Land Use Effect on Soil Organic Carbon Stocks, Microbial Biomass and Basal Respiration in Bundelkhand Region of Central India

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FULL-LENGTH RESEARCH ARTICLE

Land Use Effect on Soil Organic Carbon Stocks, Microbial Biomass and Basal Respiration in Bundelkhand Region of Central India

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Abstract A field experiment was conducted at Indian Council of Agricultural Research (ICAR), Central Agroforestry Research India, Jhansi (U.P.), India, to assess the effect of land use on soil organic carbon stocks (SOCs), microbial biomass carbon (MBC) and basal respiration by selecting sixteen land uses including one cropland system. The results revealed that agroforestry system (AFS) performed better as compared to other land use systems. *Acacia nilotica*-based AFS has the highest SOCs (23.39 Mg ha^{-1}), followed by *Dalbergia sissoo*-based AFS in 0–15 cm soil depth. Among the pure tree plantation, *Jatropha curcas* observed highest SOCs (15.78 Mg ha^{-1}) in 0–15 cm soil depth. However, silvopasture system is able to build up (20.88 Mg ha^{-1}) more SOCs than pure tree plantation systems. Soil MBC was also recorded significantly higher under *Acacia nilotica*-based AFS (764.61 µg g^{-1}) in 0–15 cm depth, while the basal respiration was highest under silvopasture system irrespective of SOCs and MBC. Overall, our study results indicated that the SOC in the different land use systems is not only influenced by difference in age and density of tree but also largely controlled by different management practices adopted. The principal component analysis (PCA) data have shown that two major components (PC1 and PC2) have represented 70.90% of the total variation. And among the parameters, BR followed by soil organic carbon (SOC) was found to be the most sensitive factor while assessing the impact of land use changes on soil quality. We also found that SOCs, microbial biomass carbon and basal respiration have a strong correlation between each other.

Keywords *Acacia nilotica* · Agroforestry system · Climate change · Soil organic carbon stocks · Principal component analysis (PCA)

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Introduction

Climate change and global warming phenomena signal a worldwide warning in terms of food insecurity, displacement of human settlement, human health threats, etc., which curtails the life of human wellbeing and made it miserable. Scientific evidence had shown that the rising level of carbon dioxide (CO_2) in the atmosphere is the primary cause of global warming [22]. Soil stores a large amount of carbon, and among this soil organic carbon (SOC) represents the largest terrestrial organic carbon (C) pool which globally contains over 1550 Pg C at 1 m depth [29]. Thus, consider the soil ecosystem has a huge potential to sequester C [5]. However, the adoption of different agricultural management practices like tillage

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operation, irrigation, incorporation of manures, etc., have an impact on SOC storage in soil [16, 32, 39]. The potentiality of different land use systems on long-term C storage has an immense role while tapping the importance of particular land use system on carbon storage potential in comparison with other land use system [53]. Indeed, the management of organic C and nutrient pools in soil is crucial as it not only affects the plant's survival and its growth but also influences its productivity.

Soil microbial biomass carbon (MBC) as a liable SOC fraction tends to be more sensitive to changes in tree species or land use than the total SOC [31, 49]. Soil respiration is often measured for quantifying microbial activity in soil [54]. Under different land use systems inhabiting the plantation of different tree species can exhibit different litter fall and decomposition pattern [41]. This could differ in their nutrient release pattern and indirectly influence the microbial activity in the soil. For example, Jandl et al. [24] reported that tree species affect SOC stocks due to the amount and quality of organic matter input through litter fall and their root activity. However, Vesterdal et al. [46] claimed that information on effect of tree species on SOC stocks is scattered and needs to be carefully examined.

On this aspect, limited studies have been conducted so far in India and the studies are mostly focused on natural forest or some extent with horticultural crops [25, 26] so information in artificial planted area including agroforestry system is meagre. In Bundelkhand region of central India, land use systems occupied by different tree species have a role in mitigating climate change in terms of carbon sequestration potential. However, information regarding soil organic carbon stocks compared with different land use systems is meagre. Thus, the present study was formulated to assess the effect of different land use systems on soil organic carbon stock potentiality as well as soil microbial activity in different land use systems. As, it is perceived that species composition and associated management practices would have significant influence on the soil nutrient flux and dynamics in different land use systems. Consequently, it will reflect on the microbial activity dependence on system complexity and self-regulating potential of different land use systems. In this context, our proposed investigation was able to decipher the soil properties change including below-ground microbial respiration under varied types of plantations and agroforestry systems. The objective was framed to know about the various species and different age group plantations effects on soil carbon stock and related parameters as there is paucity of information on these aspects, and it would be quite interesting to know the below-ground microbial activity under varied ecological niche. In-depth analyses of enzymatic processes in the soil are still required and would generate more information in the future.

Materials and Methods

Description of Study Site

This study was carried out at ICAR, Central Agroforestry Research Institute (CAFRI), Jhansi, India, in well-established sixteen different land use systems comprising of different tree species (Table 1). The climate of the study area is characterized by hot dry summers and cold winters. The mean annual rainfall of the area is about 900 mm, about 80% of which is received during July and September. The soils are classified as Haplic-Solonetz, very strongly alkaline, loam to clay loam in A and B horizons.

