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Assessment of soil microbial and enzyme activity in the rhizosphere zone under different land use/cover of a semiarid region, India

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Abstract

Background: Land use/cover and management practices are widely known to influence soil organic matter (S_{OM}) quality and quantity. The present study investigated the effect of different land use, i.e., forests viz. mixed forest cover (MFC), *Prosopis juliflora* (Sw.) DC-dominated forest cover (PFC), and cultivated sites viz. agriculture field (AF), vegetable field (VF), respectively, on soil parameter, microbial activity, and enzymes involved in soil nutrient cycle in a semiarid region of India.

Results: The results showed a significant reduction ($P < 0.05$) in soil carbon (S_C), soil nitrogen (S_N) content (~ 30–80%) and consequently the soil microbial biomass carbon (S_{MBC}) (~ 70–80%), soil basal respiration (S_{BR}), soil substrate-induced respiration (S_{SIR}), and soil enzyme activities (β -glucosidase, acid phosphatase, and dehydrogenase) under cultivated sites in comparison with forest sites. Pearson's correlation showed that a positive correlation of S_C with S_{MBC} , S_{BR} , S_{SIR} ($P < 0.01$), and enzymatic activities (i.e., β -glucosidase, dehydrogenase) ($P < 0.05$) may imply the critical role of S_C in regulating microbial and enzymatic activity. Also, a positive correlation of soil moisture with urease activity ($P < 0.01$) was found suggesting it as a significant abiotic factor for soil biological functions. Additionally, based on the PCA analysis, we observed the clustering of S_{MBC}/S_C ratio and qCO_2 nearby AF.

Conclusion: Our study suggests that soil microbial parameters (S_{MBC} , S_{BR} , S_{SIR} , S_{MBC}/S_C , qCO_2) and enzyme activity are key indicators of soil health and fertility. Land use/cover alters the S_{OM} content and soil microbial functions. The management strategies focusing on the conservation of natural forest and minimizing the land disturbances will be effective in preventing soil carbon flux as CO_2 and maintaining the S_C stock.

Keywords: Land use changes, Soil microbes, Soil enzymes, Semiarid ecosystems, Land management practices

Background

Land-use/cover change is considered as one of the major factors of global climate change, biodiversity loss, and ecological degradation (Kooch et al. 2018). In the semi-arid tropics of India, the rapid population growth requires continuous expansion of cultivated lands to support food demand, economic development, and

reduce poverty (Wani et al. 2015). Deforestation and land use conversions are major ecological problems in these regions. The conversion of natural forest into agricultural land significantly alter the soil processes and properties, and therefore, soil functioning (Celik 2005; Dawson and Smith 2007). Previous studies have reported that land use/cover would affect the soil physical, chemical, biological properties, and also soil organic matter (S_{OM}) dynamics, which subsequently alters the soil quality and fertility (Zhao et al. 2013). Further, the variation in land use/cover influences the soil microbial functions

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by affecting the soil carbon (S_C) and nitrogen (S_N) cycle (Sousa et al. 2012). Microbial indices related to S_{OM} such as soil microbial biomass carbon (S_{MBC}) and nitrogen (S_{MBN}), basal respiration (S_{BR}), substrate-induced respiration (S_{SIR}) (Anderson and Domsch 1978), and microbial (MQ) and metabolic quotients (qCO_2) are a good indicator of soil nutrient dynamics (Raiesi and Beheshti 2014; Goenster et al. 2017) and would provide an early warning of soil quality deterioration (Cookson et al. 2007; Huang and Song 2010).

Soil microbes despite comprising a small fraction of the total mass of S_{OM} play a critical role in soil processes, S_{OM} decomposition, nutrient cycling, etc. They are significantly influenced by human interventions involving land conversions (Smith and Paul 1995; Kabiri et al. 2016). Additionally, the management practices, variation in quality and availability of substrate, fine roots activity, litter quality, vegetation composition, plant biomass, and belowground processes also change the S_{OM} content, hence, affect the soil microbial community structure and functions. Recently, there has been an increased interest in the studies investigating the effect of conversion of natural forests into farmlands and agricultural management practices on soil microbial community structure and functions (Ye et al. 2009; Nielsen and Ball 2015; Goenster et al. 2017; Thapa et al. 2018; Lacerda-Júnior et al. 2019).

Soil enzyme activities are the indicators of microbial community and functions. They reflect changes in soil biochemical processes and S_{OM} dynamics attributed to human-induced variation in abiotic and biotic factors in soil (Trasar-Cepeda et al. 2008). Soil enzyme activities related to S_{MBC} and soil organic carbon (SOC) are often used for comparison of different land use with varying S_{OM} content (Waldrop et al. 2004; Bastida et al. 2007). Measurement of soil enzyme activities in key nutrient cycling (C, N, and P) and oxidation–reduction processes have been used widely as a potential indicator for determining the effect of land use conversions and management practices on soil health (Acosta-Martínez et al. 2007; Pandey et al. 2014; de Medeiros et al. 2015). Therefore, an investigation of soil microbial characters and enzyme activities is critical in studying the land conversions and focusing the soil management.

Principal component analysis (PCA) has been widely used as a statistical tool to determine the most sensitive factor explaining the significant variation among the different land use/cover (Notaro et al. 2014; Pandey et al. 2014; de Medeiros et al. 2015, 2017; Moghimian et al. 2017).

Previous studies in India evaluated the effect of land use conversions on soil microbiota and soil enzymes (Singh and Ghoshal 2014; Kumar and Ghosal 2017; Rai et al. 2018; Tiwari et al. 2019). However, not many such

studies have compared the soil microbial parameters and enzymes in different land use/cover in semiarid regions of India. The present study was conducted in forests and agroecosystems of Delhi, India. Delhi, being an urban city, is among the most polluted cities in the world. It is one of the largest growing cities with a decadal growth of 21.20% and a population of 16.8 million (Census of India 2011). Rapid population growth and growing economy are the main drivers of land use/land cover changes (Jain et al. 2016). The forest ecosystems are notified as reserved and are located on ridge areas which are the extensions of Aravalli hills with a length of 32 km. The growing urbanization and encroachment have led to the complete loss of vegetation, and only a few areas of the forests have been protected in Delhi (Sinha 2014). The impact of urbanization processes, such as land use conversions, deforestation, and the shift in vegetation composition, is known to alter soil structure and physicochemical properties (Pickett et al. 2001; Yan et al. 2016). It is assumed that these processes will influence soil nutrient cycling and affect soil microbial functions and enzyme activities (Rai et al. 2018). This study hypothesizes that soil microbiological and enzyme attributes vary across different land use/cover, and therefore, could be used as sensitive indicators of soil health. The purpose of this study is to evaluate the effect of different land use/cover types (i.e., forest cover and cultivated land) on soil microbial parameters (S_{MBC} , S_{BR} , S_{SIR} , S_{MBC}/S_C , qCO_2). Further, the study also determines the activity of selected soil enzymes involved in soil nutrient cycling, i.e., carbon (β -glucosidases), nitrogen (ureases), phosphorus (acid phosphatase), and oxidation–reduction (dehydrogenase) under selected land use/cover types. Lastly, the purpose is also to understand the influence of land use/cover on the relationship among soil physicochemical properties and microbial and enzyme activity.

