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Comparative soil nutrient status of agroforestry block plantations in semi-arid Telangana

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Abstract

Trees species wise agroforestry block plantations were studied for soil properties. The tree species under block plantations were tamarind, malabar neem, teak, eucalyptus, simarouba, neem and pongamia planted in the year 2009 at AICRP on Agroforestry research blocks, Professor Jayashankar Telangana Agricultural University, Hyderabad, Telangana, India. The soils of all the tree based land use systems are slightly acidic in reaction (pH 6.03 - 6.8) and the electrical conductivity ranged from 0.21 dS m⁻¹- 0.38 dS m⁻¹, which is normal in range. Significantly higher soil organic carbon was recorded under tamarind (5.04 g kg⁻¹) and lower soil organic carbon was recorded under teak block plantation (2.83 g kg⁻¹). Significantly higher values of soil available N and P₂O₅ were recorded in pongamia block plantation (201 kg ha⁻¹, 36 kg ha⁻¹, respectively) and lower soil available N recorded under teak and melia block plantations (175 kg ha⁻¹, 30 kg ha⁻¹, respectively). Significantly higher values of soil available K₂O was observed in melia (573 kg ha⁻¹) at 0-15cm depth over all other plantations. In all the tree-based land use systems, soil macro nutrients (OC, N, P₂O₅ and K₂O) decreased from surface soil (0 - 15 cm) to subsurface soil layers (15 - 30 cm, 30 - 45 cm). Significant and positive interaction was observed between the land use systems and soil depth. Significantly higher values of organic carbon fractions (C_{VL}- 3.07 g kg⁻¹, C_L- 2.75 g kg⁻¹, C_{LL}- 3.10 g kg⁻¹, C_{NL}- 2.64 g kg⁻¹ and total organic carbon - 11.56 g kg⁻¹), microbial biomass carbon (231.43 mg kg⁻¹) were recorded in tamarind block plantation and lower values of carbon fractions were recorded in simarouba block plantation (C_{VL}-3.07 g kg⁻¹, C_L-1.65 g kg⁻¹, C_{LL}- 1.91 g kg⁻¹, C_{NL} 1.93 g kg⁻¹) and teak block plantation (C_{VL}-2.82 g kg⁻¹, C_L-1.80 g kg⁻¹, C_{LL}- 2.24 g kg⁻¹, C_{NL} 1.70 g kg⁻¹ and total organic carbon -8.56 g kg⁻¹). Soil organic carbon was significantly and positively correlated with all available nutrients (0.63*) and total organic carbon (0.986**).

Keywords: Block Plantations, soil organic carbon, available nutrients, total organic carbon, soil carbon pools and microbial biomass carbon

Introduction

The atmospheric CO₂ concentration has increased from its pre-industrial concentration of about 280 μmol mol⁻¹ to over 425 μmol mol⁻¹ by 2025 (NOAA, 2025) [1], with a continuous upward trajectory and further accelerating annual increases. This ongoing increase in atmospheric CO₂ concentration, together with increases in other greenhouse gases (GHGs), is raising global average temperatures. If these ongoing emissions cannot be halted, temperature will continue to increase over the 21st century. To reach the goal of keeping the rise in temperature below 1.5 °C, drastic reductions in emissions must be accompanied by the removal of a large quantity of carbon dioxide from the atmosphere (IPCC, 2018) [2]. According to the Intergovernmental Panel on Climate Change (IPCC) (Lewis *et al.*, 2019) [3] about 730 billion tons of CO₂ must be removed from the atmosphere within this century. Most carbon is absorbed and fixed in terrestrial and aquatic ecosystems (Singh *et al.*, 2015) [4]. Terrestrial ecosystems store about 2100 GtC in living organisms, litter and soil organic matter, which is almost three times the amount that currently exists in the atmosphere. The world's forests store approximately 861 GtC, with 44% in soil (up to one-meter depth), 42% in living biomass (above- and belowground), 8% in dead wood, and 5% in litter. In total, this is equivalent to nearly a century's worth of the current annual fossil fuel emissions at the mondial level (Pan *et al.*, 2011) [5]. Soils constitute the largest organic C sink on Earth and their capacity to act as an atmospheric

CO₂-C sink is recognized globally (Minasny *et al.* 2017) [6]. One of the keyways to limit the impacts of climate change is to reduce the amount of carbon released into the atmosphere.

