International Journal of Plant & Soil Science

34(20): 312-319, 2022; Article no.IJPSS.88514
ISSN: 2320-7035

Assessment on the Impact of Various Agroforestry Systems on Soil Quality Parameters

V. Ramaswamy [a#], K. Sivakumar [a*¥], S. Thiyageshwari [a‡] and R. Anandham [b¥]

[a] *Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore, India.*
[b] *Department of Agricultural Microbiology, Tamil Nadu Agricultural University, Coimbatore, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2022/v34i2031157

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/88514

Original Research Article

Received 08 April 2022
Accepted 17 June 2022
Published 20 June 2022

ABSTRACT

An experiment was conducted during month of February 2022 at Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore to identify the effect of different agroforestry systems on soil quality parameters. Soil samples were collected from nine different agroforestry systems from three major agroforestry sites such as agrisilviculture, silvihorticulture and silvipasture systems. Soil was analysed for soil quality parameters viz., pH, EC, bulk density, porosity, available nitrogen, available phosphorus, available potassium and available micronutrients. Different agroforestry systems show their effect as variations in soil physical and chemical properties. Results from the study reveals that the agroforestry system *Acacia leucophloea* + Guinea grass shows higher fertility status than other agroforestry systems. This system was noticed to have higher amount of available nitrogen, available phosphorus, available potassium and available micronutrients compared to other agroforestry systems taken into account for research. *Casuarina equisetifolia* + Sorghum agroforestry system was observed to have low available P, available K and available micronutrients than other systems. Further studies are needed to define an agroforestry system for proper land use management and improving fertility status of the soil by including other soil quality parameters viz., biological and microbial parameters.

[#]*M.Sc. (Ag) Research Scholar;*
[¥]*Assistant Professor;*
[‡]*Professor;*
**Corresponding author: E-mail: sivak1974@yahoo.co.in;*

Keywords: Agroforestry; soil fertility; silvipasture; nutrient status; physico-chemical properties; soil quality.

1. INTRODUCTION

Agroforestry systems are one among the major land use systems where the tree species were grown along with other crops. This is a kind of practice where the agriculture crops and the forest trees were combined to receive various benefits for the human kind. This combination not only restricts with the combination of trees with agricultural crops. It also includes horticultural trees as well as shrubs, pastures, fodders etc. Depending upon the combination of the enterprises, the names were defined accordingly. These agroforestry systems are being practiced in our Tamil Nadu in almost all the districts which comes under the seven agro climatic zones. This practice is not a new one as it is adopted from traditional to recent newly emerged industrial agroforestry [1]. This practice of agroforestry cultivation results in various environmental benefits such as conserving biological diversity that reduces the erosion and increases the diversity of the plant and animal species. On the other hand, this practice improves the fertility status of the soil, enhances the nutrient recycling and helps in carbon sequestration from the atmosphere. In terms of economic benefits, agroforestry cultivation increases the cash flow by combining various enterprises in a single piece of land so that the farmer can get additional income through these components and it also improves land productivity [2].

In general, block plantations, home gardens and bund planting are the common practices of agroforestry systems found in the state. These systems are raised to supply the essential needs like timber, raw materials for industries, food, fodder and fuel etc [3]. In Tamil Nadu, various types of agroforestry systems like agrisilviculture, silvipasture, agrihorticulture, hortipasture are more commonly followed in Coimbatore and Erode districts of Tamil Nadu. *Acacia leucophloea* with *Cenchrus ciliaris* is naturally evolved silvipasture system in the Erode and Coimbatore districts of Tamil Nadu over 1.20 lakh ha [1].

Soil quality has been defined as capacity of specific kind of soil to function within natural ecosystem and its boundaries to sustain the productivity of plant and animal, enhancing the quality of air and water followed by sustaining the human habitation and health [4]. These agroforestry systems have also displayed the significant evidence for their capacity to improve the soil fertility and also to enhance the soil quality. It creates various impact on the soil physical, chemical and biological properties which ultimately results in change of soil quality [5]. Earlier studies reported that the agroforestry systems alter the physico-chemical and biological properties of the soil and also the organic matter content. Various authors in their research suggested that agroforestry systems ameliorate the adverse effect on soil quality, soil fauna and flora caused by wind and temperature [6]. Traditional agroforestry systems promote better soil fertility than mono cropping systems [7]. Presence of soil microorganism also acts as an indicator of good fertile soil. Agroforestry system also enhances the soil nutrient pools and efficiency of microbial substrate [8]. Researchers identified that agroforestry system acts as an efficient alternative management system for salt affected soils and degraded lands [9,10]. Hence with this context, a research work was carried out to evaluate the soil quality parameters under different agroforestry systems to understand the influence and impact of agroforestry systems on soil physical and chemical properties which enhances fertility status of the soil.

