis cineraria* based agroforestry system on soil attributes in rainfed arid western Rajasthan

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Received: 11th October, 2023 Accepted: 17th November, 2024

Abstract

The experiment was conducted at Agricultural Research Station (SKN Agriculture University) Fatehpur-Shekhawati, Sikar (Rajasthan) during 2016-2019 to find out the distribution pattern of soil pH, EC, OC and available nutrients (N, P, K and S) under *Prosopis cineraria* (*khejri*) based agroforestry system in comparison to the sole cropping system. The results envisaged that soil pH was lower in *P. cineraria*-based agroforestry system (7.80) than sole cropping-based system (7.85) at 0 to 15 cm soil depth and the corresponding values were 7.99 and 8.02 at 15 to 30 cm soil depth. No significant difference was observed in electrical conductivity (EC) between the systems and cropping pattern at both the soil depths, except cropping pattern at 0 to 15 cm soil depth. Organic carbon (OC) content increased significantly in *P. cineraria*-based agroforestry system in comparison to the sole cropping system at both soil depths. However, the interaction between systems and crops was found significant only at 0 to 15 cm soil depth. Available nitrogen content (kg/ha) was significantly higher (97.90 and 79.55) in *P. cineraria*-based agroforestry system in comparison to the sole cropping system (83.09 and 58.24) at both the soil depth, respectively. Available phosphorus content (kg/ha) in soil was significantly higher (15.58 and 10.89) in *P. cineraria*-based agroforestry system in comparison to the sole cropping system (12.94 and 9.84) at both the soil depth. Available potassium content (kg/ha) was also found to be significantly higher in *P. cineraria*-based agroforestry systems (283.77 and 256.87) in comparison to sole cropping systems (271.71 and 247.80) at different soil depths, respectively. The available sulfur content was also found to be significantly higher in *P. cineraria*-based agroforestry system. The study indicated that *P. cineraria* trees improved soil conditions beneath their canopies in comparison to the sole crop.

Keywords: Agroforestry systems, *Kharif* crops, *Prosopis cineraria*, Soil nutrients

Introduction

Prosopis cineraria-based agroforestry systems in arid regions of India are an integral part of livelihood and environmental security. *Prosopis cineraria*, locally known as *Khejri,* has played a significant role in the rural economy of arid western Rajasthan, India. Farmers of the region knew the value of this tree for decades and crops like millets and pulses are grown under the tree traditionally in rainfed conditions. *P. cineraria*-based agroforestry system in western Rajasthan covers about 47% of the total area. This tree-based agroforestry system is known to improve organic matter contents, total nitrogen, available phosphorus and soluble calcium, as well as decrease soil pH (Mahesh *et al*., 2017). Changes in the physico-chemical properties and nutrient status of soil under tree-based agroforestry systems were also reported earlier (Singh *et al*., 2022). The effects of different agroforestry systems on soil fertility are difficult to generalize. The improvement of soil fertility depends upon species characteristics and the management system adopted. There is evidence that soils under the trees were richer in organic matter and nutrients than those in the surroundings without a tree cover. *Prosopis cineraria* is a ubiquitous tree in alluvial plains of western Rajasthan and is generally accepted by farmers who have a strong belief that soil health and vegetative growth under the tree is better than in other areas under the same management conditions (Kaushik and Kumar, 2003; Singh *et al.,* 2008). The tree provides brushwood for fencing, top feeds for cattle and, timber for households and food from the fruits during famine years to rush forward scarcity periods (Khatri *et al.,* 2010). The appropriate agroforestry systems are known to improve soil physical properties, maintain soil organic matter and promote nutrient cycling. In agroforestry systems, nutrient addition takes place through leaf litter, pruning of woody compounds and atmospheric fixation. The practice of long-term agroforestry systems plays a significant increase in depth-wise changes in organic carbon (Kaur *et al.*, 2023). Some nutrients, otherwise considered unavailable to crops because they are below the rooting zone of annual crops, might be brought into the system from deeper layers in the soil with the help of tree roots. Trees are able to return nutrients through dead organic matter, *i.e.*, leaves, branches, twigs, fruits and flowers. Thus, it helps in the enrichment of top soil layer, which is available for agricultural crops. It is accepted that a large increase of nutrients stored in trees and topsoil compartments of tree-based crop systems leads to greater efficiency in nutrient cycling and resource sharing. Increased soil organic matter is known to promote better soil structure which improves the moisture-holding capacity of soil. Various nutrient studies conducted in agroforestry systems support the view that trees help in the enrichment of the nutrient pool by adding organic matter, reducing losses, and checking soil erosion and the most important beneficial effect of trees on soil can include the improvement of soil structure and availability of nutrients. A better understanding of the positive effects of trees on soils, and analysis of what this represents in terms of nutrients and other benefits is an important step towards increasing the use of trees on farms. Therefore, this study was carried out to find out the influence of *P. cineraria*-based agroforestry system in comparison to sole cropping system on different soil attributes for sustainable management of soil in the arid ecosystem and further scientifically promotion of the tree species in agroforestry.

