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Microbial Community, Biomass and Physico-Chemical Properties of Soil in Dry Tropics

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Abstract

Soil physicochemical and microbial properties can be regarded as an important tool to assess soil quality and health. Studying the soil properties under different land use types is great practical significant for land use and soil management regarding soil carbon dynamics and climate change mitigation. However, the changes in land-use types and their effects on soil physicochemical and microbial properties are largely debated and rather unclear. Four different land use types were used to study soil microbial and soil physico-chemical properties. Soil organic carbon and total nitrogen, soil microbial biomass and microbial diversity were determined by micro kjeldahl method, fumigation and extraction method and FAME GC-Ms, respectively. Among all land use pattern the highest water holding capacity (40.06±0.74%), porosity (0.539±0.011%), soil macro-aggregates (64.16±2.64%), organic carbon (0.84±0.054%), total nitrogen (0.123±0.013%), microbial biomass carbon (570.65±35.05 µg/g) and nitrogen (84.21±3.186 µg/g), basal respiration (3.64±0.064µg/g) and *b-glucosidase* (809.68±39.7µgµg PNP g-1 dry soil h-1) were found to be under natural forest followed by in decreasing order bamboo plantation, degraded forest and agricultural land. Significant differences were observed among the land use types with microbial biomass carbon and *B-glucosidase* activity. Furthermore, the correlation of analysis showed that microbial biomass, organic carbon, *b-glucosidas* activity, total nitrogen, moisture content, porosity, water holding capacity, soil macro aggregates were positively correlated to each other and negatively correlated with bulk density, meso and micro soil aggregates at $p<0.05$. The PLFA analysis showed that microbial community diversity exhibited distinct patterns among land-use types. The conversions of natural forest to other land use type, the amount of PLFA were reduced significantly. The natural forest had high microbial diversity followed by in decreasing order bamboo plantation, degraded forest and agricultural land. Among the organisms G^- bacteria and fungi were showed decreasing order from natural forest, bamboo plantation, degraded forest and agricultural land. The reverse was true for G+ bacteria. The result of this study showed that soil physico-chemical and microbial properties were significantly affected by land use types. Thus bamboo based fallow has the potential for improving soil quality and properties in the short term.

Keywords: Microbial soil diversity, Land use type, Microbial biomass, Soil Physico-chemical properties

Background

Soil microorganisms are important components of terrestrial ecosystems (Chandra et al., 2016) and drive many soil services such as nutrient cycles (Yin *et al*., 2010; Kirk *et al.,* 2004 and Garbeva et al., 2004) and maintenance of soil function which directly involve in maintaining soil fertility and its structure (Kujur and Patel et al., 2014). They are also involved in mediating global climate change, by acting as C sources and sinks, and by generation of greenhouse gases such as nitrogen oxides and methane. Different studies have demonstrated that the soil microbial activity, biomass, and composition depend on plant type, parent material and agricultural practices. As an important part of soil ecosystem, land use changes strongly impact soil functions, particularly microbial biomass and activity, microbial community, soil organic carbon and nitrogen and other soil physical properties (Tripathy and Singh, 2009). Maintaining soil quality (which includes various soil biological, physical and chemical properties) is of major importance for any soil management strategy.

Conversion of natural forest to other land-use types leads to not only climate change, loss of biodiversity, change in ecosystem services etc, but also affects soil biological and physico-chemical properties (Tilman, 2001; Ashagrie et al., 2007). Several studies have documented that the conversion of natural forest to other land-use types significantly influenced soil health and quality (Yu et al., 2012 and Kumar and Ghoshal, 2017), particularly in temperate regions (Kumar and Ghoshal, 2017). However, restoration of forests poses a major challenge globally, particularly in the tropics, as the forests in these regions are more vulnerable to land-use change (Kumer and Ghoshal., 2017 and Jackson et al., 2007). Therefore, how land-use change affects the community composition in terms of disturbance and ecosystem restoration in the dry tropics yet not clearly studied (Kumer and Ghoshal., 2017).

Increasing evidence has shown that soil microbial attributes are potential early indicators of the changes in soil quality because these parameters are more sensitive than are the chemical and physical properties of soil. The microbial biomass has been characterized as a sensitive index for changes in the soil organic carbon that result from management and land use. Hence, microbial community structure, biomass, and specific functions of soil microorganisms appear to be of major importance for general soil functions and if detectable could serve as sensitive soil quality indicators (Jenkinson & Ladd, 1981). Therefore, the present study aims to investigate the effect of different land use types (Natural forest, Degraded forest, Bamboo plantation and Agricultural land) on the microbial community and other physic-chemical properties of soil. The study hypothesized that different land use types significantly affect the microbial community and physico-chemical properties.