Materials and methods

Study area

This study was carried out in a semiarid region of Delhi, which is part of the National Capital Territory (NCT) of India, lies between 28.41° N and 28.41° N; 76.84° E and 77.40° E, and covers an area of 1483 km². It is bounded by the Indo-Gangetic alluvial plains, Thar Desert, and Aravalli Range. The climate of Delhi is semiarid and dry and greatly influenced by the Himalayas and the Thar Desert due to its proximity. The climate is characterized by hot summers (April–June), monsoons (July–September), and cool and dry winters (November–December). The study area receives most of the annual rainfall during the monsoon season. The vegetation of the study area is ravine thorn forest, which belongs to the ecosystem type of tropical thorn forest (6B/C) (Champion and Seth 1968) and covers 33% of the total forest area,

whereas 67% is covered by plantation/tree outside forest (TOF) areas (FSI 2017). The vegetation is mainly dominated by middle-story thorny trees, which are interspersed with open patches due to their scattered distribution (Sinha 2014). The parent material of Delhi ridge soil is quartzite or sandstone, with sandy loam to loam texture (Chibbar 1985). *Prosopis juliflora*, which is an exotic species, is the dominant tree in the forest. *Acacia nilotica* (L.) Delile, *Acacia leucophloea* (Roxb.) Willd., *Salvadora oleoides* Decne, and *Cassia fistula* L. are among the commonly found native trees (Sinha 2014; Meena et al. 2016). For the study, four sites were selected with two sites each for agriculture and forest land use, respectively, in the semiarid region of Delhi. The sites were selected on the basis of predominant land use activity, level of anthropogenic intervention and vegetation cover as (i) mixed forest cover (MFC), (ii) *P. juliflora*-dominated forest cover (PFC), (iii) agriculture field (AF), and (iv) vegetable field (VF) (Meena et al. 2020). The mixed forest cover (MFC) was considered as a native vegetation cover (28.68° N; 77.22° E). In MFC, *P. juliflora* was found to be the most dominant species but other associated tree species viz. *Pongamia pinnata* L., *Azadirachta indica* Juss., *A. nilotica*, and *C. fistula* were also observed (Meena et al. 2019). The *P. juliflora*-dominated forest cover (PFC) is an exotic tree cover (28.69° N; 77.22° E). The agriculture field (AF) was located near the Nazafgarh drain (28.54° N; 77.87° E) and was mainly cropped with wheat (*Triticum aestivum* L.) from October to May and common bean (*Phaseolus vulgaris* L.) from September to October. The AF was irrigated by a tube well during the growing season. Lastly, the vegetable field (VF) was located along the Yamuna flood plains (28.53° N; 77.33° E). The major vegetable grown were chilies (*Capsicum annum* L.) throughout the year except between September and November, during which cabbage (*Brassica oleraceae* L.) was grown. The water pumped regularly from the Yamuna River for irrigation in the VF. The management practices such as tillage, pesticide and fertilizer application, runoffs, and plant or crop rotation in cultivated lands are expected to affect the soil microbes. The soil physicochemical properties of the sites are given in Table 1.

Soil sampling and analysis

The sampling was conducted by randomized quadrat sampling experimental design during September 2012. For each land use, three quadrats of 10 × 10 m were selected for soil collection. The sampling points were ensured to be homogenous with respect to elevation and slope. From each quadrat, the soil samples were collected after removing the litter from five different points at 0–10-cm depth and pooled together to obtain a composite sample. Therefore, three soil samples were

Table 1 Soil physical and chemical factors of four land uses of the semiarid region of Delhi

Soil parameters	PFC	MFC	AF	VF
S_C/S_N	9.52 (0.11) ^a	10.15 (0.08) ^a	9.5 (0.18) ^b	12.4 (0.09) ^c
S_P (mg L ⁻¹)	2.22 (0.01) ^a	1.95 (0.02) ^b	1.73 (0.02) ^c	1.84 (0.62) ^{bc}
S_M (%)	3.57 (0.03) ^a	5.41 (0.05) ^b	3.92 (0.05) ^c	4.70 (0.02) ^d
Soil texture	Sandy loam	Sandy loam	Loamy sand	Sandy loam

Values are means (standard error) and letters denote significant difference among land use types ($P < 0.05$)

S_C/S_N soil carbon to soil nitrogen ratio, S_P soil phosphorus, S_M soil moisture, PFC *P. juliflora* forest cover, MFC mixed forest cover, AF agriculture field, VF vegetable field

selected for each land use type, with a total of 12 samples. The visible root mass was removed from the soil samples by hand. The litter layer was removed thoroughly before analysis. The soil samples were passed through a 2-mm sieve, ground in a mortar with a pestle, and stored at room temperature for further analysis. The soil moisture (S_M) content was measured using the gravimetric method. For microbial parameters and enzymes, a subsample of 2-mm freshly sieved soil was stored in zipped plastic bags at 4 °C till further analysis. S_C and S_N concentrations were measured using the CHNS Analyzer (Elementar vario). Available S_P was measured by using an ammonium molybdate blue method (Allen et al. 1974).

Soil microbial biomass carbon (S_{MBC}), basal (S_{BR}) and substrate-induced respiration (S_{SIR})

The S_{MBC} was estimated by using the chloroform fumigation extraction method (Witt et al. 2000), where 35 g of fresh soil was fumigated with 2 ml ethanol-free $CHCl_3$ and incubated for 24 h in the dark at 25 °C. The fumigated soils were extracted with 140 ml of 0.5 M K_2SO_4 , and unfumigated control soils were extracted immediately without fumigation. The resulting extracts were filtered and examined by the TOC analyzer (Elementar vario). The S_{MBC} was calculated as the difference between fumigated and unfumigated sample with a conversion factor of 0.38 (Vance et al. 1987).