Land use/land cover change is one of the key factors which affect the soil organic carbon pool remarkably. The reason for this being the rate of input (e.g. plant litter) and rate of output (e.g. SOC mineralization) of soil organic matter (SOM), because of alterations in plant community and land management practice (Poeplau and Don, 2013) [7]. When natural forests are converted to croplands, the soil structure gets disrupted enhancing the mineralization of organic matter by microbes subsequently leading to SOC loss (Golchin and Asgari, 2008) [8].

To understand how soil organic carbon (SOC) is lost or stabilized in soil, SOC stocks in soil can be classified into different functional pools depending on their varying residence time viz. labile and non-labile pool. Labile pool (active pool) is the most sensitive pool available relatively in small proportion as it is easily affected by fluctuation in environmental conditions. They rapidly decompose and get oxidized easily with any changes in land use practice (Haynes, 2005) [9]. Another SOC pool is the non-labile pool (passive pool) which is more stable and recalcitrant fraction of SOC forming organic-mineral complexes with soil mineral and gets decomposed slowly by microbial activity (Wiesenberg *et al.*, 2010) [10]. Thus, the labile SOC pools serve a better indicator of soil quality to assess variations caused by land use changes (Vieira *et al.*, 2007) [11], while the non-labile SOC pools add to the total organic carbon stocks (Chan *et al.*, 2001) [12]. In an ecosystem functioning, land use change affects SOC pools to determine whether soil acts as sinks or sources of C in the global C cycle (Degryze *et al.*, 2004) [13]. Trees are beneficial to storing carbon, which is a major contributor to climate change. The more mature a tree is, the more carbon it stores in its woody biomass (Schwab, 2009) [14]. Although trees are not the single answer, healthy and mature trees have the potential to make significant carbon mitigation returns. In view of the importance of trees in storing soil organic carbon further improving the soil nutrient status the present study was undertaken under different tree-based land use systems.

Materials and Methods

Block Plantations of Eucalyptus, Pongamia, Neem, Tamarind, Teak, *Melia dubia* and Simarouba planted in 2009, which were maintained at AICRP on Agroforestry, Rajendranagar, Professor Jayashankar Telangana Agricultural University, Telangana, India were studied for soil nutrient status in the year 2023. All the plantations were maintained naturally without any irrigation, fertilizer application and other cultural operations. After fourteen years, the organic carbon accumulation and different pools of organic carbon under different block plantations were studied. The climate of the study region is semi-arid tropics. A total of 63 soil samples were collected from different land uses in three depths (0-15 cm, 15-30 cm and 30-45 cm). The samples collected were shade dried, processed and sieved for further analysis. The soil parameters were analyzed using standard methods, i.e., The soil pH and EC were measured using 1:2.5 soil water suspension and the EC results were expressed in dS m⁻¹ at 25°C (Jackson, 1973) [15], available organic carbon by wet oxidation method given by Walkley and Black (1934) [16]. The different fractions of organic carbon were analyzed following standard procedures (Mandal *et al.*, 2008) [17].