Results

Soil Physico-chemical properties

Soil physico-chemical properties differed significantly under four land-use patterns (Table 1 and Figure 2). Soil porosity (0.539%), soil aggregates and water holding capacity (WHC) (40.06%) significantly higher in natural forest. However, soil moisture content and bulk density were significantly higher in bamboo planation (2.78%) and agricultural land (1.37 g/cm^3), respectively at $p<0.05$ (Fig 2). Soil aggregates, including macro-aggregates, meso-aggregates and micro-aggregates were significantly affected by land use types. Across different land use types, macro-aggregates constituted (42–64%) of total soil followed by meso-aggregates (25 to 33.6%) and micro-aggregates (10–20%) (Table 2). Macro-aggregates were significantly higher in natural forest (64.16%) followed by bamboo plantation (51.65%), degraded forest (46.83%) and agricultural land (42.94%). The soil organic carbon and total nitrogen ranged from (0.435%-0.84%) and (0.123%-0.014%), respectively. The %OC and tN were found to be the highest in natural forest, followed by bamboo plantation and the lowest in agricultural land (Table 2). The highest %OC value (0.84%) and tN (0.123%) were found in natural forest soil and the lowest %OC (0.435%) and tN (0.014%) in the agricultural land. The analysis of variance showed that there was significant difference between natural forest and other land use types at $P<0.05$ in soil total nitrogen.

Soil Microbial Biomass, Basal Respiration (BR) and Enzyme Activity

As shown in Table 2, results of the **MBC** and **MBN**, **BR** and enzyme activity varied significantly among the land use patterns. The highest **MBC** and **MBN** were obtained from natural forest; whereas the least was recorded in agricultural land. The mean values for **MBC** were 570.65, 233.94, 479.03 and 225.59µg/g in the natural forest, bamboo plantation degraded forest and agricultural land, respectively. Likewise, the mean **MBN** values under the natural forest, bamboo plantation degraded forest and agricultural soils were 84.21, 48.95, 63.05 and 43.14µg/g, respectively. The maximum **BR** was found in natural forest, and decreased substantially in bamboo plantation, degraded forest, and attained its minimum in the agricultural land (3.64, 3.37, 2.69 and 2.56µgCO2-C g^{-1} h^{-1}, respectively) (Table 2). Similarly, the results of the *b-glucosidase* activity varied significantly among the land uses and the activity was ranged from 380.5 to 809.69µg PNP g^{-1} dry soil h^{-1}. Natural forest has shown maximum *b-glucosidase* activity (805.69) whereas degraded forest has shown the least *b-glucosidase* enzyme activity (380.8). The natural forest had 35.82% of enzyme activity followed by bamboo plantation (25.54%), agricultural land (21.81%) and finally the degraded forest (16.83%).

Pearson's correlation coefficients between MBC, SOC, MBN, *b-glucosidase* activity, STN, moisture content, porosity, WHC, soil aggregates and bulk densityis given in Table 3. MBC, SOC, MBN, *b-glucosides* activity, STN and soil macro aggregates were strongly positively correlated to each other, and negatively correlated with bulk density, meso and micro soil aggregates. Additionally, soil organic carbon and total nitrogen were positively correlated with porosity (r=0.703 and 0.555), water holding capacity (r=0.76 and 0.66) and macro soil aggregates (r=0.929 and 0.970) while less/weakly correlated with moisture content (r=0.548 and

0.01). In contrast, soil organic carbon and nitrogen negatively correlated with bulk density (r=-0.722, and -0.568, $p<0.05$, respectively), soil meso (r= -0.901, -0.989, respectively) and micro aggregates (r= -0.946 and -.936, $p< 0.05$, respectively). Macro soil aggregates was found to be significantly positively correlated with soil total nitrogen (r=0.97, $p<0.05$). Moreover, MBC, MBN and *b-glucosidase* were strongly correlated with each other.

In comparison to physical variables, strong and significant correlations were found between chemical and biological variables. Microbial biomass carbon and nitrogen, *b-glucosidase*, showed strong positive correlation with SOC, soil tN and macro soil aggregate; weakly correlated to porosity, WHC and moisture contents. However, they were negatively correlated with bulk density, soil meso and micro aggregates.

Soil microbial PLFA profiles

Results of the soil microbial PLFAs from different land use types are presented in (Table 4). The bacterial PLFAs and fungal PLFAs were significantly higher in natural forest and bamboo plantation than in degraded forest and agricultural land. The highest total bacterial and fungal PLFAs were recorded in forest soils with a dominance of G- PLFAs over the corresponding G^+ PLFAs (G+/G−PLFA ratio of 0.42). However, the smallest amount of total bacterial and fungal PLFAs was recorded in agricultural land. The conversation of natural forest to bamboo plantation, degraded forest and agricultural land resulted in a significant increase in G^+ PLFAs, however, sharp decreased in G^- PLFAs and fungal PLFAs. The F: B ratios were significantly higher in natural forest soil and bamboo plantation soils than degraded forest and agricultural land (Table 4).

