Comparative Analysis of Soil Physico-Chemical Properties Across Different Land-Use Systems

ABSTRACT

A research investigation was conducted at the Research Farm, the Department of Forestry, College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, located in Jabalpur, Madhya Pradesh. The aim of this study was to assess the impact of various land-use regimes on the physical and chemical characteristics of soil during the Rabi season, namely during the fiscal years 2022-23 and 2023-24. An experimental split-split plot design was used to perform the experiment. The main plot consisted of two land-use systems: Agroforestry system (S_1) and Open system (S_2). The sub-plots were the different crop establishment methods: Broadcasting (M_1), Line sowing (M_2) and Transplanting (M_3). Within each sub-plot, four sub-sub plots were laid which represented different boron levels: Control (B_0), 1 kg B ha^{-1} as Basal (B_1), 2 kg B ha^{-1} as Basal (B_2) and ½ kg B ha^{-1} as Basal + ½ kg B ha^{-1} as foliar (B_3). The soil samples under the treatments were tested to determine the physico-chemical properties of the soil. The results indicated that the agroforestry system had a significantly positive influence on the physical and chemical properties of the soil, in comparison to the open system. The agroforestry system reduced pH (7.07), bulk density (1.30 g cm^{-3}) and electrical conductivity (0.28 dS m^{-1}) in soil. The agroforestry system promoted organic carbon (0.72%) and water holding capacity (39.52%) of soil. Available nutrients *viz.* nitrogen, phosphorus, potassium and boron in the soil, with respective values of 290, 18.8, 191 kg ha^{-1} and 0.76 mg ha^{-1}increased under agroforestry system compared to the open system. Therefore, this study asserts that among the different land-use systems, agroforestry enhancesthe physico-chemical properties, and adoption of tree based farming system in the long run can improvesoil fertility.

Keywords: Agroforestry, mustard, open system, physico-chemical properties, shisham, soil.

INTRODUCTION

Intense agricultural practices in the tropical and sub-tropical region of the Indian sub-continent are causing a decline in soil fertility and depletion of organic matter (Scotti et al., 2015 and Gomeiro, 2016). The health and sustainability of agroecosystems heavily rely on the soil condition, making it a crucial resource (Magdoff, 2001 and Arshad and Martin, 2002). The majority of soils lack adequate fertility to provide all the essential elements required for healthy growth and development (Lal, 2009). Moreover, achieving a consistent crop production and maintaining soil health over an extended period is challenging. Agriculture depletes nitrogen, phosphorous and potassium at a faster pace than mineral fertilisers restore them, leading to nutrient mining (Jones *et al*., 2013 and Sanyal *et al*., 2014). Nevertheless, this problem may be effectively addressed by the use of agroforestry techniques. Agroforestry systems are often recognized as a holistic and effective remedy for the issues arising from intensive agriculture (Sarvade and Singh, 2014; Cardineal *et al*., 2021 and Pantera *et al*., 2021).

The large-scale implementation of agroforestry Systems (AFS) is an essential strategy to diversify land use systems and fulfil the diverse needs of people, while diminishing adverse effects on the agricultural environment(Udawatta*et al*., 2019 and Jose 2019). Ecological interactions in Agroforestry systems offer several benefits which include improved soil fertility through nitrogen fixation (Kim and Issac, 2022), increased organic matter (Fonte *et al*., 2010), nutrient recycling (Sileshi *et al*., 2020), higher biomass production per unit area, enhanced uptake of water and nutrients (Gama-Roudrigues, 2011 and Fahad *et al*., 2022) and the provision of a protective barrier against soil erosion and wind as provided by trees (Atangan *et al*., 2014; Tomar *et al*., 2021 and Jinger *et al*., 2022). The judicious choice of tree and crop species in Agroforestry systems is essential for mitigating land degradation, enhancing soil productivity (Fahad *et al*., 2022), assuring land sustainability (Raj *et al*., 2019) and boosting resource allocation efficiency (Dhyani *et al*., 2009). Agroforestry is considered a sustainable land management approach that improves soil quality and health. The implementation of an agro-forestry land use system might be considered a feasible approach to partially alleviate land degradation.