Materials and Methods

***Site conditions*:** The experiment was conducted from 2016-2019 under *P. cineraria*-based agroforestry system systematically planted in 5 x 5 m spacing and sole cropping system during *Kharif* (rainy seasons) in rainfed conditions at Agricultural Research Station, Fatehpur-Shekhawati, Sikar (27˚56′10.37′′ N latitude, 74˚59′04.51′′ E longitude) in India. The climate is tropical and characterized by hot dry summer (maximum temperature reaches 48ºC), cold, dry winter (minimum temperature reaches -5ºC) and warm rainy seasons (maximum temperature 25–35ºC). Summers are very hot with high air temperatures (up to 48ºC in mid-May), extending from mid-March to mid-June or up to receives pre-monsoon rainfall. The strong winds (20-60 kmh^{-1}) prevail in summer and most of the rainfall is received from July to September. The average annual rainfall during the experimental period was 295 mm in 70% of rainfall received between July and August. The soil of the site of the experiment was loamy sand with low organic carbon content and the initial soil properties of experimental site at two soil depth *i.e.*, 0 to 15 cm and 15 to 30 cm were recorded (Table 1).

***Experimental design and cultivation practices*:** The experiment was laid in randomize block design in 5 x 5 m spacing *P. cineraria* tree plantation (25 years old) with five treatments of different *kharif* crops commonly cultivated by farmers in the area *viz.*, pearlmillet (*Pennisetum glaucum*), clusterbean (*Cyamopsis tetragonoloba*), green gram (*Vigna radiata*), moth bean (*Vigna aconitifolia*) and cowpea (*Vigna unguiculata*) in six replications for comparison between influence of tree based agroforestry system on soil properties with sole cropping systems; the same treatments were replicated in control plots with common cultivation practices (Table 2).

***Soil sampling and analysis*:** To find out the influence of *P. cineraria* based agroforestry system on different soil attributes, soil samples were collected in 2019 from each plots with the help of an augur from 0 to 15 cm and 15 to 30 cm soil depths after harvest of crops. These samples were analyzed for different soil attributes pH, EC, OC, N, P, K and S in well equipped soil laboratory at Agricultural Research Station, Fatehpur. The pH of soil was determined in 1:2 (soil: water) suspension using combined electrode (glass and calomel electrodes) by digital pH meter (Datta *et al.*, 1997). The electrical conductivity (EC) was determined in supernatant liquid of the same extracts with the help of conductivity bridge and expressed in dSm^{-1} at 25°C (Jackson, 1973). Soil organic carbon (SOC) was determined by rapid titration method (Walkley and Black, 1934). Available nitrogen (N) was determined following alkaline $KMnO_4$ method (Subbiah and Asija, 1956). Available phosphorus (P) was extracted with 0.5 M $NaHCO_3$ solution (8.5 pH) and P content in the extract was estimated calorimetrically (Olsen *et al.*, 1954). Available potassium (K) was determined by extraction of soil with neutral normal ammonium acetate (pH 7.0 in 1:5, soil: solution ratio) and estimated with the help of flame photometer (Knudsen *et al.*, 1982). Available sulphur (S)

Table 1. Initial soil properties under sole crop and *P. cineraria* based agroforestry system