Discussion

This study demonstrated that land use change greatly impacted soil microbial community and biomass, basal microbial respiration as well as soil physic-chemical properties in the dry tropics of India (Figure 2, and Tables 1, 2, 3 and 4). Land use change may lead to changes in soil physico-chemical and biological properties through their influence on various ecological processes (Chen *et al.*, 2010 and Zhang et al., 2016). The conversion of native ecosystem to other land use types like agricultural land caused a negative response in soil physico-chemical and microbial properties in the study area. Generally, natural forest found to be significantly higher in porosity, macro-aggregates, WHC but the least in bulk density, meso-aggregates and micro soil aggregates whereas agricultural land found to be the higher in bulk density (Fig. 2 & Table 1). Similar study reported by Tripathi and Singh (2007) soil physic-chemical properties can be significantly improved for the vegetation systems having higher organic matter content such as forest, mixed forest ecosystems compared to savanna and cropland ecosystems.

The reduction in WHC, porosity, moisture content and macro aggregates, and increase in bulk density due to the conversion of natural forest to degraded forest and agricultural land (Fig 1). Such trends were also reported by Singh et al. (2009) and Chen et al. (2010). This was probably due to the decrease in organic matter and aeration following cultivation, which may promote drying (Singh *et al*, 2009); evaporation in the soil surface Singh *et al*, (2009); decreased SOC and soil aggregation (Iqbal and Goni, 2015), as a result of repeated events of sowing and harvesting. Bot and Benites (2005) also reported that bulk density was lower in soils with high organic matter content. The present study revealed that re-afforestation of the degraded forest significantly improves the soil physical properties. Bamboo planation were significantly increased the WHC, porosity, moisture content and macro aggregates, but decreased in bulk density of soil as compared to degraded forest and agricultural land (Fig 1). This is probably due to higher addition of leaf and root litter in the soil (Zhang et al., 1988 and Singh et al., 1989). the higher soil aggregates in natural forest could be due to the fact that no tillage in natural forest, lower disturbance and higher organic matter input (litters and root exudates) that bind soil aggregates together resulting in improved soil structure formation (Bot and Benites, 2005).

Soil organic C and N is considered to be one of the major attributes of soil fertility and agricultural sustainability (Lal, 2002). As per the finding of this study, the highest OC and tN was found to be under natural forest (0.84%,0.123%) and the lowest OC and tN was found to be under agricultural land (0.435%,0.014%) (Table 2). This is comparable with other similar studies elsewhere (Pereira *et al*., 2013; Gol, 2009 and Iqbal *et al*., 2014). The study indicates the degradation of natural forest and conversion to agricultural land was significantly decreased soil OC and tN. The regular addition of plant litter (above and below ground plant parts) and limited disturbances in the natural forest (grazing, logging, lack of tillage, high plant biodiversity, and root exudates) (Iqbal and Goni, 2015 and Srivatava and Singh 1991) may contribute for high soil organic carbon concentration. Moreover, the higher soil OC and tN in bamboo plantation as compared to degraded forest and agricultural land was probably due to addition of nutrient rich leaf litter to soil and also due to recycling of these nutrients (Chaudhary et al., 2008 and Behera et al., 2010: Jenkinson and Rayner (1977); Paul *et al*., (1997); Tripathi and Singh (2007); Saha *et al.,* 2010; Vesterdal and Leifeld, 2010; Tripathi and Singh, 2007 and Singh and Ghoshal, 2006).

Microbial biomass is considered a sensitive indicator of soil quality and is closely related to soil fertility. In this study, the MBC and MBN were significantly affected by land use changes. It was observed that the MBC and MBN in natural forest were found to be higher and significantly decreased in degraded forest and agricultural land (Table 2). This result is consistent with the observations of other studies ((Kara and Botal, 2008 and Pabst *et al*., 2013). The highest MBC and MBN in the natural forest is likely the result of increased supply of soil organic matter, more diverse organic matter input and associated processes. For example, previous studies have demonstrated that mixed forests exhibited higher quality of litter production and higher rate of litter decomposition and soil nutrient mineralization than monocultures. High levels of root debris and exudates supported high microbial activity (Kara and Botal, 2008; Bhuyanet al., 2013).