Results and Discussion

Soil parameters under block plantations of different agroforestry tree species

Trees species wise agroforestry block plantations were studied

for soil properties. Soil pH, EC and OC under block plantations of different agroforestry tree species were presented in the Table.1

1. Soil pH and EC

The soils of all the tree based land use systems are slightly acidic in reaction (pH 6.03 - 6.8) and the electrical conductivity ranged from 0.21 dS m⁻¹ - 0.38 dS m⁻¹ (Table 1), which is normal in range for all the land use systems as per USDA classification. In all the block plantations studied, soil pH increases from surface soil (0 - 15 cm - 6.4) to subsurface soil layers (15 - 30 cm - 6.51, 30 - 45 cm - 6.67) this is due to leaching of bases from upper soil layer to lower soil layer and decrease of organic matter from upper to lower depths. The lower soil pH in upper layer is due to higher organic matter content which releases organic acids during decomposition. There is an interaction between the land use systems and soil depths. Significantly lower value of soil pH at 0-15cm was recorded in pongamia block plantation (6.03) and higher value was recorded at 30-45cm in melia and teak (6.93). Among the land use systems soil EC decreases from surface soil (0 - 15 cm - 0.31 dS m⁻¹) to subsurface soil layers (15 - 30 cm - 0.29 dS m⁻¹, 30 - 45 cm - 0.27 dS m⁻¹). There is interaction between the land use systems and soil depths. Lower EC values were found at all depths in tamarind block plantation due to uptake of bases by tree biomass, acidic nature of litter after its decomposition and leaching of bases to lower soil layers (Tufa *et al.*, 2019) [18]; Geetha *et al.*, 2021 [19] and Varshita *et al.*, 2023) [20].

2. Organic carbon (g kg⁻¹)

The soil organic carbon contents were significantly affected by different tree based land use systems. Significantly higher soil organic carbon was recorded under tamarind block plantation (5.04 g kg⁻¹) and the lower soil organic carbon was recorded under teak block plantation (2.83 g kg⁻¹). In all the tree-based land use systems, soil organic carbon decreased from surface soil (0 - 15 cm - 5.85 g kg⁻¹) to subsurface soil layers (15 - 30 cm - 4.06 g kg⁻¹, 30 - 45 cm - 2.99 g kg⁻¹). This may be due to more additions of carbon inputs (leaf litter) in the upper layers of tree-based systems. The results are in conformity with Singh *et al.* (2021) [21] and Varshitha *et al.* (2023) [20]. There is an interaction between the land use systems and soil depth. However, significantly higher value of soil organic carbon was recorded in tamarind block plantation (5.04 g kg⁻¹) at 0-15cm depth, where more residue is added through leaf litter. Lower organic carbon value was recorded in teak block plantation at 30-45cm depth due to less leaf litter addition. Higher soil organic carbon recorded in tamarind block plantation where more residue is added through leaf litter and lower in teak with lower canopy which added less litter, that was the reason for low soil organic carbon. The results are in conformity with Lu *et al.*, 2021 [22] findings, which indicated that the high soil C accumulation under evergreen trees can result from low litter decomposability, accompanied by low soil CO₂ efflux. Furthermore, high root production by evergreen trees compared to deciduous trees, likely reflects the high percentage of organic matter under evergreen trees. Variations in organic carbon content in soils under various tree species is attributed to the age of plantation and amount of litterfall, their biochemical composition and the rate of their decomposition (Bhavya *et al.*, 2018 [23] and Varshita *et al.*, 2023) [20].

3. Soil Available N, P₂O₅ and K₂O (kg ha⁻¹)

Significantly higher values of soil available N and P₂O₅ were recorded in pongamia block plantation (201 kg ha⁻¹, 36 kg ha⁻¹, respectively) and lower soil available N recorded under teak and

melia block plantations (175 kg ha⁻¹, 30 kg ha⁻¹, respectively) (Table 2). Significantly higher values of soil available K₂O were observed in melia block plantation (573 kg ha⁻¹) at 0-15cm depth over all other plantations. Among all the tree-based land use systems, soil macro nutrients (N, P₂O₅ and K₂O) decreased from surface soil (0 - 15 cm) to subsurface soil layers (15 - 30 cm, 30 - 45 cm). There is an interaction between the land use systems and soil depth. Higher soil available N recorded in tamarind block plantation (244 kg ha⁻¹) at 0-15cm depth, available P₂O₅ was recorded in pongamia block plantation (45 kg ha⁻¹) at 0-15cm depth where more residue is added through leaf litter. Lower soil available N value (134 kg ha⁻¹) was recorded in teak block plantation at 30-45cm depth due to less leaf litter addition (Table 26). A similar outcome of higher availability of N, P and K on surface layers than subsurface horizon was reported by Geetha and her coworkers in 2021^[19].

