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Assessment of Depth-Wise Variation in Soil Physico-Chemical Properties Under Different Agroforestry System of Ayodhya District in Semi-Arid Region of India

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Abstract

Agroforestry is a sustainable land-use system that combines trees, shrubs, and crops to improve soil health and productivity. This study assesses the effects of different agroforestry systems on soil properties in the semi-arid region of eastern Uttar Pradesh, specifically in the Milkipur block of Ayodhya district, where declining soil fertility is a major concern. Soil samples were collected from three depths (0-15 cm, 15-30 cm, and 30-60 cm) under various agroforestry systems, including agri-silviculture, agri-silvi-pasture, block plantation, agri-horti-silviculture, and agri-horticulture. Results showed that soil bulk density was lowest (1.27-1.31 Mg/m^3) under agri-silviculture, while porosity (39.43-37.96%) and water-holding capacity (38.43-30.75%) were highest in agri-silvi-pasture and agri-horti-silviculture. Organic carbon content was also highest in agri-silvi-pasture, which contributed to better microbial activity and soil fertility. The study highlights that agroforestry improves soil structure, moisture retention, and nutrient cycling compared to conventional agriculture. Agri-silvi-pasture and agri-horti-silviculture proved most effective in enhancing soil health, making them suitable options for sustainable farming in semi-arid regions.

Keywords: Agroforestry systems; Soil fertility improvement; Semi-arid region; Soil physico-chemical properties; Sustainable land management

Introduction

Agroforestry is a sustainable land-use system that integrates woody perennials, such as trees, shrubs, and bamboos, with agricultural crops and/or livestock within the same land management unit in a spatial or temporal arrangement (Nair, 1993; Abbas et al., 2017). This practice facilitates ecological and economic interactions between its components, enhancing productivity, resource conservation, and environmental sustainability (Lundgren & Raintree, 1982; Xu et al., 2013). Traditional agroforestry has been widely practiced across various landscapes and climatic zones, playing a crucial role in soil conservation, biodiversity enhancement, and improving land productivity (Asaye, 2017).

The assessment of soil quality is fundamental to understanding the impact of agroforestry systems on soil health. Soil quality is often evaluated based on physical, chemical, and biological parameters that influence soil functionality and productivity (Karlen et al., 1997). Soil microbial biomass carbon (SMBC), a labile component of soil organic carbon (SOC), is widely recognized as a sensitive indicator of management practices affecting soil health (Carter & Rennie, 1982; Franzluebbers et al., 1994). Additionally, agroforestry systems influence soil physical and chemical properties, such as bulk density, porosity, water-holding capacity, cation exchange capacity, and nutrient availability, primarily through the addition of organic matter from leaf litter and root exudates (Li et al., 2007; Sartori et al., 2007).

Agroforestry systems mimic natural ecosystems by enhancing soil structure, reducing erosion, and improving nutrient cycling (FAO, 2010; Pandey, 2007). Numerous studies have demonstrated the role of agroforestry in improving soil fertility through biological nitrogen fixation, organic matter accumulation, and nutrient recycling (Young, 1986; Buresh & Tian, 1998; Nasielski et al., 2015). The decomposition of organic matter in agroforestry systems releases essential nutrients, improving soil microbial activity and enzyme functions critical for maintaining soil fertility (Ren et al., 2016; Hairiah et al., 2020). Moreover, the presence of diverse plant species in agroforestry systems supports microbial diversity and enhances enzyme activity, further contributing to soil health (Beule et al., 2022). Soil microbial biomass, enzyme activity, and soil organic matter are strongly influenced by agroforestry practices, which in turn affect nutrient availability and soil fertility (Wasis, 2012; Siarudin et al., 2021). The improved soil microclimate and root interactions in agroforestry systems enhance below-ground biodiversity, contributing to soil resilience against degradation (Desta et al., 2018; Kar et al., 2019). Trees in agroforestry systems also enhance soil organic matter through continuous litter fall, root biomass accumulation, and nutrient cycling (Gebremedhin et al., 2017; Mesfin et al., 2020a).