The metabolic activities of soil microbial communities under four different land use types was quantified by measuring the amount of CO_2 produced or O_2 consumed in a given soil (Table 2). The study found that natural forest was higher in soil BR while agricultural land was recorded the least. Natural forest and bamboo planation were significantly different from degraded forest and agricultural land. The similarity of the soil basal respiration values in the different areas suggested similar microbial activity (Pereira *et al*., 2013). The higher basal soil respiration in the natural forest indicates the higher soil microbial activity due to the permanent and continuous addition of source of labile organic matter to the soil and the consequent stimulation of heterotrophic microorganisms; rapid decomposition of organic residues that make nutrients available for plant growth (Araújo *et al*., 2009; Pereira *et al*., 2013). Soil BR in bamboo plantation was 2% lower than natural forest, but 5% and 6% higher than degraded forest and agricultural land, respectively. Such arise in soil basal respiration showed the trend of restoration of degraded forest towards the natural forest occurring with bamboo plantation.

The present study revealed that change in land use significantly affects the *b-glucosidase* activity. From Table 2, it can be seen that the *b-glucosidase* activity in the natural forest is quite higher than other land use types. This is consistent with previous studies (Bandick and Dick, 1999; Roldan *et al*., (2005). The higher *b-glucosidase* activities in natural forest may be the consequence of both microbial growth and stimulation of microbial activity by enhanced resource availability (increase in the input of organic matter in the soil and improvement of soil physical properties), as well as of changes in microbial community composition (Bhattacharya *et al*., 2005; Eivazi and Tabatabai, 1990; Iovieno et al., 2009; Tejada et al., 2009; Mandal et al., 2007 and Nayak et al., 2007; Kong *et al*., 2007; Liu *et al*., 2008). Compared to natural forest the *b-glucosidase* activity in bamboo planation was 10% lower; while 9% and 4% higher than degraded forest and agricultural land, respectively. It was significant at $p<0.05$. The increment of enzyme activity in bamboo plantation as compared to degraded forest and agricultural land may be due to addition of leaf litter from bamboo, which leads to stimulate microbial metabolism and decomposition rate (Masciandaro *et al*., 2003). Unlikely, the *b-glucosidase* activity was deceased as compared to natural forest may be due to the thinner canopy and greater soil exposure may have resulted in greater temperature and soil moisture fluctuation, as well as of other factors that influence the decrease microbial activity (Pereira *et al*., 2013).

According to Oyedele *et al.*, (2015) microbial biomass carbon and microbial biomass nitrogen were significantly correlated to the physico-chemical properties of the soil. The same result was found in the present study (Table 3). On average 95% of the microbial biomass and activities were governed by the soil organic carbon, soil total nitrogen, water holding capacity, soil aggregates, porosity and bulk density either positively or negatively (Table 4). The significant positive relations between the soil MBC and SOC agree with earlier reports by (Logah*et al*., 2010; Yang *et al*., 2010; Makova *et al*., 2011; Cheng *et al*., 2013; Bhuyan*et al*., 2013). This might be due to microbial biomass concentration depended on the organic matter availability to microbial activity (Anderson &Domsch, 1989), however, Insam & Domsch (1989) found no correlation between the biomass carbon and organic carbon. Similarly, SOC was significantly correlated to STN (Yang *et al*., 2010; Cheng *et al*., 2013; Kara and Bolat, 2007) while STN was strongly related to MBN agrees with results by (Yang *et al*., 2010). These results indicate that MBN levels in the soils were determined by SOC and STN (Adeboye *et al*., 2011). Several studies have found strong correlations between MBN and STN (Anderson and Domsch, 1989; Insam *et al*., 1989).

Furthermore, the significant positive relations between the soil MBC and MBN agree with earlier reports by (Li *et al*., 2013; Kara and Bolat, 2007). As mentioned above, soil organic carbon significantly positively correlated with soil total nitrogen; soil organic C increases, the total N increase and vice versa. The dynamics of N in mineral soil is closely linked to C, because most N exists in organic compounds and heterotrophic microbial biomass, which utilize organic C for energy. As a result, the microbial biomass N showed a significant positive correlation with microbial biomass C. On the other hand, significant positive correlations between microbial biomass carbon, soil basal respiration and microbial biomass nitrogen indicate that the dynamics of these three elements are closely interlinked in the nutrients poor tropical soils (Arunachalam, 2003).