The S_{BR} was measured by the alkali absorption method (Isermayer 1952). Briefly, 50 g of soil preincubated at 60% water-holding capacity (WHC) was incubated with 10 ml 0.05 M NaOH solution at 25 °C for 24 h. After incubation, 2 ml $BaCl_2$ (0.5 M) and 2–3 drops of phenolphthalein indicator were added into the NaOH beaker which was then titrated with 0.1 M HCl dropwise. The S_{SIR} of soil was estimated by the rate of initial maximal respiration of microorganisms after the amendment of soil subsamples with glucose (Anderson and Domsch 1978). The preincubated soil subsamples (60% WHC) was mixed with glucose (30 mg g⁻¹ soil) and incubated with 0.05 M NaOH at 22 °C for 3 h. The CO_2

released was measured by titrating the NaOH solution with 0.1 M HCl. The S_{BR} and S_{SIR} were expressed as CO_2 C mg g^{-1} h^{-1} .

Soil enzyme activities

The β -glucosidase activity was estimated by using p-nitrophenyl- β -D-glucoside (PNG) as a substrate and incubating 1 g of soil with 0.25 ml toluene, 4 ml modified universal buffer (pH 6), and 1 ml PNG solution (25 mM) for 1 h at 37 °C (Eivazi and Tabatabai 1988). After incubation, 1 ml of $CaCl_2$ solution and 4 ml Tris buffer (pH 12) were added, and absorbance was taken at 400 nm using a spectrophotometer (RIGOL, USA). The activity of β -glucosidase was expressed as μ g PNG g^{-1} dwt h^{-1} at 37 °C. The urease activity was determined by using urea as a substrate as described by Yao et al. (2006). Five grams of moist soil was incubated with 1 ml methylbenzene, 10 ml of 10% urea 20 ml citrate buffer (pH 6.7) for 24 h at 37 °C. One milliliter of filtered soil solution, 1 ml of sodium phenolate, and 3 ml of sodium hypochlorite were added and diluted to 50 ml, and absorbance was determined at 578 nm using a spectrophotometer (RIGOL, USA). The activity of urease was expressed as NH_3 -N g^{-1} h^{-1} at 37 °C. Acid phosphatase activity was analyzed using p-nitrophenyl phosphate (p-NPP) as substrate as described by Schneider et al. (2000). Five grams of moist soil was mixed with 20 ml acetate buffer (pH 5.2) and 100 mM p-NPP and incubated at 30 °C for 30 min. After incubation, 1 ml of $CaCl_2$ and 4 ml of 0.2 M NaOH were added after incubation in order to terminate the reaction. The absorbance was determined using the spectrophotometer at 405 nm (RIGOL, USA). The activity of AP was expressed as μ g p-NPP g^{-1} h^{-1} at 30 °C. Dehydrogenase activity was measured using triphenyl tetrazolium chloride (TTC) as a substrate (Thalman 1968), where the TTC solution (0.3–0.4 g/100 ml) was mixed with 5 g of moist soil and incubated for 24 h at 30 °C. After incubation, 40 ml of acetone was added, and absorbance was determined at 546 nm using a spectrophotometer (RIGOL, USA). The activity of dehydrogenase was expressed as μ g TTC g^{-1} h^{-1} .

Statistical analysis

One-way analysis of variance (ANOVA) was used to evaluate the effect of land use on selected variables (S_M , S_P , S_C , S_N , S_{MBC} , S_{BR} , S_{SIR} , S_{MBC}/S_C , qCO_2 , β -glucosidase, ureases, acid phosphatase, dehydrogenase activity) using Tukey's test at $P < 0.05$. Pearson correlation analysis was performed to estimate the correlation of selected variables among the land use. All the statistical analysis was done using SPSS version 16.0. Principal component analysis (PCA) was used to evaluate the relationship of multivariate data using XLSTAT 2020.

Results

Soil chemical and microbial parameters

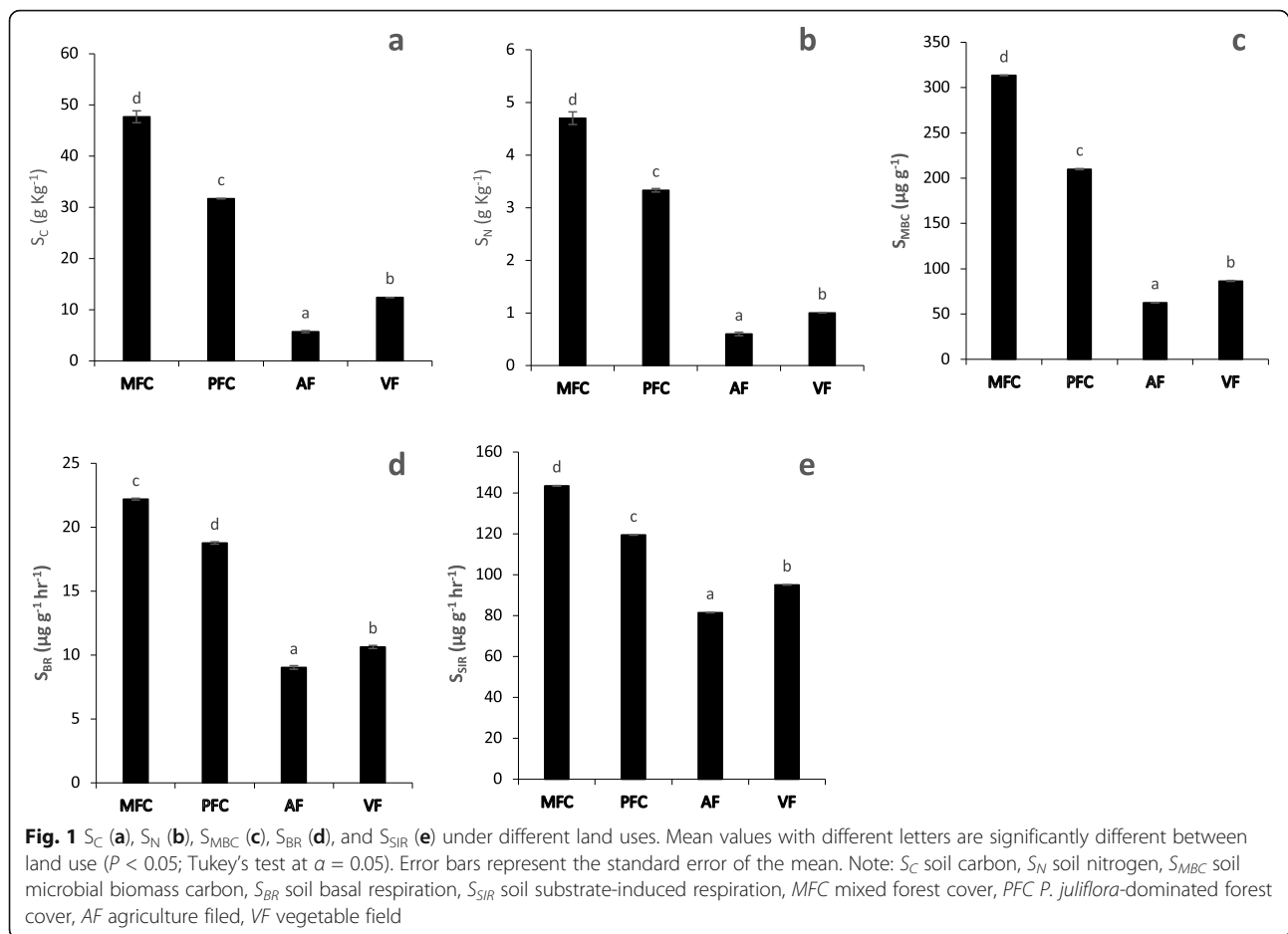
The S_C and S_N concentrations ($g\ kg^{-1}$) at 0–10-cm depth were found to be significantly influenced by land use type (Fig. 1a, b). Both S_C and S_N were higher under natural forests as compared with arable soils. The highest S_C and S_N ($g\ kg^{-1}$) were evaluated under MFC (47.70 ± 1.16 ; 4.70 ± 0.12) followed by PFC (31.70 ± 0.06 ; 3.33 ± 0.033), VF (12.40 ± 0.01 ; 1 ± 0), and AF (5.70 ± 0.20 ; 0.60 ± 0.03), respectively. The S_C and S_N were significantly different among the four land uses ($P < 0.05$).