Soil Sampling and Analyses

Soil samples were collected at two depths (0–15, 15–30 cm) using power auger during November 2017 from different land use systems. For obtaining a representative sample, five soil cores were collected from different land use systems and composite soil samples were made for each land use. Samples were transported to the laboratory in polyethylene bags and stored at 4 °C until analysis. Subsamples of air dried soil was used for determining soil pH and electrical conductivity (dS m^{-1}) in soil/distilled water (1:2) suspension mentioned by [23], organic carbon [48]. Soil bulk density was also measured by using gravimetric method [2]. Soil OC stocks (t ha^{-1}) at different soil depths in different land use systems were calculated by using the following formula:

$$\begin{aligned}\text{Soil OC stock}\left(\text{t ha}^{-1}\right) = {} & \text{SOC}\left(\text{g kg}^{-1}\right) \\ & \times \text{bulk density}\left(\text{Mg m}^{-3}\right) \\ & \times \text{soil depth (m)} \times 10\end{aligned}$$

Microbial biomass C was estimated following the chloroform-fumigation and extraction method [47]. Microbial biomass carbon (MBC) in the soil is calculated as MBC (μg g^{-1}) = $(C_F - C_{UF}) / K_{EC}$, where C_F = carbon in fumigated soil; C_{UF} = carbon in unfumigated soil; K_{EC} = 0.35 and represents the efficiency of microbial biomass C [27, 51]. Carbon dioxide evolution rates were measured using the alkali absorption method. Basal soil respiration was determined by the method described by Grisi [18], whereby the CO_2 evolved from soil was absorbed by the NaOH. Next, the NaOH titration was carried out using phenolphthalein after precipitated with barium chloride solution.

Metabolic quotient (qCO_2) and microbial quotient (MQ) were also calculated by using the formula given by Anderson and Domsch [3] as metabolic quotient = BR/MBC and microbial quotient = MBC/SOC, where BR =

Table 1 Status of different land use systems studied

S. no	Land use	Age (Year)	Tree density (tree/ha)	Latitude	Longitude
1	*Anogiessus pendula* plantation	21	400	25°30′49.17″	78°33′12.51″
2	*Azadirachta indica* plantation	17	833	25°30′52.42″	78°33′8.32″
3	*Hardwickia binata* plantation	21	400	25°30′55.46″	78°33′8.83″
4	*Jatropha curcas* plantation	13	1250	25°30′58.86″	78°33′0.73″
5	*Pongamia pinnata* plantation	12	400	25°30′57.88″	78°33′2.58″
6	*Ziziphus jujaba* plantation	7	156	25°30′53.38″	78°32′49.19″
7	*Aegle marmelos*-based AFS	27	166	25°30′55.55″	78°32′54.98″
8	*Acacia nilotica*-based AFS	15	740	25°30′57.53″	78°32′59.58″
9	*Bamboo vulgaris*-based AFS	10	100	25°30′40.55″	78°32′36.73″
10	*Dalbergia sissoo*-based AFS	22	312	25°30′49.58″	78°32′44.43″
11	*Phyllanthus emblica*-based AFS	21	100	25°30′53.81″	78°33′10.1″
12	*Psidium guajava*-based AFS	13	277	25°30′19.54″	78°32′36.53″
13	*Tectona grandis*-based AFS	23	555	25°30′29.53″	78°32′29″
14	Silvopasture	11	400	25°30′44.07″	78°32′59.79″
15	Scrubland	–	–	25°30′36.71″	78°32′45.49″
16	Crop land	–	–	25°30′16.65″	78°32′40.79″

S. no. 1–6 are pure plantations; No. 7–14 are agroforestry systems

basal respiration; SOC = soil organic carbon; MBC = microbial biomass carbon.

Statistical Analysis

One-way analysis of variance (ANOVA) was carried out in accordance with the procedure suggested by Gomez and Gomez [17]. Duncan's multiple range test (DMRT) at $p < 0.05$ was performed to elucidate the effect of land use systems on different soil parameters. Subsequently, LSD at $p < 0.05$ was also carried out to compare the means of different soil parameters in different soil depth of each land use system. DMRT and LSD were done by using SPSS 17.0 (SPSS Inc., Chicago, USA) windows version package. Principal component analysis biplot was prepared by using open software *R*.

Results

Effect of Land use Systems on Bulk Density, pH and Electrical Conductivity (EC)

Soil bulk density was significantly ($p < 0.05$) influenced by different land use systems not by soil depth (Table 2). The bulk density in *Acacia nilotica*-based AFS was the lowest (1.30 Mg m^{-3}), followed by *Dalbergia sissoo*-based AFS (1.32 Mg m^{-3}) and highest under crop land (1.55 Mg m^{-3}) in 0–15 cm depth. A similar trend was also observed in 15–30 cm depth. However, the result indicated that there was no significant difference across the depths. The soil pH of the present study showed wide variation (6.59 to 8.56 in 0–15 cm depth) under different land use systems. *Ziziphus jujuba* plantation has lowest pH (6.59), followed by *Acacia nilotica*-based AFS (6.70) and crop land (8.56) at 0–15 cm soil depth. Similar trend was also observed in 15–30 cm depth. Soil electrical conductivity (dS m^{-1}) was found to be highest under *Psidium guajava*-based AFS (0.233 dS m^{-1}), followed by *Tectona grandis*-based AFS (0.228 dS m^{-1}), while the lowest soil EC (0.058 dS m^{-1}) was recorded under scrubland at 0–15 cm soil depth. *Psidium guajava*-based AFS recorded highest soil EC, followed by cropland at 15–30 cm soil depth.