The results of the present study showed that natural forest was highest in microbial diversity (PLFAs) than bamboo plantation, degraded forest and agricultural land. The results of the present investigation were corroborates with the many previous research reports (Torsvik and Ovreas, 2002; Mishra, 1996). The study revealed that there were higher PLFAs from G^+ bacteria along the land use types than G^- and fungal PLFAs. The better G^+ adaptability to various environmental stresses relative to their G^- counterparts is attributed to their ability to form spores, which promote survival under conditions of carbon (C) limitation (Boylen and Ensign,1970), and possibly facilitates growth of the former over the latter (Moore-Kucera and Dick, 2008). Among the bacterial PLFAs, G^- PLFAs appeared to be more prone to disturbance. The decrease in the fungal community in degraded forest could be because filamentous fungi are more sensitive to physical disturbance than single celled organisms (Kabir et al., 1999). In agricultural land, physical disturbance, mainly tillage, destroyed fungal mycelium networks, and the combination of mechanical destruction, soil compaction, and reduced pore volume collectively led to the lowest fungal PLFA values (Bardgett et al., 2001; Garcia-Orenes et al., 2013). This might be due to changes in litter quantity and quality, which possibly accounts for the changes in bacterial and fungal PLFAs (Denef et al., 2009).

Soil physico-chemical and biological properties were significantly affected by land use change. Water holding capacity, porosity, soil macro-aggregates, soil organic carbon, and soil total nitrogen were found to be higher in natural forest followed by in decreasing order bamboo plantation, degraded forest and agricultural land. In contrast to this, agricultural land was higher in bulk density as compared with other land use types whereas natural forest was lower in bulk density. Soil organic carbon, soil total nitrogen, moisture content, porosity, water holding capacity, soil macro aggregates were positively correlated to each other and negatively correlated with bulk density, meso and micro soil aggregates. Among the four land use type's natural forest had high microbial diversity followed by in decreasing order bamboo planation, degraded forest and agricultural land. Thus bamboo based fallow has the potential for improving soil quality in the short term.

Methods

Study area and Description of sites

The study was conducted in Baranas Hindu University, Varanasi, India from March to August, 2016. Samples were collected from Barkachha, Mirzapur district. Mirzapur is located at 25.15° N 82.58° E. It has an average elevation of 80 meters (265 feet). It is a city in Uttar Pradesh, India, roughly 650 km from both Delhi and Kolkata, almost 89 km from Allahabad and 57 km from Varanasi. It has a population of 233,691 (2011 census). The climate in Mirzapur is warm and temperate. In winter, there is much less rainfall than in summer. The average annual temperature and rainfall is 26°C and 975 mm, respectively. The study area was classified into four sites based on their vegetation cover: Natural forest, Degraded forest, Bamboo plantation and agricultural land (Fig 1).

The forest site was the mixed dry deciduous type dominated by *Acacia catechu* Wild., *Albiziaodoratissima Benth*., *Acacia nilotica (L.) Willd*. *Boswelliaserrata Roxb*., *Nyctanthesarbortristis L*., with scattered trees of *AzadirachtaindicaJuss*. And *ZizyphusglaberrimaSantap*. The forest floor was covered with herbaceous vegetation comprising *Ocimumamericanum L*., *Pisumarvense L*., *Rhynchosia minima (L.) DC*., *Cassia sophera*(L.) Roxb.,*Acrocephalusindicus (Burm. f.) Kuntze*.,*Cynodondactylon L.,* and *Oplismenusburmannii Ritz*. The degraded forest site was dominated by *Z. glaberrima*, *ChrysopogonfulvusSpreng*.,*Heteropogoncontortus L.,Adina cordifoliaRoxb*. and scattered trees of *ButeamonospermaLamk*. Herbaceous vegetation in the degraded forest was dominated by *Cassia tora L.,Oldenlandiadiffusa Roxb., Sporobolus spp*., *Panicumpsilopodium Trin*. and *Alysicarpusvarginalis (L.) DC*.

Soil Sampling and Techniques

Soil sample was taken from four land use types (NF, DF, BP and AL). The natural forest was further divided into six sub-sites of 100m x 100m. From each sub-site, four soil samples were collected (i.e. 24 soil samples in total from each study site) and mixed to represent the single composite sample of a study site. The same procedure was followed for degraded forest, bamboo plantation and agricultural land. The samples were collected from 15cm depth by using core borer. Then the sampled soil was immediately brought to the laboratory by (approx. 250g) in clean, dry and sterile polythene bags using sterilized spatula. The soil physico-chemical characteristics (moisture, pH and organic content) were analyzed by standard methods as suggested by (Allen *et al*., 1974 and Waksman 1952).

Soil analysis

Soil physico-chemical characteristics; moisture, Bulk density/particle density, Porosity, Soil water holding capacity (WHC), Soil aggregates, pH and organic content were analyzed by standard methods as suggested by (Allen *et al.,* 1974; Waksman, 1952; Kemper and Chepil, 1965).