Similar to the S_C , higher S_{MBC} was estimated under forest as compared with cultivated land uses (Fig. 1c) and followed the trend as MFC > PFC > VF > AF (313.54 ± 0.34 , 209.98 ± 0.63 , 86.57 ± 0.53 , and 62.57 ± 0.29 , respectively). The S_{MBC} was significantly different among the four land uses ($P < 0.05$). The S_{MBC}/S_C was highest under AF (1.1), followed by VF (0.7), PFC (0.66), and MFC (0.65), respectively (Fig. 2a).

The S_{BR} was greater under forest as compared to cultivated sites and followed the trend as MFC > PFC > VF > AF (22.20 ± 0.07 , 18.77 ± 0.09 , 10.63 ± 0.12 , and $9.03 \pm 0.14\ \mu$ g g^{-1} h^{-1} , respectively) (Fig. 1d). The S_{SIR} also followed similar trend as 143.50 ± 0.15 , 119.51 ± 0.16 , 95.06 ± 0.11 , and $81.48 \pm 0.11\ \mu$ g g^{-1} h^{-1} for MFC, PFC, VF, and AF, respectively (Fig. 1e). Both S_{BR} and S_{SIR} varied significantly among the land use (MFC, PFC, VF, AF; $P < 0.05$). The metabolic quotient (qCO_2) was used to evaluate the efficiency of S_{MBC} in utilizing the S_C (Anderson and Domsch 1990). The value of qCO_2 was estimated to be 0.14, 0.12, 0.09, and 0.07 μ g $S_{MBC}\ g^{-1}\ h^{-1}$ for AF, VF, PFC, and MFC, respectively. A significant increase in qCO_2 was observed under cultivated as compared with forest land use (Fig. 2b).

Soil enzyme activity

The activity of selected enzymes is shown in Fig. 3a, b, c, and d. The β -glucosidase activity (μ g PNG g^{-1} h^{-1}) was significantly high in MFC (623.71 ± 5.75) than PFC (398.40 ± 9.01), AF (57.58 ± 0.94), and VF (32.95 ± 0.49), respectively. Among the forest, the activity of urease (μ g NH_3 -N g^{-1} h^{-1}) was found to be significantly greater in MFC (41.58 ± 0.56) than PFC (30.40 ± 0.48) at $P < 0.05$. Among cultivated lands, high urease activity (μ g NH_3 -N g^{-1} h^{-1}) was evaluated under VF (38.34 ± 0.39) as compared to AF (34.06 ± 3.11). However, the values were not significant among AF and VF ($P > 0.05$). The acid phosphatases (μ g hydrolyzed phenol g^{-1} h^{-1}) was high under MFC (1051.98 ± 65.40) followed by PFC (287.18 ± 6.93), VF (95.22 ± 4.54), and AF (68.02 ± 4.23), respectively. The activity of acid phosphatases was significantly different among forest land uses (MFC, PFC) ($P < 0.05$). However, no significant difference was determined under cultivated land uses (AF, VF) ($P >$



0.05). The activity of dehydrogenase was significantly high under MFC than PFC (1.22; 1.03 $\mu\text{g TTC g}^{-1} \text{h}^{-1}$, respectively) ($P < 0.05$). However, no dehydrogenase activity was detected under arable land uses (AF and VF).

Based on the combined data set for all land uses, Pearson's correlation analysis evaluated a significant correlation among the studied soil variables (Table 2). A significant strong positive correlation was found between S_C , S_N , S_{MBC} , S_{BR} , and S_{SIR} ($P < 0.01$). The positive correlation of β -glucosidase and dehydrogenase was observed with S_C , S_N , S_{MBC} , S_{BR} , and S_{SIR} ($P < 0.05$). Additionally, a significant positive correlation was found among S_M and urease activity ($P < 0.01$). Further, the $q\text{CO}_2$ showed a significant negative correlation with S_C , S_{BR} , and S_{SIR} ($P < 0.01$), and S_N ($P < 0.05$), respectively.

The principal component analysis (PCA) extracted three components with PC 1, PC 2, and PC 3 explained 71.38, 19.55, and 9.07% of the variance, respectively. For the biplot, PC 1 and PC 2 components were used, which together explained 90.34% of the variance. The PC 1 loadings were large and positive for S_C , S_N , S_P , S_{MBC} , S_{BR} , and S_{SIR} , and activity of β -glucosidase,

dehydrogenase, and acid phosphatase, while negative for $q\text{CO}_2$ and S_{MBC}/S_C (Fig. 4). In PC 2, loadings were large and positive only for S_C/S_N , S_M , and urease activity in comparison with those in PC 1. Among the land uses, PFC and MFC are closely associated with the variables of S_C , S_N , S_{MBC} , S_{BR} , and S_{SIR} , and enzyme activities. However, VF and AF are closely associated with $q\text{CO}_2$ and S_{MBC}/S_C .