Effect of land use systems on Soil Organic Carbon, (SOC), Soil Organic Carbon Stocks (SOCS) and Soil Organic Matter (SOM)

The distribution of soil organic carbon (SOC) content (g kg^{-1}) in both soil depth under different land use systems indicated significant differences (Table 3). Overall, we observed that there was decline of 29.35% SOC in 15–30 cm over 0–15 cm irrespective of different land uses. Amongst the land use systems, the 0–15 cm soil layer in *Acacia nilotica*-based agroforestry system had highest SOC (12.00 g kg^{-1}), followed by *Dalbergia sissoo*-based AFS (11.40 g kg^{-1}), the cropland having the lowest (4.20 g kg^{-1}) SOC. Other land use systems which consist

Table 2 Effect of different land use types on pH, EC and bulk density in different depth

Land use	pH			EC (dS m^{-1})			BD (Mg m^{-3})		
	0–15	15–30	Between layers	0–15	15–30	Between layers	0–15	15–30	Between layers
Anogiessus pendula plantation	7.56^{cde}	7.27^{b}	*	0.062^{a}	0.039^{a}	*	1.40^{bcd}	1.44^{abc}	ns
Azadirachta indica plantation	7.42^{c}	7.70^{c}	ns	0.145^{d}	0.083^{bc}	*	1.41^{bcd}	1.48^{bcde}	ns
Hardwickia binata plantation	7.96^{fg}	7.83^{c}	ns	0.119^{c}	0.087^{bc}	*	1.39^{bc}	1.42^{abc}	ns
Jatropha curcas plantation	7.50^{cd}	7.24^{b}	ns	0.109^{c}	0.069^{b}	*	1.46^{def}	1.46^{bcd}	ns
Pongamia pinnata plantation	7.76^{ef}	7.69^{c}	*	0.143^{d}	0.094^{cd}	*	1.47^{ef}	1.48^{bcde}	ns
Ziziphus jujuba plantation	6.59^{a}	6.50^{a}	ns	0.089^{b}	0.083^{bc}	*	1.41^{bcd}	1.45^{abc}	ns
Aegle marmelos-based AFS	8.04^{g}	7.60^{c}	*	0.157^{de}	0.099^{cd}	*	1.42^{cde}	1.45^{abc}	ns
Acacia nilotica-based AFS	6.780^{a}	7.22^{b}	*	0.083^{b}	0.107^{d}	*	1.30^{a}	1.34^{a}	ns
Bamboo vulgaris AFS	7.15^{b}	7.26^{b}	ns	0.074^{ab}	0.050^{a}	*	1.45^{cdef}	1.51^{bcde}	ns
Dalbergia sissoo-based AFS	7.72^{def}	7.59^{c}	ns	0.116^{c}	0.092^{cd}	ns	1.32^{a}	1.36^{ab}	ns
Phyllanthus emblica-based AFS	7.06^{b}	7.28^{b}	ns	0.120^{c}	0.083^{bc}	*	1.39^{bc}	1.43^{abc}	ns
Psidium guajava-based AFS	8.44^{h}	8.59^{e}	ns	0.233^{f}	0.200^{e}	ns	1.35^{ab}	1.41^{abc}	ns
Tectona grandis-based AFS	7.83^{fg}	8.26^{d}	*	0.228^{f}	0.344^{g}	*	1.35^{ab}	1.43^{abc}	ns
Silvopasture	7.80^{efg}	8.11^{d}	*	0.165^{e}	0.206^{e}	*	1.35^{ab}	1.36^{ab}	ns
Scrubland	7.06^{b}	7.06^{b}	ns	0.058^{a}	0.073^{b}	*	1.50^{fg}	1.57^{e}	ns
Crop land	8.56^{h}	8.65^{e}	ns	0.222^{f}	0.243^{f}	ns	1.55^{g}	1.56^{de}	ns
Mean	**7.58**	**7.62**		**0.133**	**0.12**		**1.41**	**1.45**	

Values followed by different alphabets in parenthesis are significantly different at $p < 0.05$ based on Duncan's multiple range test (DMRT). Significance between soil layers of same fruit crop at $p < 0.05$, ns: non-significant

Table 3 Effect of different land use types on SOC, SOCS and SOM in different depth