In the semi-arid regions of eastern Uttar Pradesh, India, where soil degradation and declining fertility pose significant challenges to sustainable agriculture, agroforestry presents a viable solution for soil restoration and productivity enhancement. However, limited research has been conducted on the comprehensive assessment of soil physico-chemical and biological properties under different agroforestry systems in this region. Understanding the impact of agroforestry practices on soil quality parameters is essential for optimizing land management strategies and ensuring long-term agricultural sustainability.

Therefore, this study aims to assess the physico-chemical and biological properties of soil under different agroforestry systems in this region. Specifically, it evaluates the impact of agroforestry on soil physical properties such as bulk density, porosity, and water-holding capacity; analyses chemical properties, including soil organic carbon, pH, cation exchange capacity, and nutrient availability; and examines biological properties such as microbial biomass carbon (MBC) and enzyme activities. These insights will contribute to a better understanding of the role of agroforestry in improving soil fertility and promoting sustainable agricultural landscapes in semi-arid regions.

Material And Method

The present study was carried out at Milkipur block of Ayodhya District in Eastern Uttar Pradesh, India during 2024-2025. Ayodhya district has a damp and humid climate with average temperatures ranging during summer is 32.5°C and whereas in winter, the annual temperature is around 16°C. District Ayodhya lies at the latitude 26.79909 °N, and longitude 82.2047 °E, at an average elevation of 90 meters from mean sea level.

Soil of the experimental site is an Inceptisole and endisole. Texturally, the district has got domination of three types of soil: Deep loamy soil: This soil type covers 56% of the district, deep silty soil: This soil type covers 10% of the district and deep fine soil: This soil type is moderately alkaline or sodic and covers 18% of the district.

Soil properties
Soil physical properties

The soil bulk density was measured by Specific gravity method by pycnometer (Singh, 1980), particle density measured by Pycnometer Method (Edward Y. H. Keng, 1969), porosity was calculated by formula and the maximum water holding capacity (MWHC) and soil infiltration rate were measured as per the methods detailed by Keen-Raczkowski box method (1921).

Soil chemical properties

Soil pH, and soil organic carbon were studied using the soil samples collected from existing agroforestry system from selected villages of Milkipur block of Ayodhya district. Soil pits were excavated at the depth of 0-15 cm, 15-30 and 30-60 cm in all the existing agroforestry system from selected villages of Milkipur block of Ayodhya district. The soil samples were collected with help of post whole auger and depth were divided in to three horizons viz. 0-15 cm, 15-30 cm, 30 - 60 cm. The samples of the same plot were mixed together. The composite samples were air-dried and ground to pass through a 2-mm sieve. This sample was used to estimate soil chemical properties. Soil pH was determined using an aqueous suspension of soils (1 :2.5 soil: distilled water ratio) using an 'Electro' pH meter. Organic carbon content of the soil was estimated by the (Walkley and Black method).

Result and Discussion

Soil Physical properties

Bulk Density

The bulk density was increased with increasing soil depth both under different agroforestry system. The soil bulk density for all the soil depths (0-15 cm, 15-30 cm as well as 30-60 cm) was significantly higher (1.67, 1.72, 1.75) in agri-horticulture system as compared to different agroforestry system revealed from (Table 1). Among all the agroforestry system the maximum bulk density for all the soil depths was observed from agri-horticulture (1.67, 1.72, 1.75) based agroforestry system while lowest founded in agri-silviculture system (1.27, 1.29 and 1.31). The reduction in soil bulk density under trees in different agroforestry system is attributed to the addition of organic matter through litter fall, fine root recycling etc. The findings of the present study showed the inverse relation between soil bulk density and soil organic carbon content which has been also reported earlier (Gupta and Sharma, 2008). Similarly, the significant reduction in soil bulk density as compared to sole agricultural cropping or scattered trees on field has been reported as under the canopy of *Prosopis juliflora* (Nayak et al., 2009).