Discussion

S_{MBC} indicates the size of the S_C labile pool (Hanson et al. 2000) and is sensitive to land use conversions. The study reported a higher S_{MBC} from forests (PFC, MFC) as compared with cultivated sites (AF, VF), with a significant reduction of ~ 70 – 80% . Regular tillage in cultivated land use often damages the soil aggregates and exposes the S_{OM} for oxidation (Fang et al. 2014; Raiesi and Salek-Gilani 2020). Our results agree with the findings reported from previous studies indicating higher S_{MBC} under natural forest than arable land use (Ananyeva et al. 2008; Zhao et al. 2012; Mganga and Kuzyakov 2014; Kooch et al. 2019; dos Santos et al.

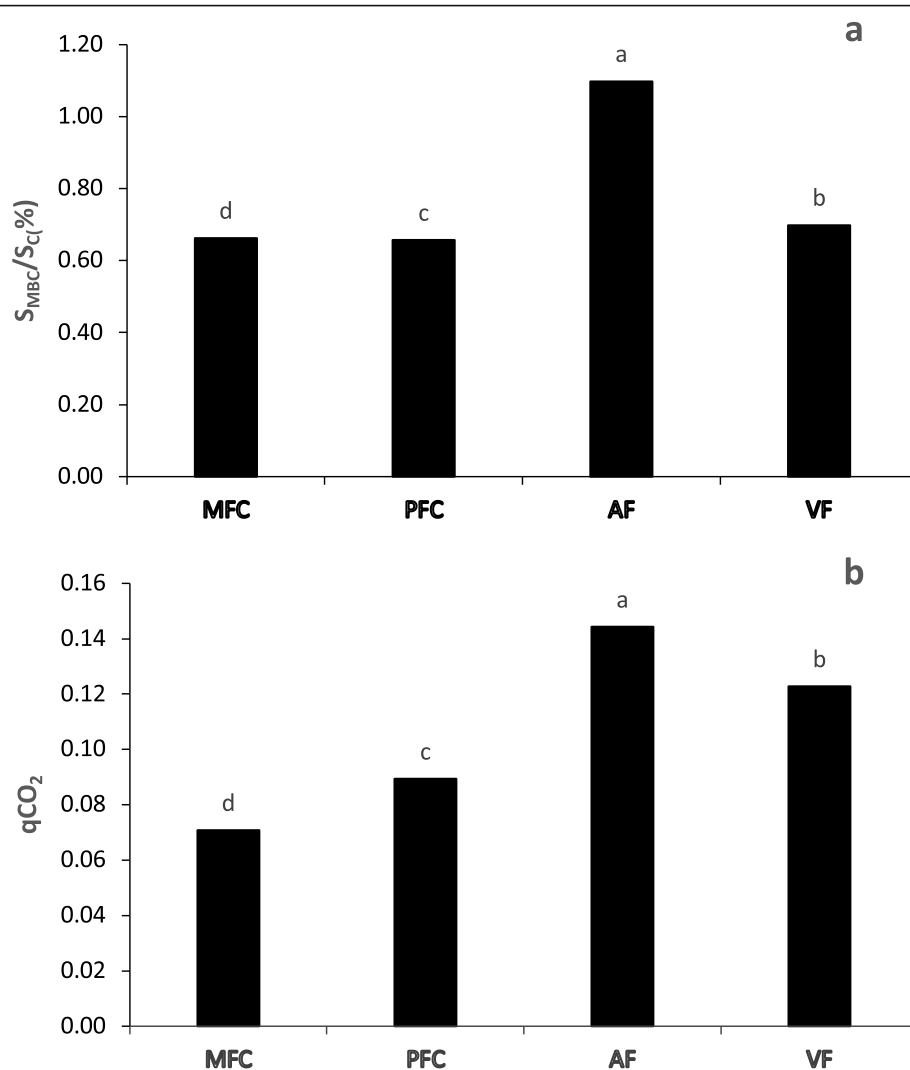


Fig. 2 S_{MBC}/S_C (a) and qCO_2 (b) under different land uses. Mean values with different letters are significantly different between land uses ($P < 0.05$). Note: S_{MBC}/S_C soil microbial biomass carbon to soil carbon ratio, qCO_2 metabolic quotient, MFC mixed forest cover, PFC *P. juliflora*-dominated forest cover, AF agriculture filed, VF vegetable field

2019). The long-term accumulation of S_{OM} input, S_{OM} quality, and quantity determine the S_{MBC} (Moore et al. 2000). It was evident in our study by the strong positive correlation of S_{MBC} with S_C and S_N .

Vegetation cover influences the quality and quantity of litter accumulation, therefore, affect S_{OM} decomposition (Tiwari et al. 2019). The increased plant diversity in MFC favors plant rhizosphere by providing various substrates to soil microbes (dos Santos et al. 2019). Also, the varying quality of litter affects the S_{OM} decomposition, which could explain low microbial activity in PFC as the leaves of *P. juliflora* has higher lignin content and does not degrade rapidly. In this study, high S_C and S_N contents were detected in sites presenting the greater plant diversity and vegetation cover. According to de

Medeiros et al. (2017), high tree density and diversity of dominant species in intermediate and late regenerative stages increase the root biomass, organic matter, litter content, and SOC in tropical dry forests of the semiarid Brazilian region.

The variability of the humic substrate also indicates the differences in S_{BR} (heterotrophic respiration) and S_{SIR} (potential respiration) among various land use/cover types. The highest S_{BR} and S_{SIR} values were found in MFC, and the lowest were recorded under AF. Kooch et al. (2019) also reported a higher S_{SIR} , S_{MBC} , S_{BR}/S_{MBC} under natural forests and plantations as compared with agricultural sites. Higher aboveground and belowground biomass (Meena et al. 2020), fine root activity (Davidson et al. 2002), and litter content