2. MATERIALS AND METHODS

2.1. Study Site

The present investigation was carried out at Department of Soil Science and Agricultural Chemistry at Tamil Nadu Agricultural university, Coimbatore. For this study, the soil samples were collected from Forest College and Research Institute, Mettupalayam which is 40 km away from the Coimbatore in the northern direction at the foothills of Nilgiris. The total area covers about 200 ha. Samples were collected at two different depths in three replicates from the root zone at 0-30 cm and 30-60 cm which were considered as surface and subsurface samples respectively during February month of 2022. The agroforestry systems were established in the spacing of 5 m x 5 m. The agroforestry area consists of various agroforestry sites such as silvipasture, hortipasture, agrisilviculture, silvihorticulture, silvimediculture and individual silviculture trees. In the present study, we had selected 9 agroforestry systems from three different agroforestry sites namely

Table 1. List of agroforestry systems

Sampling agroforestry systems	Agroforestry sites
Melia dubia + Sorghum	Agrisilviculture
Dalbergia sissoo + Sorghum	Agrisilviculture
Casuarina equisetifolia + Sorghum	Agrisilviculture
Melia dubia + Turmeric	Silvihorticulture
Eucalyptus spp + Curry leaf	Silvihorticulture
Toona ciliata + turmeric	Silvihorticulture
Acacia leucophloea + Guinea grass	Silvipasture
Glyricidia sepium + Co (BN) grass	Silvipasture
Melia dubia + Hedge Lucerne	Silvipasture

silvihorticulture, silvipasture and agrisilviculture system. The details of the systems are as follows (Table 1).

2.2 Soil Analysis

The soil analysis of soil quality parameters was carried at the laboratory of Department of Soil Science and Agricultural Chemistry in Tamil Nadu Agricultural University, Coimbatore.

2.2.1 Physical properties

Bulk density of the soil samples collected from various agroforestry systems were determined using cylinder method [11]. Porosity of the soil samples were calculated using the formula (1-BD/PD) x100.

2.2.2 Physico-chemical properties

The pH of the soil under various agroforestry systems were determined using 1:2.5 soil -water ratio using pH meter [12]. Electrical Conductivity of the soil samples were analysed using the same soil water suspension used for measuring pH after half an hour before stirring using Conductivity meter [11].

2.2.3 Chemical properties

Walkley and Black method was used for the estimation of the organic carbon in the soil [13].Available nitrogen in the soil was determined using Alkaline permanganate method [14]. Available phosphorus was measured using Sodium bicarbonate extractable P by Olsen method and the intensity of blue colour was measured in spectrophotometer [15]. Available potassium in the soil was measured using Neutral normal ammonium acetate method and the values were calculated from the extract using Flame Photometer [16].The available micronutrients in the soil samples were determined using DTPA extractant by measuring the intensity using atomic absorption spectrophotometer [17].

2.2.4 Statistical analysis

The experimental data were subjected to analysis of variance (ANOVA) using AGRESS software version 7.01 and the means were compared and the significant differences were tested at probability level of 0.05.