This paper will provide empirical insights into the physical and chemical features of soil under varied land use systems, specifically focusing on mustard cultivation with varying crop establishment methods and levels of boron. The findings will offer valuable guidance for researchers in formulating and executing land-use programs that safeguard soil health and guarantee enduring environmental sustainability.

MATERIAL AND METHODS

Study site

The experiment was conducted in the *Dalbergia sissoo* based agroforestry and open system at the Research Farm, Department of Forestry, College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh. The experimental site is situated at an altitude of 391 meters above sea level. The location of the area is at a latitude of 23^{o} 12' 50" north and a longitude of 79^{o} 57' 56" east in the Kymore Plateau and Satpura Hill agroclimatic zones of Madhya Pradesh. The climate is defined by extremely hot and dry summers, with an average highest temperature of 46°C and extremely cold and dry winters, with an average lowest temperature of 4°C. Jabalpur receives an average annual precipitation of 1350 mm. The region is famous for its high relative humidity levels, which reach 80 to 90% during the rainy season, 60 to 75% during the summer and 20 to 23% during the winter.

The experiment employed a split-split plot design, with land-use systems (S_1 = agroforestry and S_2 = open system) as main plot treatment, crop establishment methods namely M_1 = broadcasting (randomly scattered), M_2 = line sowing (30 x 10 cm) and M_3 = transplanting (45 x 15 cm) as sub-plot treatments. Furthermore, the four sub-sub plot treatments included different levels of boron application (B_0 = Control *i.e.*, 0 kg ha^{-1}, B_1 = 1 kg ha^{-1} as basal, B_2 = 2 kg ha^{-1} as basal and B_3 = ½ kg ha^{-1} as basal + ½ kg ha^{-1} as foliar) in the rabi seasons of 2022–23 and 2023–24. The experiment consisted of using 24 distinct treatment combinations ($S_1M_1B_0$, $S_1M_1B_1$, $S_1M_1B_2$, $S_1M_1B_3$, $S_1M_2B_0$, $S_1M_2B_1$, $S_1M_2B_2$, $S_1M_2B_3$, $S_1M_3B_0$, $S_1M_3B_1$, $S_1M_3B_2$, $S_1M_3B_3$, $S_2M_1B_0$, $S_2M_1B_1$, $S_2M_1B_2$, $S_2M_1B_3$, $S_2M_2B_0$, $S_2M_2B_1$, $S_2M_2B_2$, $S_2M_2B_3$, $S_2M_3B_0$, $S_2M_3B_1$, $S_2M_3B_2$, $S_2M_3B_3$). The treatments were allocated randomly into three distinct replications. Mustard was grown in the plots measuring 3.6 m x15 m between the alleys of 24-year-old *Dalbergia sissoo* trees. The trees are planted with a uniform distance of 5 x 5 m. Recommended dose of fertiliser (80:40:40 N: P: K kg ha^{-1}, respectively) was supplemented to the crop.

Soil Sampling and Analysis

Prior to sowing the crop for field experiment, a comprehensive soil sample was collected to assess the initial soil condition. The purpose of obtaining a soil sample before conducting the experiment was to obtain initial data for physico-chemical properties of soil. In order to get spatial diversity, five distinct sampling locations were chosen at random within each area and collected using an auger from the root zone at a depth of 0-15 cm.

After collection of soil samples, they were carried to the laboratory and underwent different procedures for different properties. To achieve uniformity, the soil samples were grounded into smaller particles and any undesirable material was removed. The pH of soil was measured using a glass electrode on a digital pH meter (Piper, 1966) after allowing it to reach equilibrium for half an hour in a 1:2.5 ratio of soil to water. The soil sample's electrical conductivity was measured at 25^{o}C using a conductivity meter (Black, 1965) in a 1:2.5 ratio of soil to water suspension. The organic carbon content was assessed using the method developed by Walkley and Black (1934). The alkaline potassium permanganate method, as described by Subbiah and Asija (1956), was used for the determination of nitrogen available in the soil. The method used for extraction of available phosphorus was performed by following the procedure described by Olsen *et al*., (1954). Available potassium was assessed by extracting it with 1 N ammonium acetate solution at pH 7 and the potassium concentration was measured using a flame photometer, as described by Jackson, 1973. The boron availability was estimated using the hot-water soluble method developed by Gupta (1967), which was further simplified by the utilisation of azomethine-H (John *et al*., 1975).