Particle Density

The soil particle density was increased successively with increasing soil depth from 0-15 cm to 30-60 cm under different agroforestry system as well as scattered trees on field. The maximum particle density at 0-15 cm, 15-30 cm and 30-60 cm depth was observed in agri-silvi-pasture (2.77, 2.72, and 2.73 Mgm^{-3}) based agroforestry system while founded minimum (2.29, 2.17, and 2.19 Mgm^{-3}) scattered trees on field. Similarly, the lower particle density was recorded under different agroforestry system as compared to the scattered trees on field primarily due to the higher soil organic carbon content under tree species by addition of organic matter through leaf litter, twigs, pruning debris etc (Tandel et al., 2009).

Porosity

The soil porosity decreased with increasing soil depth from 0- 15 to 30-60 cm. The soil porosity (%) was significantly higher under the different agroforestry system as compared to the scattered trees on field. Among the different agroforestry system, the highest soil porosity was observed under agri-silvi-pasture (39.43%, 38.12% and 37.96%) based agroforestry system at the (0-15 cm, 15-30 cm and 30-60 cm) depth which was significantly higher over the other agroforestry systems. The increase in soil porosity under agroforestry systems as compared to the sole agriculture or scattered trees on field might be due to the addition of organic matter through leaf litter and penetration of fine roots of trees in soil. The similar findings were reported) after their research that the soil porosity and water holding capacity improved under trees as compared to the agriculture field or scattered trees on field by (Tandel et al., 2009).

Sr. No.	*(AFS)*	*Depth*	*BD (Mgm^{-3})*	*PD (Mgm^{-3})*	*Porosity (%)*	*WHC (%)*
1.	(AS)	0 – 15	1.27	2.63	38.64	34.95
		15 – 30	1.29	2.53	36.97	33.78
		30 – 60	1.31	2.59	36.79	32.87
		Mean	**1.29**	**2.58**	**37.47**	**3.87**
		Range	**1.27 -1.31**	**2.53 -2.63**	**36.79 -38.64**	**32.87 - 34.95**

2.	(ASP)	0 – 15	1.38	2.77	39.43	35.86
		15 – 30	1.41	2.71	38.12	31.45
		30 – 60	1.44	2.73	37.96	30.43
		Mean	**1.41**	**2.74**	**38.50**	**32.58**
		Range	**1.38 - 1.44**	**2.71 - 2.77**	**37.96 - 39.43**	**30.43 - 35.86**
3.	(Block Plantation)	0 – 15	1.37	2.45	38.97	32.57
		15 – 30	1.39	2.35	37.56	32.23
		30 – 60	1.42	2.29	37.47	31.98
		Mean	**1.39**	**2.36**	**38.00**	**32.26**
		Range	**1.37 - 1.42**	**2.29 - 2.45**	**37.46 - 38.97**	**31.98 -32 57**
4.	(AHS)	0 – 15	1.35	2.34	37.78	38.43
		15 – 30	1.37	1.92	36.31	36.65
		30 – 60	1.39	2.11	35.94	30.75
		Mean	**1.37**	**2.12**	**36.68**	**35.28**
		Range	**1.35 - 1.39**	**1.92 - 2.34**	**35.94 - 37.78**	**30.75 - 38.43**
5.	(AH)	0 – 15	1.68	2.51	34.53	33.79
		15 – 30	1.72	2.46	33.24	32.76
		30 – 60	1.75	2.53	33.14	29.52
		Mean	**1.72**	**2.50**	**33.64**	**32.02**
		Range	**1.68 - 1.75**	**2.46 - 2.53**	**33.14 - 34.53**	**29.52 – 33.79**
6.	(SToF)	0 – 15	1.33	2.29	34.19	31.97
		15 – 30	1.36	2.17	33.92	30.98
		30 – 60	1.37	2.19	32.98	30.12
		Mean	**1.35**	**2.22**	**33.70**	**31.02**
		Range	**1.33 - 1.37**	**2.17 -2.29**	**32.98 - 34.19**	**30.12 - 31.97**
		T. Average	**1.42**	**2.42**	**36.33**	**32.84**
		S. Deviation	**0.13**	**0.20**	**1.82**	**1.28**

Table 1: Soil physical properties under different agroforestry systems.