Soil properties	Sole crop		*P. cineraria*	
	0–15 cm	15–30 cm	0–15 cm	15–30 cm
pH	8.09	8.24	8.04	8.21
EC (ds/m)	0.10	0.08	0.03	0.03
OC (%)	0.12	0.09	0.19	0.11
N (kg/ha)	68.84	46.04	78.25	50.02
P (kg/ha)	8.86	8.06	11.10	8.06
K (kg/ha)	240	195	276	218
S (kg/ha)	8.23	7.09	8.36	7.65

Table 2. Cultivation practices of different *Kharif* crops followed during the study

Kharif crops	Variety	Seed rate (kg/ha)	Spacing (cm) row x plant	Fertilizers (kg/ha) N	P	Other operation
P. glaucum	RHB 177	4	45x45	20	10	Hoeing and weeding
C. tetragonoloba	RGC 1033	15	30x10	05	10	Hoeing and weeding
V. radiata	SML 668	10	30x10	05	10	Hoeing and weeding
V. aconitifolia	RMO 257	10	30x10	05	10	Hoeing and weeding
V. unguiculata	RC 19	15	30x10	05	10	Hoeing and weeding

was determined by extracting the soil sample with 0.15% $CaCl_2$ (Williams and Steinbergs, 1959).

Data were statistically analyzed using the SPSS statistical package. R (version 4.2.1) statistical software was used to display the correlograms for representing correlation between soil parameters. Pearson's correlation coefficient among each pair of variables was estimated using the 'corrr' package in R. R program' Performance Analytics' was utilized to plot correlation plots.

Results and Discussion

***Soil pH, electrical conductivity and organic carbon*:** Soil pH, electrical conductivity (EC) and organic carbon (OC) at different soil depths (0–15 and 15–30 cm) were recorded (Table 3-4; Fig 1). The effect of *P. cineraria* based agroforestry system and different intercrops were found significant on soil pH at both the soil depths (0–15 cm and 15–30 cm), whereas EC was observed significant with intercrops at 0 to 15 cm soil depth only. However, interaction between system and crops found non-significant at both the soil depths. *P. cineraria* based agroforestry systems recorded low pH than sole cropping system in all the crops at both the soil depths except *Vigna aconitifolia* at 15 to 30 cm soil depth. The soil pH was recorded lower in both the soil depth 0 to 15 cm (7.80) and 15 to 30 cm (7.99) under *P. cineraria* based agroforestry system than sole cropping system (7.85 and 8.02) at 0 to 15 cm and 15 to 30 cm soil depths, respectively. For the electrical conductivity (EC), no significant difference was observed in between systems and cropping pattern at both the soil depths except cropping pattern at 0 to 15 cm soil depth.

The reduction in pH value under *P. cineraria* might be attributed to the presence of higher content of organic matter, soluble calcium and comparatively lower content of $CaCo_3$. The reduction of soil pH under tree cover was due to accumulation and subsequent decompositions of organic matter which released organic acids. Similar results in reduction of soil pH under agroforestry system at top soil layer were observed earlier (Rather *et al.*, 2023; Gupta and Sharma, 2009). The organic carbon content increased significantly in *P. cineraria* based agroforestry system in comparison to sole cropping system at both soil depths (0–15 cm and 15–30 cm) however, the interaction between systems and crops was found significant only at 0 to 15 cm soil depth and it was non-significant at 15 to 30 cm soil depth. Decreasing trends of OC was observed with increasing soil depth in all the treatments. The highest soil OC recorded in *P. cineraria* based agroforestry system (0.23) at 0 to 15 cm soil depth and lowest recorded in sole cropping system (0.10) at 15 to 30 cm soil depth. Among the crops at 0 to 15 cm soil depth highest OC was recorded in *Cyamopsis tetragonoloba* (0.22) and lowest

Table 3. Effect of systems (*P. cineraria* based agroforestry and sole crop) on soil pH and EC