3. RESULTS AND DISCUSSION

3.1 Bulk Density and Porosity

From Table 2, it was noticed that the bulk density of the soil sample was found to increase with increase in soil depth. The values of bulk density of the soil ranged from 1.20 g/cm^3 to 1.38 g/cm^3 in surface with a mean value of 1.28 g/cm^3 and 1.22 g/cm^3 to 1.41 g/cm^3 in subsurface depth with a mean value of 1.31 g/cm^3. The highest bulk density was recorded in *Toona ciliata* + Turmeric agroforestry system while the lowest value was found in *Acacia leucophloea* + Guinea grass system. The soil bulk density reduction under agroforestry systems is attributed to the addition of organic matter through litter, recycling of fine roots and twigs etc [18]. Porosity of the soil samples ranged from 46.7% to 52.6% with a mean value of 50.5% in the surface. In subsurface samples, it ranged from 46.2% to 52.5% with a mean value of 50%.The maximum porosity was found in *Acacia leucophloea* + Guinea grass system and the minimum value was recorded in *Melia dubia* + Hedge Lucerne system. The porosity values decreased with increase in depth which is due to the addition of organic matter content by the litter fall from agroforestry tree species. These findings were similar with the results of earlier works where they found that the soil porosity decreased with increase in depth under agroforestry systems [19,20].

Table 2. Effect of various agroforestry systems on bulk density and porosity

Agroforestry systems	Bulk Density (g/cm^3)		Porosity (%)	
	0-30 cm	30-60 cm	0-30 cm	30-60 cm
Melia dubia + Sorghum	1.23	1.25	51.4	50.4
Dalbergia sissoo + Sorghum	1.26	1.30	50.9	50.1
Casuarina equisetifolia + Sorghum	1.31	1.35	51.4	51.3
Melia dubia + Turmeric	1.33	1.37	49.3	49.0
Eucalyptus spp + Curry leaf	1.21	1.23	52.2	51.8
Toona ciliata + turmeric	1.38	1.41	48.7	47.5
Acacia leucophloea + Guinea grass	1.20	1.22	52.6	52.5
Glyricidia sepium + Co (BN) grass	1.22	1.24	51.4	51.2
Melia dubia + Hedge Lucerne	1.35	1.39	46.7	46.2
Mean	1.28	1.31	50.5	50.0
SEd	0.0307	0.0281	1.0618	0.9784
CD (.05)	0.0652	0.0595	2.2509	2.0741

3.2 Soil pH and EC

The soil pH value decreased with increase in soil depth. It was observed from the Table 3, that the maximum pH value ranged from 7.45 to 8.73 in surface sample with a mean value of 8.23. Under subsurface, the pH value ranged from 7.28 to 8.54 with a mean value of 8.08. The maximum pH was found in *Casuarina equisetifolia* + Sorghum agroforestry system and the minimum pH was recorded in *Acacia leucophloea* + Guinea grass in both surface and subsurface samples. The pH nature of the soil under most of the agroforestry system was found to be alkaline range in condition. This finding was similar to the results of [21]. From the analysis of soil sample for electrical conductivity, it was observed that the EC of the soil samples were normal in range. The EC of the surface sample ranged between 0.16 dSm^{-1} to 0.25 dSm^{-1} with a mean value of 0.21 dSm^{-1}. In terms of subsurface sample, the values of EC ranged between 0.13 dSm^{-1} to 0.23 dSm^{-1} with a mean value of 0.18 dSm^{-1}. The lowest electrical conductivity was found in the *Acacia leucophloea* + Guinea grass system and the highest value was recorded in *Eucalyptus* spp + Curry leaf system under both surface and subsurface samples. When compare to the surface sample, the EC was decreasing in the subsurface samples. The decrease in EC with increase in depth may be due to the accumulation of salts from upper surface to deeper layer of the soils. Higher EC may be attributed to the application of fertilizers, decomposition of litter and mineral salts enrichment which was in acceptance with the results of previous works [22].

Table 3. Effect of various agroforestry systems on soil ph, electrical conductivity and organic carbon

Agroforestry systems	Soil pH		Soil EC (dSm^{-1})		Soil Organic Carbon (g/kg)	
	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm
Melia dubia + Sorghum	8.21	8.04	0.18	0.14	3.00	2.40
Dalbergia sissoo + Sorghum	8.16	8.01	0.21	0.19	3.30	2.30
Casuarina equisetifolia + Sorghum	8.73	8.54	0.22	0.20	3.90	3.00
Melia dubia + Turmeric	8.32	8.19	0.17	0.13	4.20	3.30
Eucalyptus spp + Curry leaf	8.54	8.29	0.25	0.23	2.40	1.80
Toona ciliata + turmeric	8.47	8.33	0.24	0.21	4.30	3.10
Acacia leucophloea + Guinea grass	7.45	7.28	0.16	0.13	7.40	6.20
Glyricidia sepium + Co (BN) grass	8.07	7.98	0.23	0.20	6.30	5.40
Melia dubia + Hedge Lucerne	8.12	8.06	0.19	0.17	3.30	2.70
Mean	8.23	8.08	0.21	0.18	4.23	3.36
SEd	0.1638	0.1573	0.0049	0.0055	0.0605	0.0619
CD (.05)	0.3476	0.3335	0.0103	0.0117	0.1282	0.1312