Soil organic carbon and total nitrogen

Soil organic C was estimated by the **dichromate oxidation and titration method** (Kalembasa and Jenkinson, 1973), whereas total N concentration was measured by the micro kjeldahl method (Jackson, 1973) by using a Gerhardt digester and distillation unit. The calculation was done by the following formulas:

$$\%\, Organic\ carbon = \frac{(B - T) * 0.15}{Sample\ weight\ (g)}$$

$$\%N \ = \frac{(T - B) * 0.1 * 1.4}{x\ sample}$$

Whereas, B-blank titrate value; T-soil titrate value

Soil Microbial Biomass

Microbial biomass C was estimated by the **chloroform fumigation extraction method** using purified $CHCl_3$ treatment (Brookes et al., 1985; Vance et al., 1987). Microbial biomass N concentration was measured by the micro kjeldahl method (Jackson, 1973) by using a Gerhardt digester and distillation unit. Microbial biomass carbon (**µg** dry soil) and N are calculated by the following formulas:

$Microbial\ Biomass\ C = \frac{NF-F}{B} * 3168$ and

$$Microbial\ Biomass\ N = (Fu - NFu) * 207.407$$

Basal Respiration

The basal respiration/metabolic activities of soil microbial community were determined by (Namipieri*et al* 1990) method.

Calculation: µg CO_2 oven dry soil /h at $22^{O}C$ = $\frac{(Vo-V)*S*22*12*1000}{M*dwt*t*44}$

$$\mu g\ oven\ dry\ soil = \frac{(Vo - V) * S * 22 * 12 * 1000}{M * DWt. * t * 44}$$

Whereas; Vo- volume of HCl used for titration of blank (mean of three replicates); V-Volume of HCl used for titration of sample (mean of three replicates); S- the strength of the HCl in normality; M- weight of soil g/sample; dwt- the oven dry weight of 1g sample; t- time of incubation in hrs.

Soil Enzyme

β-Glucosidase activity was assayed by the method of Eivazi and Tabatabai (1988), using the substrate analogue para-nitrophenyl-β-d-glucopyranoside (pNPG). The activity of the enzyme is calculated by the following formula:

$$EA = \frac{OD}{CF} * 100 + \frac{n(n-1)x^2}{2}$$

Soil microbial community analysis

To analysis soil microbial community phospholipid fatty acid assay (PLFAs) were used. The PLFAs includes extraction, fractionation, methylation and chromatography. Phospholipid fatty acids was extracted and quantified from 3g (dry weight equivalent) of soils using a procedure described by Bossio *et al*., (1998).

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

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

Competing interests

The authors declare that they have no competing interests.

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Authors' Contributions

WG and **NG** have played a great role for the successfulness of the paper. WG and NG have involved in study designing and sample site selection, conducting laboratory experiment, data analysis, and interpretation of the analyzed data and review different article for writing up the paper.