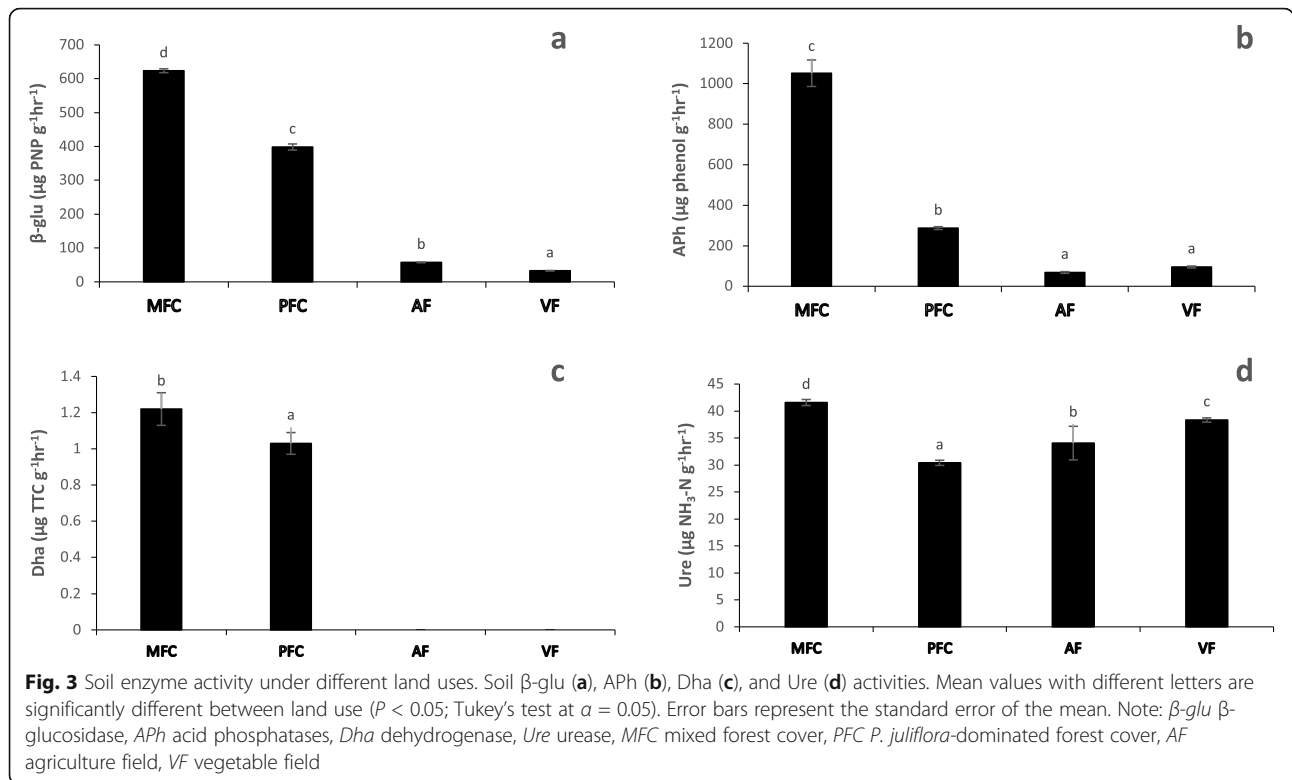
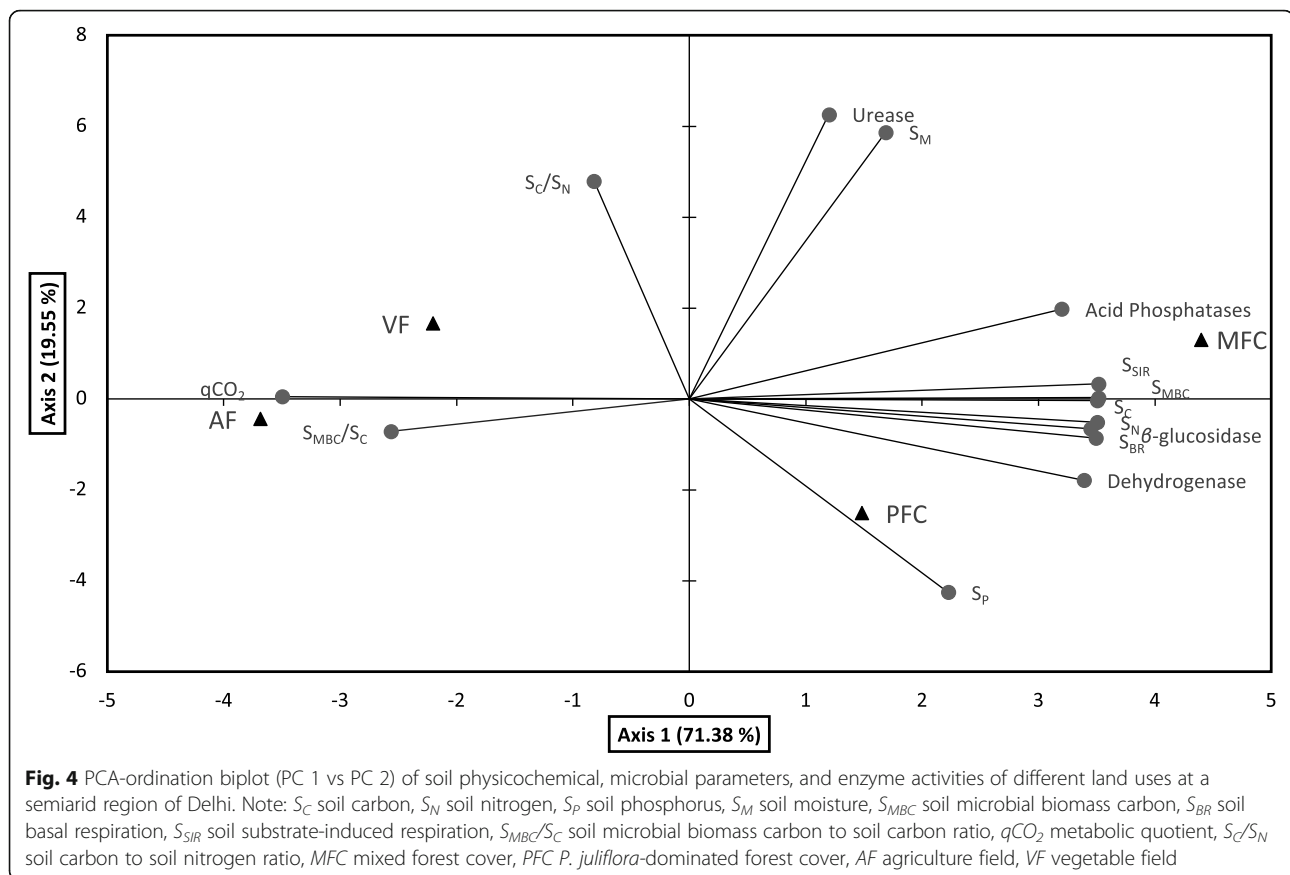


Table 2 Pearson correlation coefficients (r) between soil physicochemical, microbial parameters, and enzyme activities among different land uses of a semiarid region of Delhi