3.3 Soil Organic Carbon

From the data (Table 3), it was found that the maximum value of organic carbon in the surface sample was 7.40 g/kg and the minimum value was 2.40 g/kg with a mean of 4.20 g/kg. In subsurface samples, the value of organic carbon ranges from 1.80 g/kg to 6.20 g/kg with a mean of 3.36 g/kg. The highest organic carbon content was recorded in *Acacia leucophloea* + Guinea grass system where as the lowest value was found in *Eucalyptus* spp + Curry leaf system in surface as well as subsurface layer. Litter fall in the agroforestry species significantly increases the SOC content in the soil and improves the microbial activity in the soil. The higher SOC content under tree-based systems may also be due to annual recycling of fine root biomass and root exudates [23]. As litter fall was only in surface depth, the organic carbon content was decreasing with increase in soil depth.

3.4 Soil Available Nitrogen, Available Phosphorus and Available Potassium

From the data on Table 4, it was identified that there was an influence of different agroforestry system with regards to soil available nitrogen. The available nitrogen content ranged from 213 kg ha^{-1} to 325 kg ha^{-1} with a mean value of 266 kg ha^{-1} in surface soil. In case of subsurface samples, the available nitrogen content ranged from 179 kg ha^{-1} to 302 kg ha^{-1} with a mean value of 237 kg ha^{-1}. The highest nitrogen content was recorded in *Acacia leucophloea* + Guinea grass system and the lowest value was found in *Dalbergia sissoo* + Sorghum system in both surface and subsurface samples. The available N content in soil increased under various agro-forestry systems which is mainly due to the addition of organic matter in soil in the form of litter fall and fine root biomass. The nutrient release in soil by the mineralization process of organic matter increases the nutrient status of soil in surface samples. Due to lack of organic matter addition in the lower layers where mineralization will be limited due to minimum biological activity, hence the available nitrogen content was lower in the subsurface samples [24]. Pertaining to the data, it was found that the soil available phosphorus was decreasing with increasing in depth. The maximum value of available phosphorus 38.6 Kg ha^{-1} in surface and 32.5 kg ha^{-1} in subsurface sample with a mean value of 22.2 kg ha^{-1}. The minimum value recorded for available phosphorus was 13.3 kg ha^{-1} in surface and 11.9 kg ha^{-1} in subsurface. The mean value of available P in surface depth was 22.2 kg $ha^{-1}$and 19.4 kg ha^{-1}in subsurface layer. *Acacia leucophloea* + Guinea grass system was found to record higher phosphorus value and *Casuarina equisetifolia* + Sorghum system recorded lower phosphorus value in both surface and subsurface sample. In this study, the available phosphorus content was decreasing with increasing depth which is similar to the findings of [21] they also observed same trend in their agroforestry system studies. The available potassium content of the soil ranges from 101 kg ha^{-1} to 226 kg ha^{-1} with a mean value of 133 kg ha^{-1} in surface samples. In subsurface sample, the available potassium ranges from 94 kg ha^{-1} to 203 kg ha^{-1} with a mean value of 123 kg ha^{-1}. The available potassium content was decreasing with successive depth under all the agroforestry systems. The higher potassium content was recorded in *Acacia leucophloea* + Guinea grass system and the lower value of available potassium was found in *Casuarina equisetifolia* + Sorghum system. Higher K content may be due to the presence of higher organic matter. Decrease of soil potassium with increase in depth was noticed which is similar with the findings of [25]. This decrease of K with increase in depth may be the reason of receiving limited organic matter which decreases the potassium content of the soil.