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Figure Legends

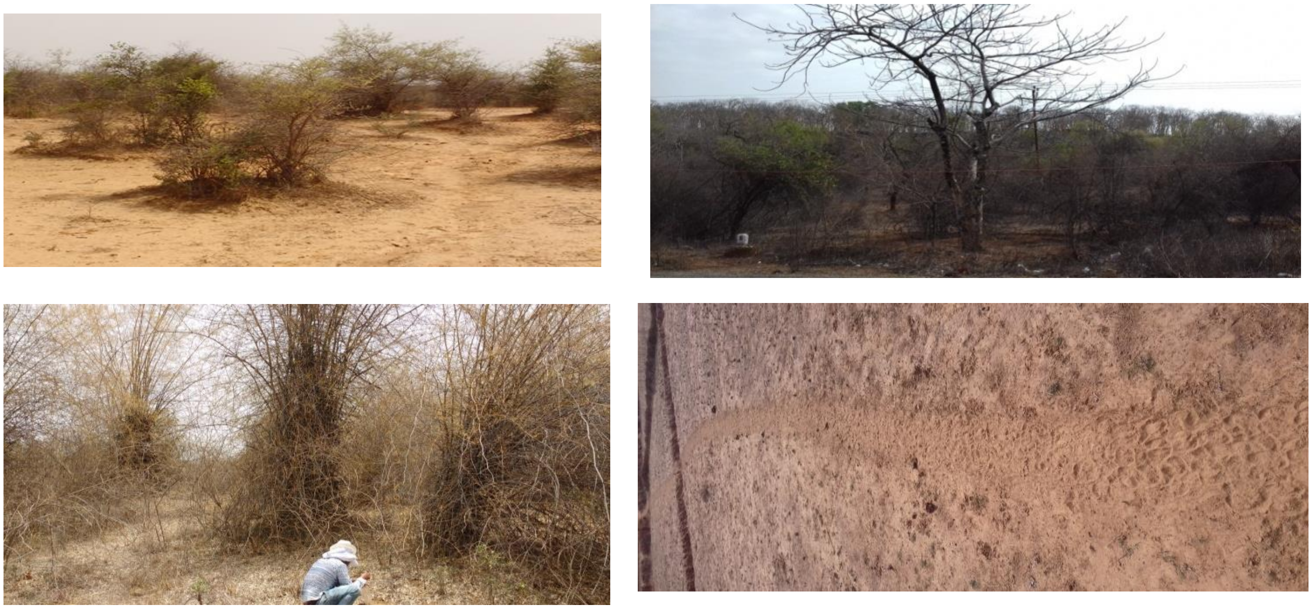

Figure 1. Study sites: Natural forest (NF), Degraded forest (DF), Bamboo plantation (BP) and Agricultural land (AL), respectively.

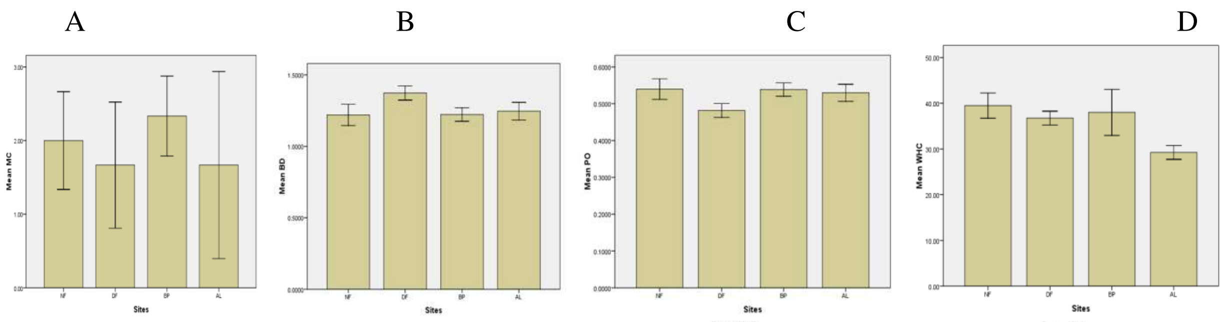

Figure 2. Comparison of MC, BD, porosity and WHC under different land use types: Natural Forest (NF), Degraded Forest (DF), Bamboo Plantation (BP) and agricultural Land (AL)

Table 1. Percentage of distribution of different dry aggregate soil size classes in different land use types

Soil aggregates (%)	**Land use type**				**LSD**
	NF	DF	BP	AL	
Macro-aggregates	64.16±2.64^{a}	46.83±1.00^{b}	51.65±5.4^{b}	42.94±1.11^{b}	8.48
Meso aggregates	25.68±2.48^{a}	35.16±0.73^{b}	33.10±4.74^{b}	36.39±1.69^{b}	9.28
Micro-aggregates	10.16±1.38^{a}	18.01±0.96^{b}	15.25±1.86^{ba}	20.66±1.81^{b}	4.65

Values are mean ± SE. In each rows, values having different superscript are significantly different from each other ($P < 0.05$).

Table 2. Soil organic carbon (SOC), soil total nitrogen (STN), Microbial biomass carbon (MBC), Microbial biomass nitrogen (MBN) and soil basal respiration (SBR) under different land use types.

	Land use type				LSD
	NF	DF	BP	AL	
SOC (%)	0.84±0.054^{a}	0.448±0.113^{b}	0.72±0.074^{a}	0.435±0.042^{b}	0.21
STN (%)	0.123±0.013^{a}	0.027±0.003^{b}	0.033±0.0034^{b}	0.014±0.0016^{b}	0.021
MBC (µg/g)	570.65±35.05^{a}	233.94±60.36^{b}	479.03±21.48^{a}	225.59±20.84^{b}	114
MBN (µg/g)	84.21±3.186^{a}	48.95±2.506^{b}	63.05±4.281^{c}	43.14±1.784^{b}	9.23
MBC/MBN	6.77	4.78	7.59	5.23	
SBR (µg CO_2)	3.64±0.064^{a}	2.69±0.11^{b}	3.37±0.067^{a}	2.56±0.11^{b}	0.29
B-glucosidase (µgµg PNP g-1 dry soil h-1)	809.68±39.7^{a}	380.50±17.02^{c}	577.28±84.39^{b}	492.88±58.13^{c}	181.35

Values in Mean ± SE, across the rows Different letters (a, b, c) show that there is difference among the mean values at the significance level $P < 0.05$.