Crop	pH						EC (dS/m)					
	0–15 cm			15–30 cm			0–15 cm			15–30 cm		
	P. cineraria	Sole	Mean	*P. cineraria*	Sole	Mean	*P. cineraria*	Sole	Mean	*P. cineraria*	Sole	Mean
P. glaucum	8.00	8.05	8.03	8.13	8.17	8.15	0.04	0.04	0.04	0.02	0.02	0.02
C. tetragonoloba	7.59	7.66	7.62	7.88	7.93	7.90	0.04	0.04	0.04	0.02	0.01	0.01
V. radiata	7.69	7.75	7.72	7.88	7.93	7.91	0.01	0.01	0.01	0.03	0.03	0.03
V. aconitifolia	8.00	8.01	8.00	8.08	8.07	8.08	0.01	0.01	0.01	0.01	0.01	0.01
V. unguiculata	7.73	7.79	7.76	7.99	8.02	8.00	0.01	0.01	0.01	0.04	0.01	0.03
Mean (system)	7.80	7.85	7.83	7.99	8.02	8.01	0.02	0.02	0.02	0.02	0.02	0.02
CD (system) = 0.039, CD (crop) = 0.061, CD (system × crop) = NS				CD (system) = 0.024, CD (crop) = 0.038, CD (system × crop) = NS			CD (system) = NS, CD (crop) = 0.022, CD (system × crop) = NS			CD (system) = NS, CD (crop) = NS, CD (system × crop) = NS		

Table 4. Effect of systems (*P. cineraria* based agroforestry and sole crop) on soil organic carbon

Crop	**Organic carbon (%)**					
	0–15 cm			**15–30 cm**		
	P. cineraria	**Sole**	**Mean**	***P. cineraria***	**Sole**	**Mean**
P. glaucum	0.21	0.13	0.17	0.12	0.10	0.11
C. tetragonoloba	0.29	0.15	0.22	0.14	0.12	0.13
V. radiata	0.24	0.14	0.19	0.14	0.10	0.12
V. aconitifolia	0.17	0.11	0.14	0.10	0.09	0.10
V. unguiculata	0.25	0.13	0.19	0.13	0.10	0.11
Mean (system)	0.23	0.13	0.18	0.12	0.10	0.11
CD (system) = 0.007, CD (crop) = 0.012, CD (system × crop) = 0.016				CD (system) = 0.005, CD (crop) = 0.008, CD (system × crop) = NS		