Water holding Capacity

Change of bulk density may affect soil water holding capacity. Therefore, as a result of decrease in bulk density of soil, an increase in porosity and water holding capacity of soils under all the agroforestry systems was recorded as compared to scattered trees on field or sole agriculture. Outcomes showed that water holding capacity was highest for Agri-horti-silviculture system (38.43%, 36.65% and 30.75%) at the depth of (0-15 cm, 15-30 cm and 30-60 cm) as well as lowest recorded from scattered trees on field (31.97%, 30.98% and 30.12%) at depth at the depth of (0-15 cm, 15-30 cm and 30-60 cm).

Soil chemical properties

Soil pH

The soil pH was significantly higher in sole agriculture field or scattered trees on field as compared to agroforestry system. Soil pH increased with increasing soil depth from 0-15 cm, 15-30 cm and 30-60 cm. The trend was common among all agroforestry systems well as under the scattered trees on field (Table 3). The highest pH for the surface soil depths (0-15 cm, 15-30 cm and 30-60 cm) was recorded under scattered trees on field (9.12, 9.38 and 9.53), which was significantly higher over the other soil samples collected from the agroforestry system. Among all the agroforestry system, the highest pH range was observed under scattered trees on field (9.12, 9.38 and 9.53) at the soil depths 0-15 cm, 15-30 cm and 30-45 cm, which was significantly higher than the other agroforestry system for all depths while, the lowest pH was recorded under Agri-horti-silviculture based agroforestry system (8.58, 8.69 and 8.78) at the depth of 0-15, 15-30 and 30-60 cm). Relatively lower pH was recorded under 0-15 cm soil depth than other soil depths. This might also be due to the leaching of soluble salts from the surface to the deeper layers of soil. Similar results and trends of variation in soil pH under agroforestry systems in comparison to crop fields has been reported by (Prasadini and Sreemannarayana, 2007; Kumar et al., 2008 and Newaj et al., 2007), also observed nominal changes in soil pH under white siris (*A. procera*) based agroforestry system after four years of experimentation as the pH value was lower compared to the initial value and it was also lower than the pH value of the Agriculture field.

Electrical conductivity

The soil EC showed a decrease with successive soil depth. The soil EC was relatively higher under agroforestry system as compared to the sole agriculture or scattered trees on field. However, the difference in EC was significant at the soil depths for 0-15 cm 15-30 cm and 30-60 cm. Among the all-agroforestry systems, the maximum EC of soil was recorded under scattered trees on field (0.29, 0.39 and 0.48) respectively at the depths (0-15, 15-30 and 30-60 cm) and the minimum EC value was founded in Agri-silviculture based agroforestry system (0.21, 0.25 and 0.34) at the depth of (0-15,15-30 and 30-60 cm). Soil electrical conductivity (EC) is a measurement correlating with soil properties that influence crop productivity, including soil texture, cation exchange capacity (CEC), drainage conditions, organic matter level, soil salinity and sub-soil characteristics. Similar results and reasons have been reported by (Newaj et al., 2007) who also observed significantly higher values for soil EC under (A. procera) based Agri-silvicultural system as compared to the agricultural field. Also contrary to this (Malik et al., 1996) observed reduction in soil EC values by 10% under tree canopy or agroforestry system as compared to the sole agriculture area which was also observed in the present study.