	S_C	S_N	S_C/S_N	S_P	S_M	S_{MBC}	S_{BR}	S_{SIR}	S_{MBC}/S_C	qCO_2	β -glu	Dha	Ure	Aph
S_C	1	0.996**	-0.248	0.616	0.486	0.998**	0.991**	0.998**	-0.710	-0.990**	0.984*	0.963*	0.348	0.919
S_N		1	-0.321	0.653	0.416	0.997**	0.997**	0.990**	-0.681	-0.983*	0.992**	0.981*	0.275	0.899
S_C/S_N			1	-0.301	0.446	-0.295	-0.325	-0.186	-0.354	0.160	-0.414	-0.444	0.495	-0.198
S_P				1	-0.292	0.592	0.706	0.607	-0.696	-0.684	0.602	0.756	-0.434	0.257
S_M					1	0.481	0.364	0.520	-0.377	-0.459	0.401	0.234	0.988**	0.720
S_{MBC}						1	0.989**	0.993**	-0.665	-0.979	0.992**	0.964*	0.346	0.931
S_{BR}							1	0.984*	-0.706	-0.986**	0.985*	0.989**	0.219	0.866
S_{SIR}								1	-0.744	-0.994**	0.971*	0.948*	0.384	0.918
S_{MBC}/S_C									1	0.801	-0.585	-0.642	-0.256	-0.494
qCO_2										1	-0.954	-0.953	-0.316	-0.867
β -glu											1	0.977*	0.266	0.914
Dha												1	0.086	0.811
Ure													1	0.622
Aph														1

S_C soil carbon, S_N soil nitrogen, S_P soil phosphorus, S_M soil moisture, S_{MBC} soil microbial biomass carbon, S_{BR} soil basal respiration, S_{SIR} soil substrate-induced respiration, S_{MBC}/S_C soil microbial biomass carbon to soil carbon ratio, qCO_2 metabolic quotient, S_C/S_N soil carbon to soil nitrogen ratio, β -glu β -glucosidase, Aph acid phosphatases, Dha dehydrogenase, Ure urease

* Correlation is significant at the 0.05 level
 ** Correlation is significant at the 0.01 level



(Chodak and Niklinska 2010) in forests maintain the S_C for a longer period. Parallel to the previous studies, the qCO_2 or metabolic quotient which measures the ecophysiological state of the soil microbial community was found to be largest for AF (Ananyeva et al. 2008; Cheng et al. 2013; Fang et al. 2014; Kooch et al. 2019). The strong negative correlation of qCO_2 with S_{MBC} , S_{BR} , and S_{SIR} indicates that reduced substrate carbon supply declines the microbial biomass size, activity, and microbial efficiency for substrate carbon utilization (Wardle and Ghani 1995; Six et al. 2006; Yang et al. 2010). Under a disturbed ecosystem, the strong competition for available carbon substrate may favor microbes that use more carbon energy in maintenance than growth (Islam and Weil 2000). Therefore, in cultivated soils, the microbial communities are more stressed and needed a regular supply of carbon sources to maintain their activity (Singh et al. 2018).

In semiarid ecosystems, S_{OM} is considered as the main controlling factor for soil microbial activity and respiration (Zhang et al. 2013; Bao et al. 2016; Meena et al. 2020). Among the cultivated sites, a comparatively higher S_M and nutrient content (S_C , S_N , S_p) in VF could explain the greater respiration values under VF than AF (Giesler et al. 2012; Tardy et al. 2014).

The S_{MBC}/S_C ratio or MQ has been widely used as an indicator of soil quality and future changes in S_{OM} (Sparling et al. 1992). It also reflects the contribution of the S_{MBC} to S_C and can be used as a sensitive measure of soil health under different land use management systems (Anderson and Domsch 1989). The previous studies have reported a high MQ in the forest as compared with cultivated land (Dinesh et al. 2004; Kooch et al. 2019). Contrastingly, in our study, the higher MQ in AF could be related to lower S_C owing to a larger proportion of the S_{MBC} to total S_C (Araújo et al. 2013). Hence, the soils in the cultivated lands are more sensitive to the change related to land use and management (Sampaio et al. 2008).

Soil enzyme activity

Soil enzyme activity is influenced by the soil characteristics related to nutrient availability, soil microbial activity, and land use management processes which modified the potential soil enzyme-mediated substrate catalysis (Kandeler et al. 1996). In this study, the activity of all the enzymes was higher under MFC. With the low level of anthropogenic influence under MFC, the soils were covered with high litter content and added greater S_{OM} . This suggests that the enzyme activities are governed by

the availability of carbon sources and S_{OM} decomposition. The intensive management practices under AF and VF constantly disturb the soil and regular removal of litter layer restricted the supply of substrate for microbes, thereby reduces the enzyme activities. Kotroczo et al. (2014) reported that under different treatments of detritus input and removal, the enzyme activities were more influenced by root activity rather than above-ground litter availability. In this case, the higher activity of root and rhizosphere in natural forests increased the enzyme activities. Previous studies reported a reduction in soil enzyme activities following the conversion of natural forests into cultivated lands (Araújo et al. 2013; Raiesi and Beheshti 2015; Vinhal-Freitas et al. 2017; Silva et al. 2019).

Urease regulates the S_N transformation and is involved in the hydrolysis of urea into ammonia and CO_2 (Kong et al. 2008). The urease activity is influenced by various soil properties including pH, soil nutrient supply, S_N , S_{MBN} , and N fertilizers (Moghimian et al. 2017). In this study, the highest urease activity was evaluated in MFC than all other land use/cover types. Our results were similar to previous findings indicating greater urease activity under natural forest than cultivated area, and indicating that the availability of fresh S_{OM} for microbial decomposition enhances the microbial activity in forest soil and increases the enzyme activity (de Medeiros et al. 2015; Vinhal-Freitas et al. 2017). Contrastingly, in cultivated fields (i.e., AF and VF), high urease activity was found despite low values of S_C and S_N . This can be explained by the regular supply of urea fertilizer to the field. Also, a strong positive correlation of urease activity with S_M supported its increased activity in VF (Zeng et al. 2009).