Land use	SOC (g kg^{-1})			SOCS (Mg ha^{-1})			SOM* (g kg^{-1})		
	0–15	15–30	Between layers	0–15	15–30	Between layers	0–15	15–30	Between layers
Anogiessus pendula plantation	6.40^{cd}	5.40^{cd}	ns	13.45^{cd}	11.67^{bc}	ns	11.03^{cd}	9.31^{cd}	ns
Azadirachta indica plantation	7.20^{d}	5.20^{bcd}	*	15.22^{de}	11.55^{bc}	*	12.41^{d}	8.96^{bcd}	*
Hardwickia binata plantation	7.10^{d}	5.20^{bcd}	*	14.80^{de}	11.08^{bc}	*	12.24^{d}	8.96^{bcd}	*
Jatropha curcas plantation	7.19^{d}	4.80^{b}	*	15.78^{ef}	10.50^{b}	*	12.41^{d}	8.27^{bc}	*
Pongamia pinnata plantation	6.80^{d}	4.70^{b}	*	15.10^{de}	10.36^{b}	*	11.72^{d}	8.10^{b}	*
Ziziphus jujuba plantation	5.71^{bc}	3.40^{a}	*	12.10^{bc}	7.39^{a}	*	9.85^{bc}	5.86^{a}	*
Aegle marmelos-based AFS	7.30^{d}	5.70^{de}	*	15.54^{def}	12.41^{cd}	*	12.58^{d}	9.82^{de}	*
Acacia nilotica-based AFS	12.00^{h}	7.90^{g}	*	23.39^{j}	15.89^{f}	*	20.68^{h}	13.61^{g}	*
Bamboo vulgaris AFS	7.30^{d}	5.40^{cd}	*	15.86^{ef}	12.25^{cd}	*	12.58^{d}	9.31^{cd}	*
Dalbergia sissoo-based AFS	11.40^{h}	7.60^{g}	*	22.55^{ij}	15.49^{f}	*	19.65^{h}	13.10^{fg}	*
Phyllanthus emblica-based AFS	8.50^{e}	5.80^{de}	*	17.71^{fg}	12.44^{cd}	*	14.65^{e}	10.00^{de}	*
Psidium guajava-based AFS	8.60^{ef}	6.30^{e}	*	17.43^{fg}	13.33^{de}	*	14.82^{ef}	10.86^{e}	*
Tectona grandis-based AFS	9.40^{f}	6.90^{f}	*	19.05^{gh}	14.78^{ef}	*	16.20^{f}	11.89^{f}	*
Silvopasture	10.30^{g}	7.30^{fg}	*	20.88^{hi}	15.87^{ef}	*	17.75^{g}	12.58^{fg}	*
Scrubland	4.90^{ab}	3.30^{a}	*	11.01^{ab}	7.76^{a}	*	8.44^{ab}	5.69^{a}	*
Crop land	4.20^{a}	2.90^{a}	*	9.70^{a}	6.80^{a}	*	7.24^{a}	5.00^{a}	*
Mean	**7.77**	**5.49**		**16.22**	**11.85**		**13.39**	**9.46**	

*Organic C (OC) data were converted to organic matter (OM) using the conventional conversion OM = OC × 1.724

Values followed by different alphabets in parenthesis are significantly different at $p < 0.05$ based on Duncan's multiple range test (DMRT). Significance between soil layers of same fruit crop at $p < 0.05$, ns: non-significant of pure plantations of different tree species showed almost similar level of SOC. In sub-surface layer (15–30 cm) the results show similar trend as observed in upper soil depth (0–15 cm).

In 0–15 cm soil profile *Acacia nilotica*-based agroforestry system contained the highest (23.39 Mg ha^{-1}) SOC, followed by *Dalbergia sissoo*-based AFS (22.55 Mg ha^{-1}), with cropland recording the lowest estimate of 9.70 Mg ha^{-1} soil organic carbon stock. We also observed that soil SOCS content was shown significant ($p < 0.05$) differences across soil depth in all the land use systems except in *Anogeissus pendula* plantation. Significantly higher SOCS content is recorded in surface layer than subsurface layer of soil. Overall, irrespective of different land use systems there was decline of 26.94% SOCS in 15–30 cm compared to 0–15 cm depth.

Effect of Land use Systems on Microbial Biomass Carbon (MBC), Basal Respiration (BR), Microbial Quotient (MQ) and Metabolic Quotient (qCO$_2$)

MBC was also found to be significant between the soil layers in all the land use system. *Acacia nilotica*-based agroforestry system has the maximum MBC (764.61 ug g^{-1}), followed by silvopasture system (693.67 ug g^{-1}), and the lowest was observed in cropland (497.42 ug g^{-1}), at the surface layer. All the pure plantations also showed wide variation with *Hardwickia binata* plantation (607.23 ug g^{-1}) which recorded the highest MBC among the pure plantation but which is at par with *Acacia nilotica*-based agroforestry system. The same is followed under subsurface layer for all the land use systems (Fig. 1). Silvopasture system achieved the highest (0.707 µg CO_2-C g^{-1} h^{-1}) basal respiration, followed by *Acacia nilotica*-based agroforestry system (0.686 µg CO_2-C g^{-1} h^{-1}) and lowest in control (0.361 µg CO_2-C g^{-1} h^{-1}). Among the plantations, *Jatropha curcas* plantation (0.508 µg CO_2-C g^{-1} h^{-1}) showed maximum basal respiration with *Ziziphus jujuba* plantation having the lowest basal respiration (0.401 µg CO_2-C g^{-1} h^{-1}). Overall, surface soils have noticed more soil respiration (37.25%) than subsurface soil layer. In surface soil layer, control (cropland) registered the maximum microbial quotient (9.46%), followed by scrubland (9.06%) as compared with other land use system (Fig. 2). However, the lowest microbial quotient was achieved by *Dalbergia sissoo*-based agroforestry system (5.78%), followed by *Acacia nilotica*-based agroforestry system (6.38%). The highest metabolic quotient qCO_2 was observed in silvopasture system (0.00102 qCO_2), followed by Bamboo-based AFS (0.00100 qCO_2) with lowest in *Hardwickia binata* plantation (0.0080 qCO_2). Most of the system showed increasing trend in the sub-surface soil (15–30 cm). Likewise, MQ, qCO_2 also showed significant effect on microbial quotient in some of land use system (*Hardwickia binata* plantation, silvopasture and cropland) by soil depth.