4. Soil organic carbon pools, total organic carbon and microbial biomass carbon (g kg⁻¹)

Soil organic carbon pools *i.e.*, very labile carbon (C_{VL}), labile (C_L), less labile (C_{LL}), non labile (C_{NL}), Microbial biomass carbon and total organic carbon (TOC) under different tree based land use systems are presented in Table 3 and 4.

Significantly higher values of organic carbon fractions were recorded in tamarind block plantation (C_{VL} - 3.07 g kg⁻¹, C_L - 2.75 g kg⁻¹, C_{LL} - 3.10 g kg⁻¹, C_{NL} - 2.64 g kg⁻¹ and total organic carbon - 11.56 g kg⁻¹) and lower values of carbon fractions were recorded in simarouba block plantation (C_{VL}-3.07 g kg⁻¹, C_L-1.65 g kg⁻¹, C_{LL}- 1.91 g kg⁻¹, C_{NL} 1.93 g kg⁻¹) and teak block plantation (C_{VL}-2.82 g kg⁻¹, C_L-1.80 g kg⁻¹, C_{LL}- 2.24 g kg⁻¹, C_{NL} 1.70 g kg⁻¹ and total organic carbon -8.56 g kg⁻¹). Soil organic carbon pools and total organic carbon decreased from surface to

subsurface soil layers in all the land use systems. Soil carbon buildup under any land use type is the balance between carbon inputs (litter fall deposits, crop residues, root exudates, root biomass and manure) and carbon losses (respiration by soil organisms) determined by the residue turnover, their quality and decomposition rate (Ranch and Schlesinger, 1992) ^[24]. Soil organic carbon was significantly and positively correlated with all available nutrients (0.63) and total organic carbon (0.986**). Significantly higher microbial biomass carbon was recorded in tamarind block plantation 231.43 mg kg⁻¹ and lower microbial biomass carbon was recorded under all other tree based land use systems except melia. Soil microbial biomass carbon decreased from surface to subsurface soil layers in all the land use systems. Interaction between land use systems and soil depths was observed for all carbon pools. Significantly higher values of C_{VL}, C_L and C_{NL} were recorded under tamarind block plantation *i.e.*, 4.31 g kg⁻¹, 3.45 g kg⁻¹ and 3.77 g kg⁻¹ at 0 - 15 cm depth, respectively over all other tree based land use systems at all depths. Significantly higher values of C_{LL} recorded under tamarind and pongamia block plantation (3.86 g kg⁻¹) at 0 - 15 cm depth over all other tree based land use systems at all depths. Significantly higher microbial biomass carbon was recorded in tamarind block plantation 231.43 mg kg⁻¹ which was on par with melia and significantly differed from all other tree based land use systems. Soil microbial biomass carbon decreased from surface to subsurface soil layers in all the land use systems. The increase of microbial biomass carbon under tree-based systems may be due to greater soil moisture and soil microbial diversity. The quantity and quality of rhizodeposition released by various tree species might favor an increase in microbial biomass carbon and its transformation (Singh *et al.*, 2021) ^[21].