Sr. No.	*(AF System)*	*Depth*	*pH*	*EC*	*SOC (%)*
1.	(AS)	0 – 15	8.71	0.21	0.49
		15 – 30	8.85	0.25	0.38
		30 – 60	8.92	0.34	0.27
		Mean	**8.83**	**0.27**	**0.38**
		Range	**8.71 - 8.92**	**0.21 - 0.34**	**0.27 - 0.49**
2.	(ASP)	0 – 15	8.84	0.22	0.46
		15 – 30	8.97	0.27	0.33
		30 – 60	9.14	0.33	0.25
		Mean	**8.98**	**0.27**	**0.35**
		Range	**8.84 - 9.14**	**0.22 -0.33**	**0.25 - 0.46**
3.	(Block Plantation)	0 – 15	8.69	0.28	0.48
		15 – 30	8.71	0.34	0.37
		30 – 60	8.83	0.39	0.26
		Mean	**8.74**	**0.34**	**0.37**
		Range	**8.69 -8.83**	**0.28 - 0.39**	**0.26 - 0.48**

4.	(AHS)	0 – 15	8.58	0.19	0.45
		15 – 30	8.69	0.29	0.31
		30 – 60	8.78	0.37	0.23
		Mean	**8.68**	**0.28**	**0.33**
		Range	**8.58 - 8.78**	**0.19 - 0.37**	**0.23 - 0.45**
5.	(AH)	0 – 15	8.62	0.26	0.44
		15 – 30	8.74	0.31	0.24
		30 – 60	8.91	0.35	0.19
		Mean	**8.76**	**0.31**	**0.29**
		Range	**8.62 - 8.91**	**0.26 - 0.35**	**0.19 - 0.44**
6.	(SToF)	0 – 15	9.12	0.29	0.39
		15 – 30	9.38	0.41	0.36
		30 – 60	9.53	0.48	0.21
		Mean	**9.34**	**0.39**	**0.32**
		Range	**9.12 - 9.53**	**0.29 - 0.48**	**0.21 - 0.39**
		T. Average	**8.89**	**0.31**	**0.34**
		S. Deviation	**0.21**	**0.04**	**0.03**

Table 2: Soil chemical properties under different agroforestry systems.

Soil organic carbon

The soil organic carbon (SOC) content was significantly higher under the tree species or agroforestry systems as compared to the sole agriculture field or scattered trees on field. Also, the SOC decreased with successive soil depths from 0-15 cm, 15-30 cm and 30-60 cm under all agroforestry systems. Among all the agroforestry systems the maximum SOC carbon was found under block plantation (0.48, 0.37 and 0.26%) which was significantly higher over the other agroforestry system, while observed minimum in scattered trees on field (0.39, 0.36 and 0.21%) at the soil depth (0-15 cm, 15-30 cm and 30-60 cm).

Conclusion

The findings of this study highlight the significant impact of agroforestry systems on improving soil physico-chemical properties in Ayodhya district, Eastern Uttar Pradesh. Long-term adoption of agroforestry practices contributes to a reduction in soil pH, enhancing nutrient availability and overall soil fertility. The integration of tree components positively influences soil structure by increasing water-holding capacity, cation exchange capacity, and infiltration rate, thereby promoting sustainable agricultural productivity. The continuous deposition of organic matter from tree litter and dynamic root interactions plays a vital role in improving soil porosity, aggregation, microbial activity, and nutrient cycling. Among the different agroforestry systems studied, Agri-Silviculture, Agri-Silvi-Pasture, Agri-Horti-Silviculture, Bamboo Block Plantation, and Agri-Horticulture systems demonstrated superior soil improvement compared to conventional agriculture. These systems contribute to better soil organic carbon content, enhanced water retention, and improved nutrient dynamics, which are crucial for long-term ecosystem sustainability. The study strongly recommends the adoption of agroforestry for improving soil health and ensuring sustainable agricultural productivity in the region. However, further research is needed to assess the long-term impacts of these practices on soil fertility and crop performance across diverse agro-climatic conditions.

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