Table 1: Physio-chemical properties of the soil in the experimental field

Constituents	Initial Value (open system)	Initial Value (agroforestry system)	Methods of analysis
A. Physical compositions			
Bulk density (g cm^{-3})	1.32	1.33	Core sample (Black *et al.,* 1965)
B. Chemical compositions			
Organic carbon (%)	0.68	0.55	Chromic acid rapid titration method (Walkley and Black, 1934)
Available nitrogen (kg ha^{-1})	252.20	245.88	Alkaline Permangantic Method (Subbiah and Asija, 1956)
Available phosphorus (kg ha^{-1})	12.26	11.04	Calorimeter method (Olsen *et al.*, 1954)
Available potassium (kg ha^{-1})	147.70	140.25	Flame photometer Method (Jackson, 1973)
Available boron (mg ha^{-1})	0.61	0.57	Hot-water soluble method (Gupta, 1967)
Soil pH	7.09	7.10	Glass electric pH meter (Piper, 1966)
EC (ds m^{-1})	0.29	0.30	Solu-bridge method (Black, 1965)

RESULTS AND DISCUSSION

Effect of Land-use Systems

The impacts of the land-use systems were recorded on soil physico-chemical parameters, including pH, EC, OC, bulk density, water holding capacity, available nitrogen, phosphorous, potassium and boron, as shown in Tables 2, 3 and 4.

The land-use system did not have a substantial impact on pH and electrical conductivity. Agroforestry, however, decreased the bulk density of the soil which in-turn promoted water retention capacity insoil as compared to the open system.Additionally, it was determined that the agroforestry system exhibits higher levels of organic matter, available nitrogen, phosphorous, potassium andboron than the open system.

Effect of Crop Establishment Methods

There were no significant influences marked on soil physico-chemical parameters (Table 2, 3 and 4) *viz.*pH, electrical conductivity, organic carbon, bulk density, water holding capacity, available nitrogen, phosphorous, potassium and boron due to crop establishment methods. However, pH, electrical conductivity and bulk density decreased with the transplanting method. Meanwhile, organic carbon, water holding capacity and available nutrients (N, P, K and B) were recorded to be highest with transplanting.

Effect of Boron Levels

The influences on soil physico-chemical parameters (Table 2, 3 and 4) due to boron levels were marked to be non-significant.

DISCUSSION

The reduction of bulk density and increased water holding capacity in soil under agroforestry systems may be attributed to the rise in organic matter resulting from the built-up of leaf litter. Thefindings have been reported by Singh *et al.*, (2018) and Mesfin and Haileselassie (2022). Furthermore, the increased content of carbon and available nutrients in soil under the agroforestry system may be attributed to the presence of leaf litter, which facilitated the accessibility of organic matter and nutrients, thereby enhancing the water retention capacity within the agroforestry system. These findings coincide with Kumar *et al.*, (2018) and Bisht *et al.*, (2017).