Principal Component Analysis (PCA)

The PCA result revealed that the first and second principal component explains, respectively, 50.0% and 20.9% of total variation. So the total contribution explains by this two component models is 70.9% of total variation (Fig. 3). The first PC showed high loadings of basal respiration (BR), SOC, and SOCs with positive effect and bulk density with negative effect. The second PC was associated with qCO2, pH and EC and expressing positive effects. Nonetheless, the parameter MQ is not showing any significant effect on both PC1 and PC2. The smaller angle between the arrays of variable BR, SOCs, SOC and MBC signifies that the positive association between these variables. On other hand, the larger angles (approach to 180°) of BD with these four variables (BR, SOCs, SOC and MBC) indicated the negative relationship. Similarly qCO2, pH and EC are positively correlated but these three variables are not correlated to BR, SOCs, SOC and MBC as their angle are near to 90°. Samples from the soil depth 0–15 cm are characterized by positive values of PC1 taking into account higher contribution of BR, SOC, SOCS and MBC. On the other hand samples from the soil layer 15-30 cm are characterized by negative values of PC1 taking into account higher contribution of BD. Soil pH and EC were found positive association with PC2 in overall soil depth (0–30 cm).

Discussion

Effect of Land use Systems on Bulk Density, pH and Electrical Conductivity (EC)

Reduction in bulk density on agroforestry-based system or pure tree plantations over crop land might be due to the continuous addition of organic residues from tree component on the surface soil layer. In our study, soil depth had no significant influenced on bulk density in all the land use system; however, it was observed that it was increasing down ward in all studied land use types [15, 43]. Generally, soil pH was lesser in tree-based land use system as compared to cropped land, and this is in conformity with Imoro et al. [21] and Singh et al. [44]. The higher EC on agroforestry land use types might be due to higher nutrient originating from accumulation of soil organic matter. This result is in conformity with Negasa et al. [34].