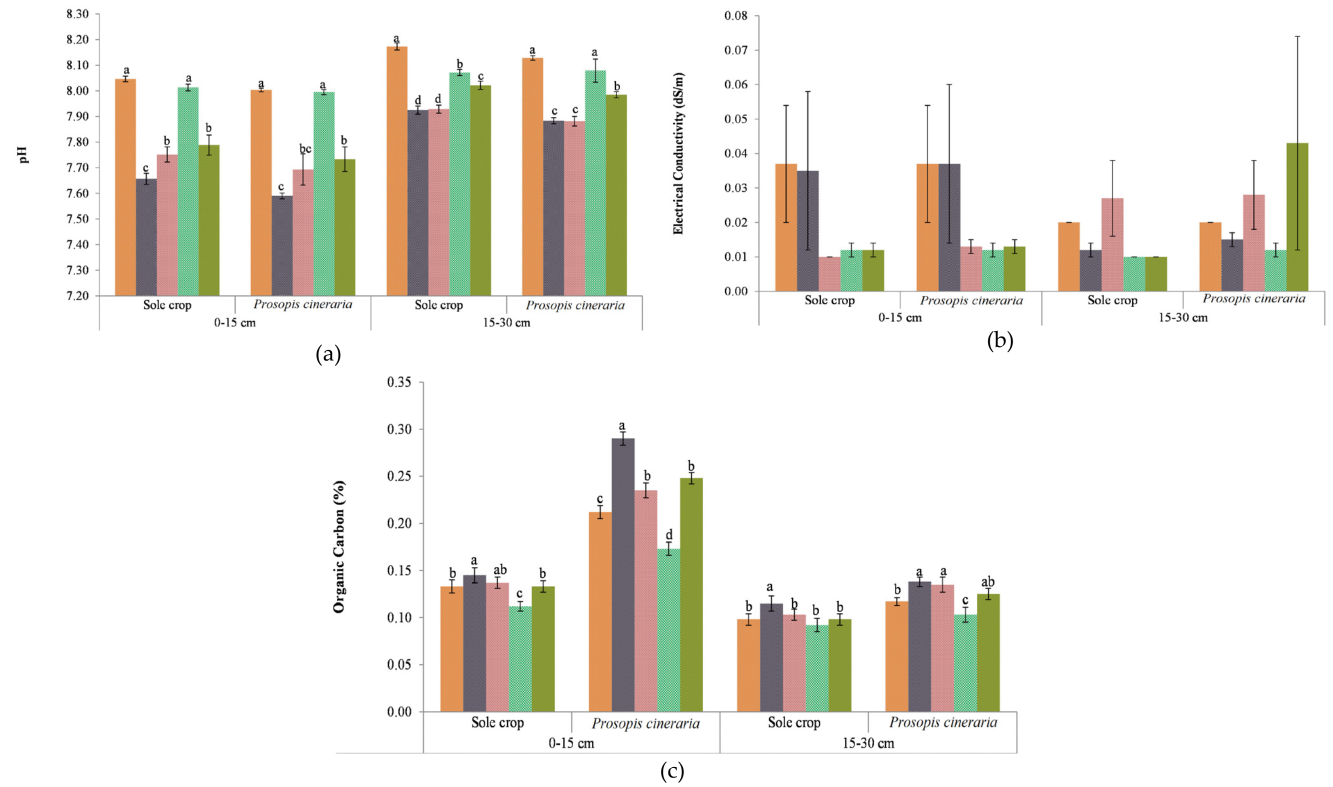

Fig 1. Depth wise values of various soil parameters (a) pH, (b) EC and (c) OC, for sole crop and *P. cineraria* based agroforestry systems [values with different letters within a group differed significantly (p <0.05) from each other]

recorded in *Vigna aconitifolia* (0.14) and same trends of OC with crops was observed at 15 to 30 cm soil depth. The soil enrichment in SOC content under tree based systems might be because of several factors such as addition of litter, annual recycling of fine root biomass and root exudates and its reduced oxidation of organic matter under tree shades (Gill and Burman, 2002; Lalitha *et al*., 2022). There was a decrease in SOC content of soil with increasing soil depth and the highest SOC was observed at 0 to 15 cm soil depth for all the treatments. This might be attributed mainly to the contributions made by litter fall at surface layer. Similar variation of SOC with increasing soil depth was observed by Chauhan *et al*. (2010). The high soil organic carbon under *P. cineraria* based agroforestry system was due to leaf litter fall of tree and its partial decompositions added to the soil organic matter.

***Available nitrogen and phosphorus*:** The available nitrogen, phosphorus, potassium and sulphur contents were recorded at different soil depths (Tables 5 and 6) and also presented in bar graph (Fig 2). The available

Table 5. Effect of systems (*P. cineraria* based agroforestry and sole crop) on available nitrogen

Crop	Available nitrogen (kg/ha)					
	0–15 cm			15–30 cm		
	P. cineraria	Sole	Mean	*P. cineraria*	Sole	Mean
P. glaucum	94.70	79.26	86.98	76.22	54.91	65.57
C. tetragonoloba	109.32	87.91	98.62	87.11	61.71	74.41
V. radiata	98.17	85.89	92.03	78.37	57.82	68.09
V. aconitifolia	92.64	79.78	86.21	76.98	58.21	67.60
V. unguiculata	94.69	82.61	88.65	79.06	58.56	68.81
Mean (system)	97.90	83.09	90.50	79.55	58.24	68.90
CD (system) = 1.282, CD (crop) = 2.027, CD (system × crop) = 2.866				CD (system) = 0.829, CD (crop) = 1.310, CD (system × crop) = 1.853		

Table 6. Effect of systems (*P. cineraria* based agroforestry and sole crop) on available phosphorus