Table 2: pH, Electrical Conductivity and Organic Carbon in soil as affected by crop establishment methods and boron levels under different systems

Treatments	Ph			Electrical Conductivity (dS m^{-1})			Organic Carbon (%)		
	Y_1	Y_2	Pooled	Y_1	Y_2	Pooled	Y_1	Y_2	Pooled
Land-use systems									
S_1	7.08	7.07	7.07	0.28	0.29	0.28	0.70	0.73	0.72
S_2	7.10	7.11	7.10	0.29	0.30	0.29	0.57	0.59	0.58
SEm±	0.05	0.04	0.04	0.02	0.01	0.01	0.01	0.01	0.01
C. D. (*P*=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	0.05	0.08	0.06
Crop Establishment Methods									
M_1	6.98	6.97	6.98	0.26	0.29	0.28	0.66	0.69	0.68
M_2	7.06	6.98	7.02	0.28	0.30	0.29	0.64	0.67	0.65

M_3	7.21	7.33	7.27	0.31	0.31	0.31	0.61	0.63	0.62
SEm±	0.07	0.36	0.21	0.02	0.01	0.01	0.02	0.02	0.02
C. D. (*P*=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Boron Levels (kg ha^{-1})									
B_0	6.97	6.72	6.84	0.27	0.28	0.27	0.64	0.67	0.65
B_1	7.05	6.95	7.00	0.28	0.30	0.30	0.65	0.68	0.66
B_2	7.21	7.35	7.28	0.30	0.31	0.29	0.66	0.68	0.67
B_3	7.12	7.35	7.24	0.29	0.30	0.29	0.60	0.63	0.61
SEm±	0.07	0.25	0.15	0.02	0.01	0.01	0.02	0.02	0.02
C. D. (*P*=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Y_1 – 2022-23 Y_2 – 2023-24

Table 3: Organic Carbon, Bulk density and Water holding capacity in soil as affected by crop establishment methods and boron levels under different systems

Treatments	**Bulk density (g cm^{-3})**			**Water holding capacity (%)**		
	Y_1	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**
Land-use systems						
S_1	1.32	1.30	1.30	38.09	40.94	39.52
S_2	1.34	1.33	1.34	35.53	37.88	36.70
SEm±	0.03	0.01	0.02	0.07	0.01	0.03
C. D. (*P*=0.05)	0.01	0.06	0.13	0.42	0.06	0.20
Crop Establishment Methods						
M_1	1.36	1.32	1.33	36.52	39.33	37.92
M_2	1.34	1.33	1.33	36.81	39.44	38.12
M_3	1.30	1.30	1.30	37.10	39.46	38.28
SEm±	0.02	0.03	0.03	0.16	0.04	0.08
C. D. (*P*=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Boron Levels (kg ha^{-1})						
B_0	1.35	1.32	1.33	36.70	39.36	38.03
B_1	1.35	1.32	1.33	36.74	39.38	38.06
B_2	1.34	1.31	1.31	36.86	39.43	38.14
B_3	1.30	1.30	1.31	36.94	39.46	38.20
SEm±	0.02	0.04	0.04	0.11	0.03	0.06
C. D. (*P*=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Y_1 – 2022-23 Y_2 – 2023-24

Table 4: Available Nitrogen, Phosphorous, Potassium and Boron in soil as affected by crop establishment methods and boron levels under different systems

Treatments	**Available nitrogen (kg ha^{-1})**			**Available phosphorous (kg ha^{-1})**			**Available potassium (kg ha^{-1})**			**Available Boron (mg ha^{-1})**		
	Y_1	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**	**Y_1**	**Y_2**	**Pooled**
Land-use systems												
S_1	286	295	290	17.6	19.9	18.8	185	198	191	0.74	0.79	0.76
S_2	275	285	280	15.5	17.8	16.6	163	174	169	0.68	0.69	0.68
SEm±	3.3	3.38	3.32	0.18	0.33	0.24	1.83	2.09	1.95	0.01	0.02	0.01
C. D. (*P*=0.05)	20.1	20.6	20.2	1.07	2.03	1.47	11.1	12.7	11.9	0.05	0.09	0.06