3.5 Available Micro Nutrients

Iron values in the samples collected ranged from 0.72 mg kg^{-1} to 2.68 mg kg^{-1} with a mean value of 1.29 mg kg^{-1} in surface sample. At 30-60 cm depth the iron values varied from 0.66 mg kg^{-1} to 2.57 mg kg^{-1} with a mean of 1.22 mg kg^{-1}. The values decreased with depth among the agroforestry systems. The highest value was seen in *Acacia leucophloea* + Guinea grass system. The lowest value was seen in *Casuarina equisetifolia* + Sorghum. Zinc values in the agroforestry systems at 0-30 cm depth ranged from 0.13mg kg^{-1} to 0.70 mg kg^{-1} with a mean value of 0.28 mg kg^{-1} Whereas, at 30-60 cm depth the values ranged from 0.08 mg kg^{-1} to 0.64 mg kg^{-1} with a mean of 0.23 mg kg^{-1}. The highest value was seen in the agroforestry system *Acacia leucophloea* + Guinea grass system. The lowest value was seen in *Casuarina equisetifolia* + Sorghum system. The zinc values decreased with depth which is similar to the trend that was observed in iron. The soil samples collected were analysed for copper and the values at surface samples ranged from 0.15 mg kg^{-1} to 1.96 mg kg^{-1} with a mean value of 0.77

mg kg^{-1}. In case of subsurface samples, the copper values ranged from 0.08 mg kg^{-1} to 1.86 mg kg^{-1} with a mean of 0.71 mg kg^{-1}. The maximum copper was found in *Acacia leucophloea* + Guinea grass agroforestry system and the minimum amount of copper was found to be noticed in *Casuarina equisetifolia* + Sorghum system in surface as well as subsurface samples. From the values it is evident that copper decreased with the depth. Manganese when analysed ranged from 0.26 mg kg^{-1} to 0.69 mg kg^{-1} with an average of 0.44 mg kg^{-1}. The soil samples collected from 30-60 cm depth ranged from 0.22 mg kg^{-1}to 0.65 mg kg^{-1} with a mean of 0.40 mg kg^{-1}. The uppermost value was recorded in the *Acacia leucophloea* + Guinea grass agroforestry system and lower most value was recorded in *Casuarina equisetifolia* + Sorghum system under both the depth and the values were noticed to decrease with increase in depth. Availability of micronutrients mainly depend upon the presence of organic matter content which prevents the oxidation and precipitation of micronutrients in the soil [26]. Since *Acacia leucophloea* + Guinea grass systems contains higher SOC, similarly it contains higher quantity of available micronutrients in both the depth when compared with other agroforestry systems.

Table 4. Effect of various agroforestry systems on soil available nitrogen, available phosphorus and available potassium

Agroforestry systems	Nitrogen (kg ha^{-1})		Phosphorus (kg ha^{-1})		Potassium (kg ha^{-1})	
	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm
Melia dubia + Sorghum	246	213	17.1	15.4	119	111
Dalbergia sissoo + Sorghum	213	179	16.9	14.8	110	99
Casuarina equisetifolia + Sorghum	224	190	13.3	11.9	101	94
Melia dubia + Turmeric	269	246	21.4	19.9	112	108
Eucalyptus spp + Curry leaf	269	235	15.5	12.3	123	117
Toona ciliata + turmeric	280	254	18.2	16.7	107	100
Acacia leucophloea + Guinea grass	325	302	22.5	20.9	226	203
Glyricidia sepium + Co (BN) grass	314	291	21.7	20.1	182	170
Melia dubia + Hedge Lucerne	258	224	20.5	17.8	122	113
Mean	266	237	18.6	16.6	133	123
SEd	6.3407	3.7034	0.4032	0.3469	2.4396	2.5072
CD (.05)	13.4419	7.8509	0.8547	0.7354	5.1718	5.3151