Crop	Available phosphorus (kg/ha)					
	0–15 cm			15–30 cm		
	P. cineraria	Sole	Mean	*P. cineraria*	Sole	Mean
P. glaucum	11.38	9.44	10.41	9.25	7.95	8.60
C. tetragonoloba	20.41	16.66	18.54	13.35	12.27	12.81
V. radiata	19.12	14.93	17.02	10.52	9.83	10.17
V. aconitifolia	11.76	10.45	11.10	9.52	8.44	8.98
V. unguiculata	15.22	13.21	14.21	11.83	10.73	11.28
Mean (system)	15.58	12.94	14.26	10.89	9.84	10.37
CD (system) = 0.447, CD (crop) = 0.707, CD (system × crop) = 1.000				CD (system) = 0.289, CD (crop) = 0.458, CD (system × crop) = NS		

nitrogen content (kg/ha) was significantly higher (97.90 and 79.55) in *P. cineraria* based agroforestry system in comparison to sole cropping system (83.09 and 58.24) at both the soil depths (0–15 cm and 15–30 cm), and the interaction between systems and crops was also found significant. Among the different crops highest nitrogen was observed in *Cyamopsis tetragonoloba* (98.62 and 74.41) at different soil depth 0 to 15 cm and 15 to 30 cm and lowest in *Vigna aconitifolia* (86.21) at 0 to 15 cm and *Pennisetum glaucum* (65.57) at 15 to 30 cm soil depth. The higher value of available nitrogen in *P. cineraria* based agroforestry was attributed to deposition of higher organic matter in soil from litter fall and fine root than the sole cropping system. High value of available nitrogen under agroforestry system was also recorded earlier (Singh *et al.*, 2016; Kaushal *et al.*, 2016).

Available phosphorus content (kg/ha) in the soil was also significantly higher (15.58 and 10.89) in *P. cineraria* based agroforestry system in comparison to sole cropping system (12.94 and 9.84) at both the soil depths. However, the interaction among the system and crops was significant only at 0 to 15 cm soil depth. *Cyamopsis tetragonoloba* crops had higher phosphorus content, 18.54 and 12.81 kg/ha at 0 to 15 cm and 15 to 30 cm soil depth, respectively, while *Pennisetum glaucum* had lower phosphorus content, 10.41 and 8.60 kg/ha at 0 to 15 cm and 15 to 30 cm, respectively. Available P decreased with an increase in soil depth in the present investigation which was in conformity with the earlier findings (Swami *et al.,* 2006). This might be due to higher activity of acidic phosphates enzyme at these soil depths under this species over other treatments, as the organic anion exudation and acid phosphatase activity might lead to an increase in the mobilization of P in rhizosphere.

***Potassium and sulphur*:** Available potassium and sulphur at different soil depths (0–15 cm and 15–30 cm) were recorded (Tables 7 and 8) and presented in bar graph (Fig 2). Potassium was also found significantly higher in *P. cineraria* based agroforestry system (283.77 and 256.87 kg/ha) in comparison to sole cropping system (271.71 and 247.80 kg/ha) at different soil depths (0 cm and 15–30 cm). However, the interaction among system and crops was found non-significant. Higher value of