Dehydrogenase activity in soil serves as an indicator of the microbiological redox system and microbial oxidative activities in soil (Casida Jr et al. 1964). It indicates the respiratory activity of the soil and can be used as a measure of microbial activity in semiarid climates (García et al. 1994; Bastida et al. 2006). In this case, no dehydrogenase activity was detected under cultivated sites (i.e., AF and VF). The reduced content of labile carbon and S_C are suggested to decrease the activity (Bastida et al. 2006). Bonanomi et al. (2011) reported a reduction by 84% in dehydrogenase activity in a low-input management regime as compared with the high-input management regime. de Medeiros et al. (2015) detected the dehydrogenase activity in soils under different intercropping areas found the lowest activity in *Manihot esculenta*, *Cajanus cajan*, *Vigna unguiculata* monoculture. The study reported that soil disaggregation due to short cropping cycle and weeding along with low vegetation cover attributed to reduced enzyme activity. Further, in dry climate conditions the abiotic stress to microbial

activity due to high temperature and low S_M influence the organic matter oxidation by dehydrogenase (Li and Sarah 2003).

In addition, β -glucosidase activity in soil is linked to the release of carbohydrates in soil, which provides a major substrate for soil microorganisms. The positive correlation of the S_C and S_{MBC} with β -glucosidase activity indicated that S_{OM} content is the major factor in its activity (Vinhal-Freitas et al. 2017). Corroborating with our results, Silva et al. (2019) evaluated β -glucosidase activity under tropical dry native forest, protected area, scrub, and maize cultivated area; reported reduced activity under the cultivated field; and suggested a closed linking of β -glucosidase with SOC and S_{OM} content. de Medeiros et al. (2015) demonstrated similar β -glucosidase activity among tropical dry forest and intercropping soils of Brazil with less aggressive management practices. The study also reported a reduced activity under semiarid ecosystems attributed due to the slow decomposition of S_{MBC} .

Similarly, the acid phosphatase activity was also higher under forests as compared to cultivated land use. Further, a nonsignificant yet positive correlation of S_C and S_{MBC} with acid phosphatase activity indicates their importance in regulating its activity (Hendriksen et al. 2016; Acosta-Martínez et al. 2018). Similar to this study, Silva et al. (2019) found no correlation between S_P and acid phosphatase. This confirms that the activity of acid phosphatase activity is also influenced by soil pH, nutrients, S_C , S_N , S_P , S_{OM} quality and quantity, microbial community structure, S_M , and soil temperature (Hendriksen et al. 2016; Maharajan et al. 2017; Moghimian et al. 2017). Raiesi and Beheshti (2015) indicated that soil pH is the main regulator of acid phosphatase activity, and narrow pH ranges attributed to no significant changes after natural forest conversions in Iran.

Factors affecting microbial and enzyme activities

The PCA evaluated the dissimilarities in soil parameters (i.e., S_M , S_P , S_C , S_N , S_{MBC} , S_{BR} , S_{SIR} , S_{MBC}/S_C , qCO_2 , β -glucosidases, ureases, acid phosphatase, and dehydrogenase activity) among the four land uses. The cultivated (i.e., AF and VF) appeared to be different from the respective forest analogs (i.e., PFC and MFC). The clustering of S_C , S_N , S_{MBC} , S_{BR} , S_{SIR} , β -glucosidase, dehydrogenase, and acid phosphatases nearby PFC and MFC indicate the critical role of S_{OM} in controlling the microbial and enzyme activities (Cheng et al. 2013). High S_{OM} in forest land use due to dense vegetation, deep rooting system, and greater amount of litter favors microbial activity (Tiwari et al. 2019). The S_M often considered as the key factor in controlling soil microbial functions. Fang et al. (2014) and Tiwari et al. (2019) suggested slower decomposition and microbial activity in

cultivated land uses as results of low S_M content. Additionally, the clustering of urease with S_M is similar to various findings, suggesting a significant role of S_M in enhancing urease activity in soil (Sahrawat 1983). Further, clustering of qCO_2 and S_{MBC}/S_C near the AF and VF suggest a reduced efficiency of microbes to utilize substrate carbon in cultivated lands (Araújo et al. 2014) as compared with more recalcitrant carbon in forest analogs.

Conclusion

Our study suggests that land use/cover changes and management practices influence the soil microbial parameters and enzyme activity in a semiarid region. Low S_{OM} in cultivated lands (AF, VF) limits the soil microbial activity thereby reducing S_{MBC} , S_{BR} , and S_{SIR} . In comparison, an increased amount of substrate quantity and quality in the native forest land uses enhances the S_{OM} content favoring high microbial activity. The variation in plant species composition, S_M content, and litter quality within the land use further affect microbial activity. Among the two forests, the higher plant diversity under MFC had significantly enhanced the S_C , S_N , S_{MBC} , S_{BR} , S_{SIR} , and enzyme activity as compared with the PFC, while among the two cultivated land uses, under AF, the intensive management practices including tillage, fallow periods, application of fertilizers, and low S_M had drastically reduced the S_{OM} quantity and quality and hence, the microbial and enzyme activity. The strong positive correlation of soil parameters (S_C , S_N) with microbial activities (S_{MBC} , S_{BR} , S_{SIR}) and soil enzymes (β -glucosidase, acid phosphatase, and dehydrogenase) further suggests the critical role of S_{OM} and soil nutrient in maintaining soil fertility. A higher S_{MBC}/S_C and qCO_2 under AF suggest that cultivated sites are more sensitive to the S_C changes in topsoil layers. Anthropogenic interventions in cultivated lands alter the soil structure and physico-chemical parameters, thereby affecting the soil microbial and enzyme activity as strongly suggested from our results. Therefore, the soil microbiological parameters are potential indicators to study soil response and S_C dynamics following land use conversions and management practices. The implication of such studies is even more significant in climate-stressed semiarid ecosystems, where effective land management practices in cultivated lands and restoration of forest ecosystems enhance S_{OM} and microbial functions.

Abbreviations

AF: Agriculture field; MF: Mixed forest cover; qCO_2 : Metabolic quotient; PCA: Principal component analysis; PFC: *Prosopis juliflora*-dominated forest cover; S_{BR} : Soil basal respiration; S_C : Soil carbon; S_C/S_N : Soil carbon to soil nitrogen ratio; S_M : Soil moisture; S_{MBC} : Soil microbial biomass carbon; S_{MBC}/S_C : Soil microbial biomass carbon to soil carbon ratio; S_{MBN} : Soil microbial biomass nitrogen; S_N : Soil nitrogen; S_{OM} : Soil organic matter; S_P : Soil phosphorus; S_{SIR} : Soil substrate-induced respiration; VF: Vegetable field

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Authors' contributions

AM proposed the idea and conducted the field sampling, data collection, laboratory analysis, data interpretation, and manuscript writing. KSR guided the study, interpreted the results, and critically reviewed the idea. All authors read and approved the final manuscript.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Competing interests

The authors declare no competing interests.

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