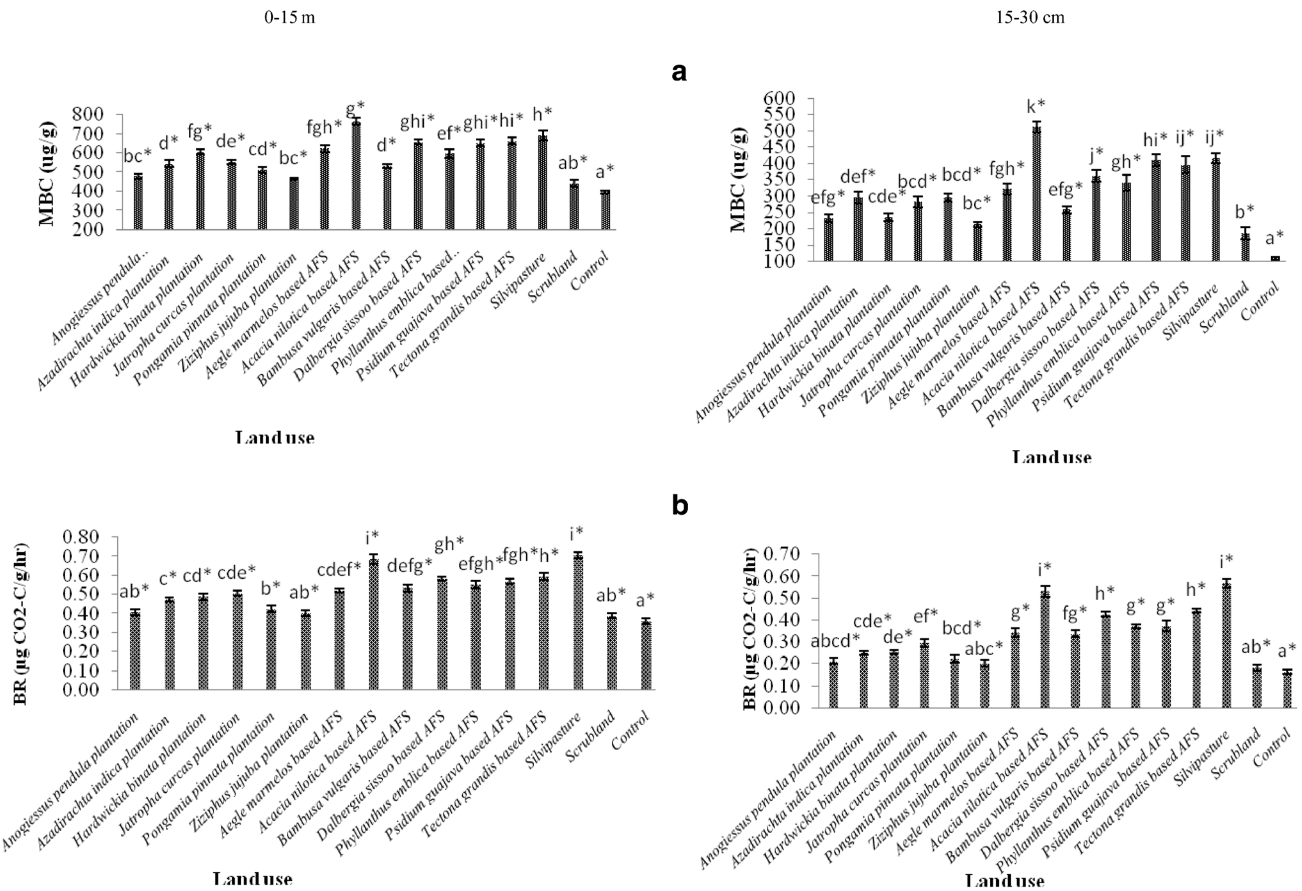


Fig. 1 **a** MBC. **b** Basal respiration in soil at two depths of different land use systems. Each bar represents the mean and standard error (n = 3). Means not sharing a letter in common differ significantly ($p < 0.05$) between same soil layers of different land use systems. Means sharing '*' in common differ significantly ($p < 0.05$) between soil layers of the same land use system

Effect of Land use Systems on SOC, SOCS and SOM

In the present study *Acacia nilotica*-based AFS was significantly higher SOC than other land use system. Owing to less impact of soil or lesser extent of tillage operation in *Acacia nilotica*-based AFS since from long time, this system is incorporated with agricultural crops mostly of mustard which is generally sown by broadcasting method, hence less disturbing soil as compared to other systems. SOC abundance is affected by land use and land cover changes [11, 19]. Pandey et al. [36] reported the SOC content under mid canopy of 12 years old *Acacia nilotica-based* agroforestry system (0–10 cm) in central India of about 11.80 (g kg^{-1}) which is within the range of value observed in our study (12.00 g kg^{-1}) of *Acacia nilotica-based* AFS (15 yrs). Continuous addition of litter and their decomposition in agroforestry systems help in improvement of SOC as compared to tree less system. The SOC content decreased with an increase in soil depth across all land use systems [20, 42]. Variation of SOC under different land use systems could be due to difference in species composition among the land use system and the impact of how long the different system has been practiced. Besides this silvocultural management (e.g. planting density, pruning, thinning), land use history also affects the variation in SOC [33]. However, in our study, *Dalbergia sissoo*-based AFS was the oldest system and in terms of tree density *Jatropha curcas* plantation having the highest number of tree as compared to other system. But these systems have more disturbance effect due to soil tillage operation and application of tree management practices such as pruning as compared to *Acacia nilotica*-based AFS which leads to less biomass overturned. *Acacia nilotica*-based agroforestry system also contributes the highest SOC as compared to other system. On this contention, Cardinael et al. [8] and Newaj et al. [35] also reported that agroforestry system has the potential to store more soil organic carbon stocks than the agricultural lands. Tumwebaze and Byakagaba [45] also observed that coffee-based agroforestry systems have more SOCS than coffee monocropping.