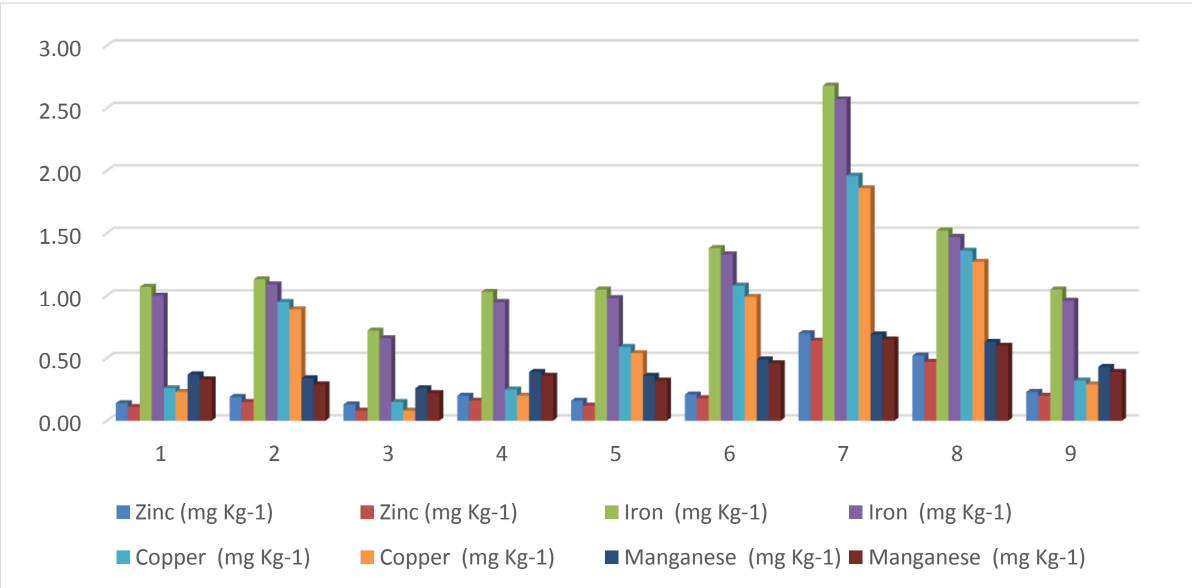

Fig. 1. Effect of various agroforestry systems on Soil Available Micronutrients

4. CONCLUSION

From the investigation, it was observed that the soil quality parameters differ significantly due to the effect of various agroforestry systems. Each tree combination had its effect on soil quality parameters. It was observed that, most of the parameters show higher value in surface samples than subsurface samples except bulk density. Under various agroforestry systems taken for research work, *Acacia leucophloea* + Guinea grass agroforestry system shows higher fertility status than other agroforestry systems as it contains higher available nutrient content (available nitrogen, available phosphorus, available potassium and available micronutrients), better soil physical (Bulk density, porosity) and physico chemical (Soil pH, Electrical conductivity) properties than others. The agroforestry system *Casuarina equisetifolia* + Sorghum shows minimum value in most of the soil quality parameters than other agroforestry systems taken into research. Hence, the findings from the research showed that *Acacia leucophloea* + Guinea grass agroforestry system would be a promising agroforestry system to improve the soil physical and chemical properties in order to sustain the soil quality. Since further more investigation is needed by including many other agroforestry systems and soil biological properties to define a better agroforestry system for proper land use and recycling of soil nutrient status which in turn enhances the fertility of the soil.