Table 1: Soil pH, EC and OC under block plantations of different agroforestry tree species (2023-24)

Land use systems	pH				EC (dS m ⁻¹)				OC (g kg ⁻¹)			
	0 - 15 cm	15 - 30 cm	30 - 45 cm	Mean (LUS)	0 - 15 cm	15 - 30 cm	30 - 45 cm	Mean (LUS)	0 - 15 cm	15 - 30 cm	30 - 45 cm	Mean (LUS)
Tamarind	6.24	6.41	6.53	6.39	0.23	0.22	0.21	0.22	6.32	5.19	3.63	5.04
Melia	6.8	6.86	6.93	6.86	0.40	0.36	0.36	0.37	6.08	4.06	3.14	4.43
Teak	6.6	6.80	6.93	6.78	0.4	0.38	0.37	0.38	4.97	2.46	1.07	2.83
Neem	6.65	6.76	6.87	6.76	0.316	0.33	0.31	0.32	5.17	4.47	3.11	4.25
Eucalyptus	6.26	6.23	6.48	6.32	0.32	0.26	0.24	0.27	5.68	4.69	3.63	4.66
Pongamia	6.03	6.32	6.51	6.29	0.23	0.20	0.2	0.21	5.52	4.46	3.577	4.52
Simarouba	6.23	6.23	6.46	6.30	0.3	0.24	0.22	0.25	5.303	3.06	2.773	3.71
Mean (Depth)	6.40	6.51	6.67		0.314	0.289	0.27		5.58	4.06	2.991	
	S.Em±	C.D (p=0.05)			S.Em±	C.D (p=0.05)			S.Em±	C.D (p=0.05)		
LUS	0.03	0.08			0.005	0.015			0.107	0.307		
Depth	0.02	0.05			0.003	0.01			0.07	0.201		
LUS × Depth	0.05	0.14			0.009	0.026			0.185	0.532		

Table 2: Available N, P₂O₅ and K₂O under block plantations of different agroforestry tree species (2023-24)

Land use systems	Available N (kg ha ⁻¹)				Available P ₂ O ₅ (kg ha ⁻¹)				Available K ₂ O (kg ha ⁻¹)			
	0 - 15 cm	15 - 30 cm	30 - 45 cm	Mean (LUS)	0 - 15 cm	15 - 30 cm	30 - 45 cm	Mean (LUS)	0 - 15 cm	15 - 30 cm	30 - 45 cm	Mean (LUS)
Tamarind	244	196	163	201	42	32	25	33	430	280	257	322
Melia	215	162	148	175	43	29	24	32	633	581	504	573
Teak	217	172	134	175	31	28	30	30	437	348	298	361
Neem	219	176	148	181	41	26	23	30	456	431	390	425
Eucalyptus	225	180	171	192	42	33	27	34	430	348	295	358
Pongamia	255	192	153	201	45	36	28	36	536	435	370	447
Simarouba	213	173	155	181	37	31.9	26	32	410	261	235	302
Mean (Depth)	227	179	153		40	31	26		476	383	336	
	S.Em±	C.D (p=0.05)			S.Em±	C.D (p=0.05)			S.Em±	C.D (p=0.05)		
LUS	2.06	6			1.22	4			6.4	19		
Depth	1.35	4			0.79	2			4.2	12		
LUS × Depth	3.57	10			2.11	6			11.2	32		

Table 3: Soil organic carbon pools under block plantations of different agroforestry tree species (2023-24)