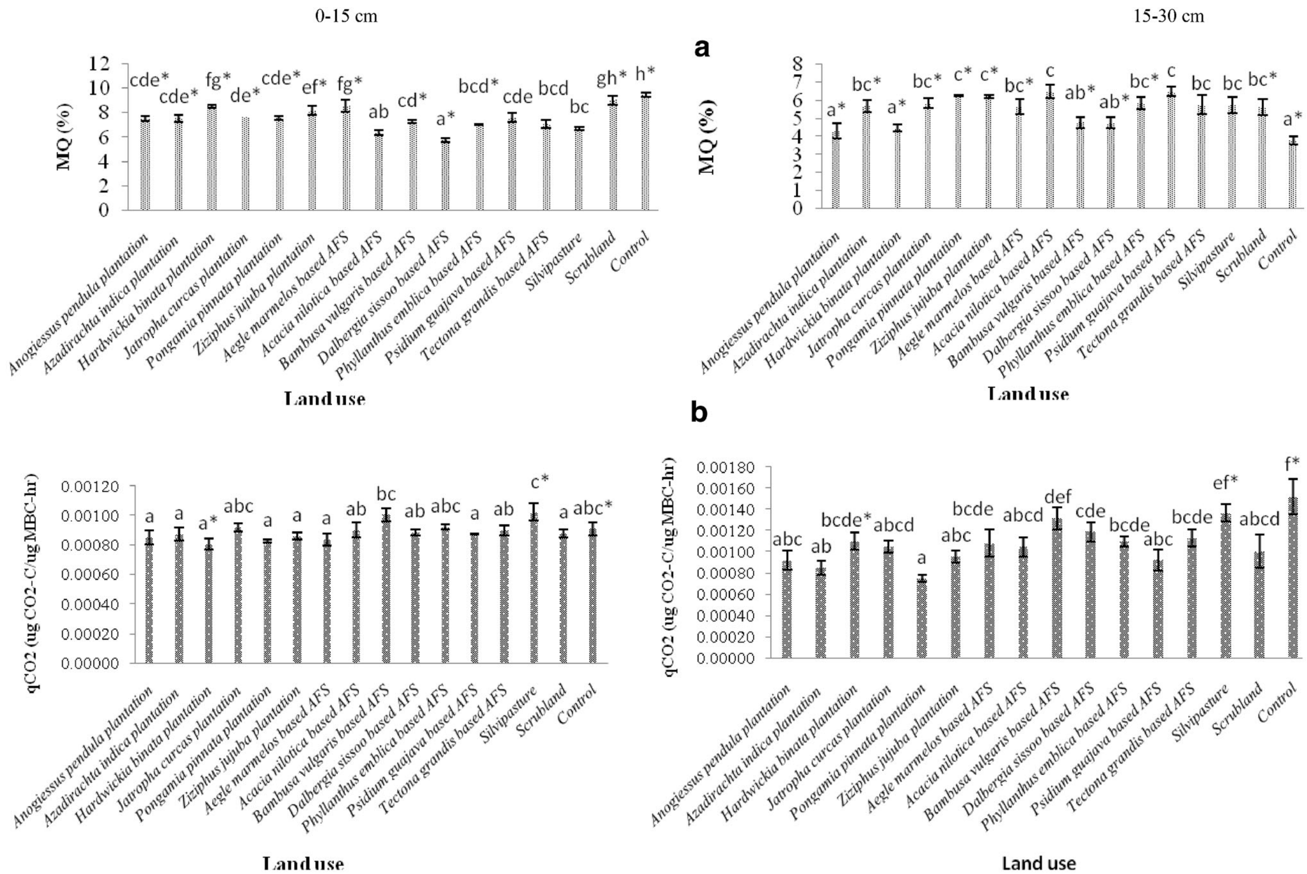


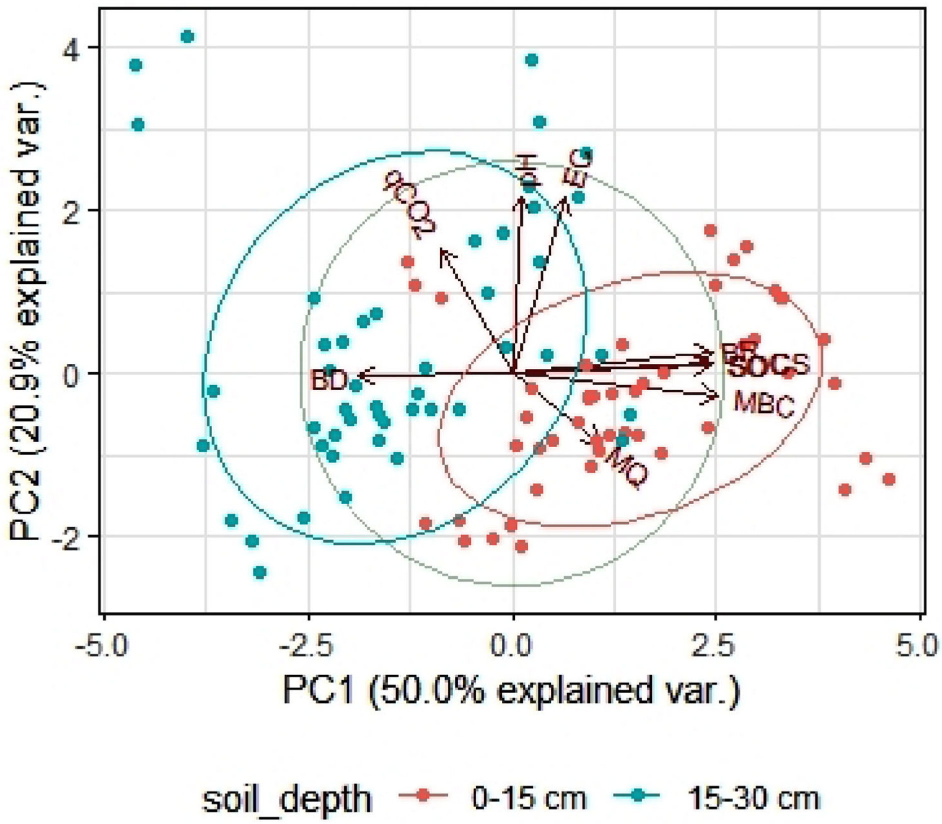
Fig. 2 **a** MQ; **b** qCO_2 in soil at two depths of different land use systems. Each bar represents the mean and standard error ($n = 3$). Means not sharing a letter in common differ significantly ($p < 0.05$) between same soil layers of different land use systems. Means sharing '*' in common differ significantly ($p < 0.05$) between soil layers of same land use system

Effect of Land use Systems on Microbial Biomass Carbon (MBC), Basal Respiration (BR), Microbial Quotient (MQ) and Metabolic Quotient (qCO_2)

Owing to higher SOC under *Acacia nilotica*-based AFS system, MBC in soil also found highest under this system; thus, we assume that SOC and MBC were highly correlated in the present study. The increase in the soil MBC was proportional to the increased organic matter content of the soil, and the same result was also reported by Debnath et al. [10]. In general, tree-based system has greater MBC than tree less system (control). This is in conformity with the Rodrigues et al. [40] where it was found higher MBC in agroforestry system as compared with tree less land. Regular tillage in open (cropland) leads to less MBC, and this result is consistent with Borie et al. [7]. The levels of microbial biomass C showed variation between soils of different tree species was also reported by many authors [37, 38]. The MBC obtained in both layers was in the order: agroforestry systems > pure plantation > scrubland > cropland. In our study, Silvopasture system has the greatest basal respiration and is comparable with Zhou et al. [55] and stated that high below-ground biomass production coupled with high root respiration rates leads to large CO_2 flux rates in the pasture site. Plantations of different species also showed variation in basal respiration in this study. The lowest CO2 respiration rates recorded for cropland soil is probably indicating their low SOC content due to poor management practices or complete removal of crop residues which ultimately reduced the food availability to microbes. Microbial activity in terms of basal respiration tends to be greater on the surface of the soil which might be due to the greater quantity and quality of plant residue that makes up the deposited organic material on surface soil, and it is in similar lines with works of Fiahlo et al. [14] and Arevalo et al. [4].