ACKNOWLEDGEMENT

We would like to extend our sincere gratitude to the Department of Soil Science and Agricultural Chemistry, Coimbatore for providing laboratory facilities to carry out the research work. We also extend our thanks to Department of Agroforestry, Forest College and Research Institute, Mettupalayam for permitting in soil sample collection.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Saravanan, S & Berry, Nanita. Agroforestry practices in Tamil Nadu, India - a boon for farmers for livelihood security. Current Science. 2021;120:10
2. Jose S. Agroforestry for ecosystem services and environmental benefits: an overview. Agrofor. Syst. 2009;76(1):1–10. DOI: 10.1007/s10457-009-9229-7
3. Saravanan S. Documentation of agroforestry models in Tamil Nadu. Agro-forestry Project completion report, Department of Forestry, Land Use and Climate Change, Institute of Forest Genetics and Tree Breeding, Coimbatore, India; 2010
4. Karlen DL, Mausbach MJ, Doran JW, Cline RG, Harris RF, Schuman GE. Soil quality: A concept, definition, and framework for evaluation (a guest editorial). Soil Science Society of America Journal. 1997 Jan; 61(1):4-10.
5. Dollinger J, Jose S. Agroforestry for soil health. Agroforestry Systems. 2018 Apr; 92(2):213-9.
6. Gupta V. Role of agroforestry in soil conservation and soil health management: A review. Journal of Pharmacognosy and Phytochemistry. 2020;9:555-558.
7. Mganga Kevin Z, Bahar S Razavi, Yakov Kuzyakov. Land use affects soil biochemical properties in Mt. Kilimanjaro region. Catena. 2016;141:22-29.
8. Rivest, David, MirenLorente, Alain Olivier, and Christian Messier. Soil biochemical properties and microbial resilience in agroforestry systems: Effects on wheat growth under controlled drought and flooding conditions. Science of the Total Environment. 2013;463:51-60.
9. Behera, Laxmikanta, Manas Ranjan Nayak, Dhiraji Patel, Abhishek Mehta, Satish Kumar Sinha, and Rajesh Gunaga. Agroforestry practices for physiological amelioration of salt affected soils. Journal of Plant Stress Physiology. 2015;1:13-18.
10. Sileshi, Gudeta Weldesemayat, Mafongoya PL, Arun Jyoti Nath. Agroforestry systems for improving nutrient recycling and soil fertility on degraded lands. In Agroforestry for Degraded Landscapes. Springer, Singapore. 2020; 225-253.
11. Gupta RP, Dakshinamurthi C. Procedures for physical Analysis of soils. IARI, New Delhi; 1981.
12. Jackson M. Soil chemical analysis, advanced course: publ. by the author, Dept. Soil Science, Univ. Wisc., Madison, Wisconsin; 1973.
13. Walkley Aldous, I Armstrong Black. An examination of the Degtjareff method for

determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science. 1934; 37(1):29-38.
14. Subbiah B, Asija GL. Alkaline permanganate method of available nitrogen determination. Current Science. 1956;25:259.
15. Olsen Sterling Robertson. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. US Department of Agriculture; 1954.
16. Stanford George, Leah English. Use of the flame photometer in rapid soil tests for K and Ca. Agronomy Journal. 1949;41(9): 446-447.
17. Lindsay WL, Norvell W. Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Science Society of America Journal. 1978;42(3):421-428.
18. 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):2813-21.
19. Nayak AK, Khan U, Sharma DK, Mishra VK, Sharma CJ, Singh R, Singh G. Spatial variability of soil physicchemical properties under Prosopis juliflora and Terminalia arjuna in sodic soil of Indo-gangetic plains. Journal of Indian Society of Soil Science. 2009;57(1):31- 38.
20. Tandel MB, Kukaldia BN, Kolambe Jadeja DB. Influence of tree cover on physical properties of soil. Indian Forester. 2009; 135(5):420-424.
21. Baswant Sushant Pralhad, P Rajendran, MP Divya, R Rajeswari, G Thangamani and Ramaha, C. Assessing the Effect of Different Agroforestry Practices on Soil Physico-chemical Properties and Microbial Activity. Int. J. Curr. Microbiol. App. Sci. 2020;9(12):2802-2816.
22. MeshramNandkishor, Vijay Dalvi, Ashish Shigwan, Satish Narkhade. Microbial community and soil fertility status as influenced by different nitrogen fixing tree species in alfisol. Indian Journal of Agroforestry. 2016;18(2):53-58.
23. Arora, Raavi, Vivek Sharma, Sandeep Sharma, Asima Maini, Dhaliwal SS. Temporal changes in soil biochemical properties with seasons under rainfed land use systems in Shiwalik foothills of northwest India. Agroforestry Systems. 2021;95(8):1479-1491.
24. Sharma, N.K., Ranjan, Rajeev, Pramanik, Monalisha, Alam NM. Dynamics of soil physical and chemical properties under wheat (*Triticum aestivum* L.)-poplar (*Populus deltoids* M.) based agroforestry system. Indian Journal of Agroforestry. 2016;18(2):41-46.
25. Mishra A, Swamy S. Eco-physiology, productivity and nutrient uptake of soyabean under Populus deltoidesbased agri-silviculture system. Journal of Soils and Crops. 2007;17(2):217-224.
26. Abraham J. Soil health in different land use systems in comparison to a virgin forest in a tropical region of Kerala. Rubber Sci. 2015;28:8-21.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/88514