Crop Establishment Methods												
M_1	278	288	284	16.5	18.8	17.7	173	185	179	0.62	0.67	0.64
M_2	281	290	285	16.6	18.7	17.6	175	186	180	0.74	0.75	0.74
M_3	283	292	287	16.7	18.9	17.8	176	187	181	0.76	0.79	0.78
SEm±	1.35	1.07	0.84	0.33	0.38	0.36	1.08	0.79	0.89	0.04	0.07	0.05
C. D. (*P*=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Boron Levels (kg ha^{-1})												
B_0	279	289	285	16.1	18.3	17.2	174	185	179	0.66	0.69	0.68
B_1	280	289	285	16.4	18.8	17.6	174	186	180	0.68	0.71	0.69
B_2	281	290	285	17.0	19.3	18.0	175	187	181	0.93	0.73	0.73
B_3	281	291	286	16.6	19.0	18.0	175	186	180	0.76	0.82	0.79
SEm±	0.86	0.99	0.56	0.28	0.29	0.28	0.57	0.71	0.5	0.03	0.04	0.03
C. D. (*P*=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Y_1 – 2022-23 Y_2 – 2023-24

CONCLUSION

The two-year research showed that intentionally integrating trees onto agricultural land using suitable species and optimal management techniques improves the soil physico-chemical characteristics. Trees enhance water retention capacity, organic matter content and nutrient accessibility by augmenting the quantity of organic matter *via* leaf biomass, branches and underground roots. The implementation of Agroforestry can enrich soil fertility and mitigate soil degradation, therefore rejuvenating the soil. Agroforestry has the capacity to restore deteriorated soils, enhance agricultural output and promote ecological sustainability. However, it is imperative to conduct a comprehensive, long-term and extensive investigation to observe the changes in the physical characteristics of soil.

REFERENCES

Arshad MA, and Martin S. Identifying critical limits for soil quality indicators in agro-ecosystems. *Agriculture, ecosystems and environment*. 2002;*88*(2): 153-160.

Atangana A, Khasa D, Chang S, Degrande A, Atangana A, Khasa D, et al. Agroforestry for soil conservation. *Tropical agroforestry*.2014;203-216.

Bisht N, Sah VK, Satyawali K,Tiwari S. Comparison of wheat yield and soil properties under open and poplar based agroforestry system. *Journal of Applied and Natural Science*. 2017;*9*(3): 1540-1543.

Black CA. Methods of Soil Analysis: CA Black, Editor-in-chief. DD Evans [and Others] Associate Editors. RC Dinauer, Managing Editor. *American Society of Agronomy*; 1965.

Cardinael R, Cadisch G, Gosme M, Oelbermann M,Van Noordwijk M. Climate change mitigation and adaptation in agriculture: Why agroforestry should be part of the solution. *Agriculture, Ecosystems and Environment*. 2021;*319*: 107555.

Dhyani SK, Newaj R,Sharma AR. Agroforestry: its relation with agronomy, challenges and opportunities. *Indian Journal of Agronomy*. 2009;*54*(3): 249-266.

Fahad S, Chavan SB, Chichaghare AR, Uthappa AR, Kumar M, Kakade V, et al. Agroforestry systems for soil health improvement and maintenance. *Sustainability*. 2022;*14*(22): 14877.

Fonte SJ, Barrios E, Six J. Earthworms, soil fertility and aggregate-associated soil organic matter dynamics in the Quesungual agroforestry system. *Geoderma*. 2010;*155*(3-4): 320-328.

Gama-Rodrigues AC. Soil organic matter, nutrient cycling and biological dinitrogen-fixation in agroforestry systems. *Agroforestry Systems*. 2011;*81*: 191-193.

Gomiero T. Soil degradation, land scarcity and food security: Reviewing a complex challenge. *Sustainability*. 2016;*8*(3): 281.

Gupta UC. A simplified method for determining hot-water soluble boron in podzol soils. Soil Sci. 1967;103: 424-28.

Jackson ML. Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., NewDelhi;1973.

Jinger D, Kumar R, Kakade V, Dinesh D, Singh G, Pande VC, et al. Agroforestry for controlling soil erosion and enhancing system productivity in ravine lands of Western India under climate change scenario. *Environmental Monitoring and Assessment*. 2022;*194*(4): 267.

John MK, Chuah HH, Nduefeld JH. Application of improved azomethine–H method for determination of boron in soils and plants. 1975;8:559-68.