Usually, qCO_2 is used as an index to evaluate substrate utilization efficiency of the soil microbial community. A high qCO_2 level indicates low substrate utilization of the soil microbial community [52]. In this study, the elevated qCO_2 in silvopasture at surface soil layer illustrates increase in SOC consumption compared with other system

Fig. 3 PCA of soil parameters at different depths



especially tree-based system. Contrarily, at the subsurface layer, cropland (control) system recorded 40% increase in qCO_2 as compared to surface layer, indicating there are more disturbances in this system. However, disturbance is most likely to increase in qCO_2, signifying that the richness of organic C from different cultures benefits respiration [6]. From this study, we also witnessed that tree-based land use system has a lower metabolic quotient (qCO_2) proving that favourable conditions for microbes and less disturbance in these systems.

The variation in the different soil properties especially SOC, MBC and BR under the present study was not only influenced by difference in age and tree density but also largely contributed by management practices involved. For instance, among the different land systems of nearly same age, viz. *Anogiessus pendula* plantation (21 yrs), *Hardwickia binata* plantation (21 yrs), *Aegle marmelos*-based AFS (27 yrs), *Dalbergia sissoo*-based AFS (22 yrs), *Phyllanthus emblica*-based AFS (21 yrs), *Tectona grandis*-based AFS (23 yrs), the highest SOC was registered under *Dalbergia sissoo*-based AFS (11.40 g kg^{-1}), followed by *Tectona grandis*-based AFS (9.40 g kg^{-1}) in the 0–15 cm soil depth, while the *Tectona grandis*-based AFS (662.76 µg g^{-1}) followed by *Dalbergia sissoo*-based AFS (658.21 µg g^{-1}) achieved highest MBC as compared to other counterparts of nearly same age. BR of the soil also followed similar trend that of soil MBC. Apparently, it is the indication of management and its associated practices intervened in the particular land use system could have produced significant influence on the different soil properties especially SOC. On this contention, several authors, viz. Fang et al. [13] and Dawson and Smith [56], have demonstrated that the SOC stabilization of the particular land use system is affected by change in management practices via altering the litter input, as well as SOC mineralization rate. Otherwise, it is perceived that SOC is likely to increase with the advancement of time under particular management regime [57, 58]. Nonetheless, the carbon dynamics in the particular land system largely affected how different management operations, viz. cropping pattern, tillage practice, nature of crops, quality and quantity of fertilizers applied, are adopted [59]. Comparatively, AFS has shown better SOC than plantations under the present study which indicates that several tree management operations like pruning and thinning are more pronounced and hence reduces the carbon input in the soil.

Principal Component Analysis (PCA)

The high loaded values based on PCA suggests that basal respiration (BR) followed by SOC was found to be the most sensitive factor in PC1 and metabolic quotient (qCO_2)

was found to be the most influential factor in PC2. The difference in land use system and its species composition influence the litter input and its associated decomposition activities including microbial communities [4] and significantly determined the basal respiration rate of the system. On this contention, there are reports that basal respiration has been considered as one of the influential indicators for assessing the soil quality under different situation [12, 28, 30]. It was also found that significant relationship exists between SOC and MBC as well as SOC and basal respiration. Moreover, MBC also showed positive significant correlation with basal respiration. However, it was also found that BD had negative significant relationship with SOC. MQ had also negative significant correlations with SOC, MBC and BR. However, qCO_2 was found to have weak positive correlation with SOC, MBC and BR. Soil bulk density tends to increase with an increase in successive soil layers signifying greater compactness in lower depth and is widely expected that increase in soil bulk density is the indication of the loss of soil organic matter [34]. So, this factor expressed the negative correlation of BD with SOC as well as MBC. The same result was reported by Fang et al. [13]. There are positive and significant relations between the soil microbial biomass C and soil organic C [9, 10]. There was very weak correlation between soil pH and MBC, and this reflects the changes in soil pH and microbial biomass associated with different land use systems under study. Wardle [50] had claimed that alterations in soil pH could bring the variation in microbial biomass. In this regard, Acosta-Martínez and Tabatabai [1] also suggested that maximum activities of soil microbial biomass occur at pH values of about 6.5.

Conclusions

The present investigation revealed the fact that land use system had a significant effect on the soil organic carbon stocks, microbial biomass carbon and basal respiration. Interestingly, *Acacia nilotica*-based AFS due to no or less disturbance in soil produced highest SOCs, signifying that land management practices had influence on the development of soil organic carbon in the soil. The information to be generated from this study can encourage the farmers and other stake holders to adopt agroforestry system while balancing the productivity vis-a-via improving the soil. Moreover, under the afforestation and reforestation activities of Kyoto protocol, agroforestry system can be brought under CDM projects with an aim to mitigate the climate change in the foreseeable future.

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