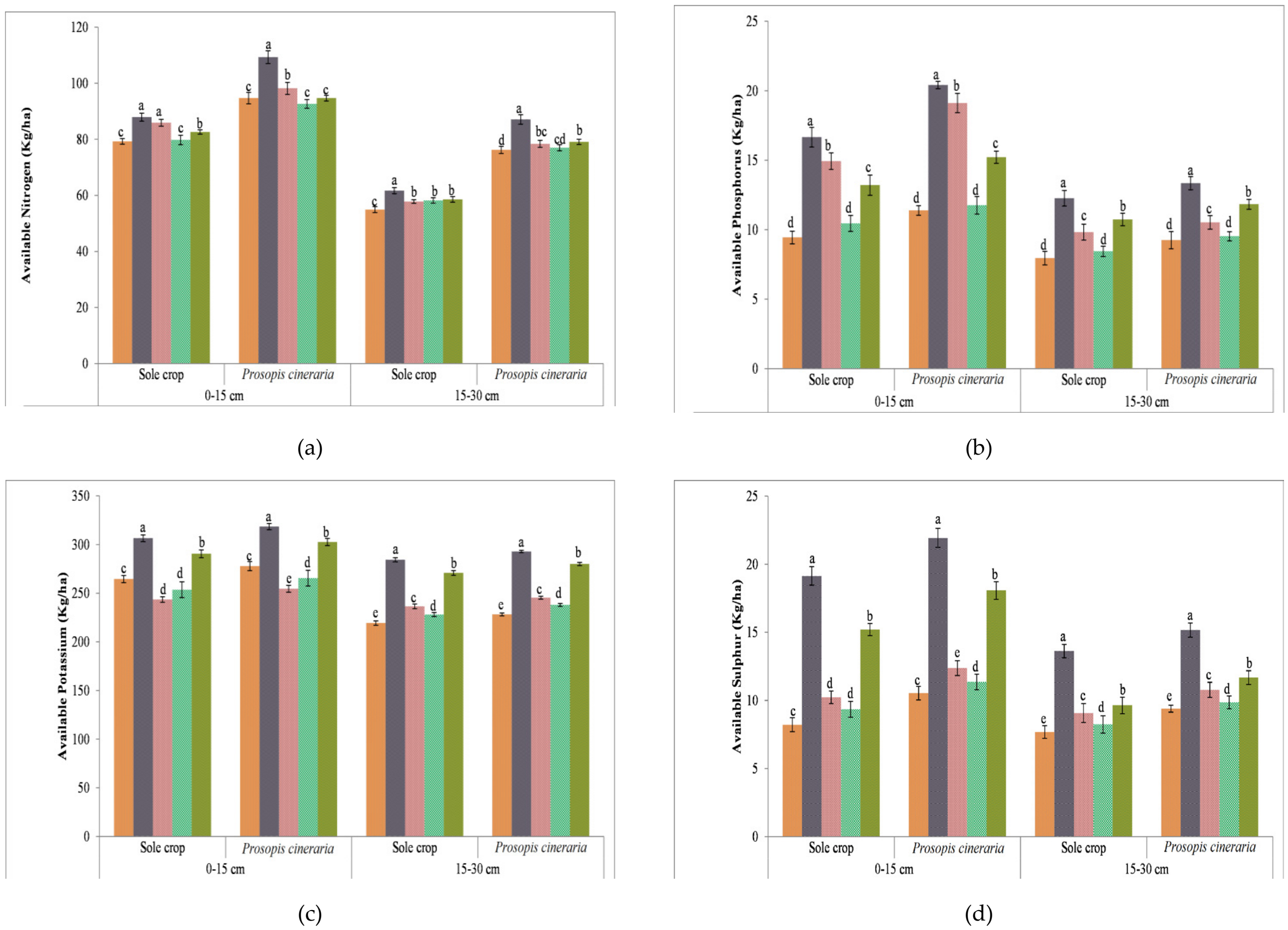

Fig 2. Depth wise values of various soil parameters (a) N, (b) P, (c) K and (d) S for sole crop and *P. cineraria* based agroforestry systems [values with different letters within a group differed significantly (p <0.05) from each other]

Table 7. Effect of systems (*P. cineraria* based agroforestry and sole crop) on available potassium

Crop	Available potassium (kg/ha)					
	0–15 cm			**15–30 cm**		
	P. cineraria	**Sole**	Mean	***P. cineraria***	**Sole**	**Mean**
P. glaucum	277.83	264.50	271.17	228.17	219.33	223.75
C. tetragonoloba	318.50	306.50	312.50	292.83	284.33	288.58
V. radiata	254.50	243.50	249.00	245.33	236.50	240.92
V. aconitifolia	265.40	253.57	259.48	238.00	228.00	233.00
V. unguiculata	302.60	290.47	296.53	280.00	270.83	275.42
Mean (system)	283.77	271.71	277.74	256.87	247.80	252.33
CD (system) = 4.356, CD (crop) = 6.888, CD (system × crop) = NS				CD (system) = 1.889, CD (crop) = 2.987, CD (system × crop) = NS		

K in tree based agroforestry system was also observed by Banerjee and Dhara (2011). This was probably as a consequence of higher amount of organic matter at the surface layer due to higher litter fall and fine root turn over at the surface layer of soil than the subsurface layer. Higher mobility of potassium at surface layer could be another cause for higher K content in surface soil than sub-surface and deeper layers of soil. Similar decreases in available K content in soil with increase in soil depth was also observed earlier (Mishra and Swamy, 2007). Release of organic acids due to organic matter accumulation under agroforestry and ultimately resulted in higher

Table 8. Effect of systems (*P. cineraria* based agroforestry and sole crop) on available sulphur