Jones DL, Cross P, Withers PJ, DeLuca TH, Robinson DA, Quilliam RS, et al. Nutrient stripping: the global disparity between food security and soil nutrient stocks. *Journal of Applied Ecology*. 2013;*50*(4): 851-862.

Jose S. Environmental impacts and benefits of agroforestry. In *Oxford research encyclopedia of environmental science*; 2019.

Kim DG, and Isaac ME. Nitrogen dynamics in agroforestry systems. A review. *Agronomy for Sustainable Development*. 2022;*42*(4): 60.

Kumar P, Mishra AK, Chaudhari SK, Basak N, Rai P, Singh K, et al. Carbon pools and nutrient dynamics under Eucalyptus-based agroforestry system in semi-arid region of north-west India. *Journal of the Indian Society of Soil Science*. 2018;*66*(2): 188-199.

Lal R. Soils and food sufficiency: A review. *Sustainable agriculture*.2009;25-49.

Magdoff, F. Concept, components and strategies of soil health in agroecosystems. *Journal of nematology*. 2001;*33*(4): 169.

Mesfin S, and Haileselassie H. Evaluation of soil physico-chemical properties as affected by canopies of scattered agroforestry trees on croplands. *South African Journal of Plant and Soil*. 2022;*39*(2):153-162.

Olsen SR, Watanabe FS, Cosper HR, Larson WE, Nelson LB. Residualphosphorusavailabilityinlong-timerotationson calcareoussoils. *Soil Science*.1954;78(2):141-152.

Pantera A, Mosquera-Losada MR, Herzog F, Den Herder M. Agroforestry and the environment. *Agroforestry Systems*. 2021;*95*(5):767-774.

Piper CS. Soil and Plant Analysis. Hans Publishers, Bombay, India; 1966.

Raj A, Jhariya MK, Yadav DK, Banerjee A,Meena RS. Agroforestry: a holistic approach for agricultural sustainability. *Sustainable agriculture, forest and environmental management*. 2019;101-131.

Sanyal SK, Majumdar K, Singh VK. Nutrient management in Indian agriculture with special reference to nutrient mining—A relook. *Journal of the Indian Society of Soil Science*. 2014;*62*(4):307-325.

Sarvade S, and Singh R. Role of agroforestry in food security. *Popular Kheti*. 2014;*2*(2): 25-29.

Scotti R, Bonanomi G, Scelza R, Zoina A,Rao MA. Organic amendments as sustainable tool to recovery fertility in intensive agricultural systems. *Journal of soil science and plant nutrition*. 2015;*15*(2):333-352.

Sharma P, Singh, MK, Tiwari P. Agroforestry: A land degradation control and mitigation approach. *Bulletin of Environment, Pharmacology and Life Sciences*. 2017;*6*(5):312-317.

Sileshi GW, Mafongoya PL, Nath AJ. Agroforestry systems for improving nutrient recycling and soil fertility on degraded lands. *Agroforestry for Degraded Landscapes: Recent Advances and Emerging Challenges*. 2020;(1):225-253.

Singh I, Rawat P, Kumar A, Bhatt P. Soil physico-bio-chemical properties under different agroforestry systems in Terai region of the Garhwal Hiamalayas. *Journal of Pharmacognosy and Phytochemistry*. 2018;*7*(5):2813-2821.

Subbiah BV, and Asijah GL. A rapid procedure for determination of available nitrogen in soil. Current Sciences.1956;25:259-260.

Tomar JMS, Ahmed A, Bhat JA, Kaushal R, Shukla G, Kumar R. Potential and opportunities of agroforestry practices in combating land degradation. *Agroforestry-small landholder's tool for climate change resiliency and mitigation*; 2021.

Udawatta RP., Rankoth LM, Jose S. Agroforestry and biodiversity. *Sustainability*. 2019;11(10), 2879.

Walkley and Black CA. An examination of the different method for determining soil organic matter and a proposed modification of the chromic acid titration method, Soil Science.1934;37:29-33.