Land use systems	Very labile (g kg ⁻¹)				Labile (g kg ⁻¹)				Less labile (g kg ⁻¹)				Non labile (g kg ⁻¹)			
	0-15 cm	15-30 cm	30-45 cm	Mean	0-15 cm	15-30 cm	30-45 cm	Mean	0-15 cm	15-30 cm	30-45 cm	Mean	0-15 cm	15-30 cm	30-45 cm	Mean
Tamarind	4.30	3.85	1.07	3.07	3.45	3.00	1.80	2.75	3.86	2.86	2.57	3.10	3.77	3.10	1.05	2.64
Melia	4.15	3.23	2.62	3.33	3.60	2.25	1.19	2.35	3.43	2.14	2.00	2.52	3.32	2.18	1.38	2.29
Teak	3.54	2.77	2.15	2.82	2.70	1.65	1.05	1.80	3.00	2.14	1.57	2.24	1.56	1.44	2.12	1.70
Neem	3.69	3.08	2.46	3.08	2.70	2.25	0.75	1.90	3.14	3.00	1.57	2.57	2.16	2.57	1.52	2.08
Eucalyptus	4.00	3.54	2.46	3.33	3.15	2.4	1.65	2.40	3.00	2.28	1.57	2.28	3.06	1.33	1.617	2.00
Pongamia	3.54	2.62	2.31	2.82	2.55	1.95	1.35	1.95	3.86	3.29	2.72	3.29	2.45	1.55	2.19	2.06
Simarouba	3.85	2.92	2.46	3.077	2.7	2.097	0.15	1.65	2.57	1.71	1.43	1.906	2.18	1.96	1.66	1.93
Mean (Depth)	3.87	3.14	2.22		2.98	2.23	1.14		3.27	2.49	1.92		2.643	2.019	1.648	
	S.Em±	C.D (p=0.05)			S.Em ±	C.D (p=0.05)			S.Em ±	C.D (p=0.05)			S.Em ±	C.D (p=0.05)		
LUS	0.028	0.079			0.019	0.053			0.019	0.055			0.018	0.05		
Depth	0.018	0.052			0.012	0.035			0.013	0.036			0.012	0.04		
LUS× Depth	0.048	0.137			0.032	0.092			0.033	0.095			0.031	0.09		

Table 4: Total organic carbon and Microbial biomass carbon in soil under block plantations of different agroforestry tree species (2023-24)

Land use systems	Total organic carbon (g kg ⁻¹)				Microbial biomass carbon (mg kg ⁻¹)			
	0-15 cm	15-30 cm	30-45 cm	Mean	0-15 cm	15-30 cm	30-45 cm	Mean
Tamarind	15.4	12.8	6.5	11.6	287.4	235.2	171.1	231.2
Melia	14.5	9.8	7.2	10.5	274.5	235.5	171.4	227.1
Teak	10.8	8.0	6.9	8.6	215.4	159.3	106.6	160.4
Neem	11.7	10.9	6.3	9.6	224.9	166.0	108.7	166.5
Eucalyptus	13.2	9.6	7.3	10.0	247.5	176.2	147.0	190.2
Pongamia	12.4	9.4	8.6	10.1	230.8	180.2	137.1	182.7
Simarouba	11.3	8.7	5.703	8.568	219.3	166.9	111.1	165.8
Mean (Depth)	12.8	9.9	6.9		242.8	188.5	136.1	
	S.Em ±	C.D (p=0.05)			S.Em±	C.D (p=0.05)		
LUS	0.08	0.23			1.80	5.2		
Depth	0.05	0.15			1.18	3.4		
LUS × Depth	0.14	0.39			3.12	9.0		

Conclusion

After fourteen years of growth, the present study revealed that the tamarind tree species recorded the highest levels of available carbon, major nutrients in soil over all other tree species studied. Due to the ability to store greater amounts of carbon in woody tissue, these woody plants exhibit superior carbon sequestration potential compared to other species. Soil organic carbon pools, total organic carbon and microbial organic carbon were recorded higher in tamarind compared to other tree species this variation was due to quantity and quality of rhizodeposition released by various tree species might favor an increase in soil carbon pools, microbial biomass carbon and its transformation. The wood density of *Tamarindus indica* contributes directly to a high carbon storage capacity which in turn leads to high litter fall. The extensive root system contributes to below-ground biomass carbon and helps to stabilize soil organic matter. These factors combine to make tamarind an excellent species for mitigating climate change through both biomass storage and improving soil carbon, particularly in agroforestry systems.

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Competing Interests

Authors have declared that no competing interests exist.

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