Crop	Available sulphur (kg/ha)					
	0–15 cm			15–30 cm		
	P. cineraria	Sole	Mean	*P. cineraria*	Sole	Mean
P. glaucum	10.53	8.22	9.38	9.40	7.69	8.54
C. tetragonoloba	21.93	19.13	20.53	15.16	13.61	14.39
V. radiata	12.37	10.23	11.30	10.78	9.07	9.92
V. aconitifolia	11.36	9.35	10.35	9.86	8.23	9.05
V. unguiculata	18.07	15.21	16.64	11.68	9.64	10.66
Mean (system)	14.85	12.43	13.64	11.38	9.65	10.51
CD (system) = 0.474, CD (crop) = 0.750, CD (system × crop) = NS				CD (system) = 0.269, CD (crop) = 0.425, CD (system × crop) = NS		

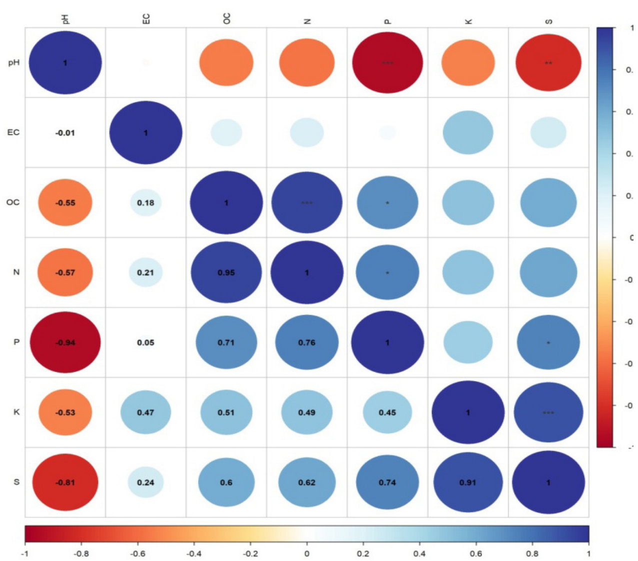

Fig 3. Correlogram showing correlation coefficient among various soil parameters [*(p <0.05); **(p <0.01)]

mineralization of potassium (Bajpai *et al.*, 2006). The status of available nutrients in soils much depends upon the quantity and quality of organic matter added to soil by different parts of the tree species and its rooting pattern.

Sulphur content was found significantly higher in *P. cineraria* based agroforestry system than sole cropping based system at two depths *i.e.*, 0 to 15 cm and 15 to 30 cm soil depth. It was 14.85 and 11.38 kg/ha in *P. cineraria* based agroforestry system and 12.43 and 9.65 kg/ha in sole cropping system at soil depth 0 to 15 cm and 15 to 30 cm, respectively. Among the crops significantly highest value of sulphur was found in *Cyamopsis tetragonoloba* crop (20.53 and 14.39 kg/ha) and lowest value of sulphur was recorded with *Pennisetum glaucum* crop (9.38 and 8.54 kg/ha) at both the soil depth. The interaction among the systems and crops was found non-significant.

Correlation coefficient among different soil attributes: Correlogram showing correlation coefficient among various soil parameters was recorded (Fig 3). The soil pH was negatively correlated with all the soil attributes and it was significantly negatively correlated with P and S. All other parameters were positively correlated with each others, however, organic carbon (OC) with N and P; N with P; and P and K with S had significantly positive correlations.

Conclusion

The present study observed low soil pH, higher organic carbon (OC), and higher available nitrogen, phosphorus, potassium and sulphur content at different soil depths (0–15 cm and 15–30 cm) under *P. cineraria* based agroforestry system in comparison to sole cropping system in rainfed condition of arid western Rajasthan. It also envisaged that the *P. cineraria* based system enriched the soil consistently and comparatively enhanced the soil physio-chemical properties sustainably than sole cropping system in arid region. Thus promotion of agroforestry system in the arid region was found beneficial for marinating the soil properties for sustainable crop production and ecological balance.

Acknowledgment

The authors are highly grateful to Indian Council of Agricultural Research (ICAR) and the Director, Central Agroforestry Research Institute (CAFRI), Jhansi, for providing valuable supports to conduct this experiment under All Indian Coordinated Research Project on Agroforestry.

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