Table 3.Correlation matrix for physical, chemical, and microbiological characteristics of soils from different land uses.

Soil variable	SBR	SOC	MBC	B-glucosidase	STN	MBN	MC	PO	WHC	BD	MA	ME
SOC	.997**	1										
MBC	.997**	1.000**	1									
B-glucosidase	0.877	0.91	0.903	1								
STN	0.815	0.828	0.811	0.901	1							
MBN	.960*	.963*	.955*	0.924	0.944	1						
MC	0.583	0.548	0.571	0.205	0.01	0.34	1					
PO	0.758	0.703	0.703	0.401	0.555	0.712	0.615	1				
WHC	0.808	0.76	0.756	0.499	0.66	0.789	0.547	.991**	1			
BD	-0.776	-0.722	-0.722	-0.423	-0.568	-0.727	-0.624	-1.000**	-.992**	1		
MA	0.926	0.929	0.918	0.909	.970*	.994**	0.251	0.703	0.787	-0.717	1	
ME	-0.89	-0.901	-0.887	-0.929	-.989*	-.982*	-0.154	-0.623	-0.718	0.637	-.994**	1
MI	-.951*	-0.946	-0.937	-0.876	-0.936	-.994**	-0.35	-0.778	-0.848	0.79	-.993**	.973*

BD, bulk density; WHC, water holding capacity; SOC, soil organic carbon; STN, total nitrogen; MBC, microbial biomass carbon; SBR, soil basal respiration; MBN, microbial biomass nitrogen;PO, porosity; MA, macro aggregates; ME, meso aggregates; MI, micro aggregates

Table 4. The amount of total phospholipid fatty acids (PLFAs), bacterial, Gram-positive bacterial, Gram-negative bacterial, and fungal PLFAs (mg/g DW) under four land uses

	NF	BP	DF	AL
G-	37.43±2.21^{a}	22.51±1.75^{d}	15.78±0.85^{b}	5.29±0.477^{c}

G+	15.61±1.25[a]	25.17±2.02[c]	30.64±0.82[b]	39.4±3.73[c]
Fungi	20.49±1.24[a]	15.55±1.14[c]	10.96±0.86[b]	8.06±0.59[b]
Total	73.55	63.23	57.38	52.75
G^+/G^-	0.42	1.12	1.94	7.44
F/B	0.386	0.326	0.236	0.18

593 Different letters in a row meant significant difference at $p<0.05$ levels.

Figures

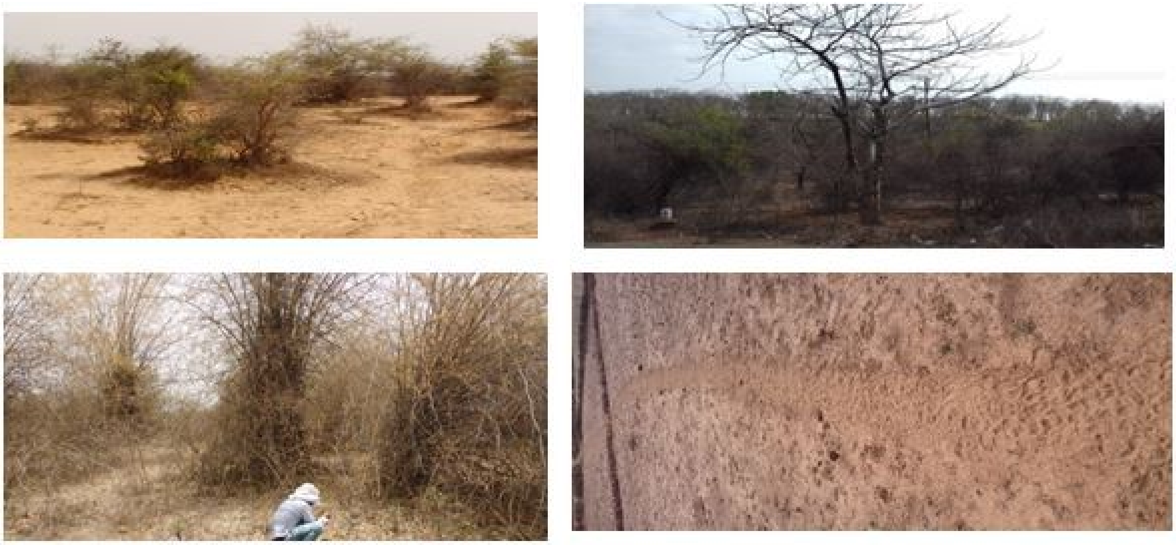

Figure 1

Study sites: Natural forest (NF), Degraded forest (DF), Bamboo plantation (BP) and Agricultural land (AL), respectively.

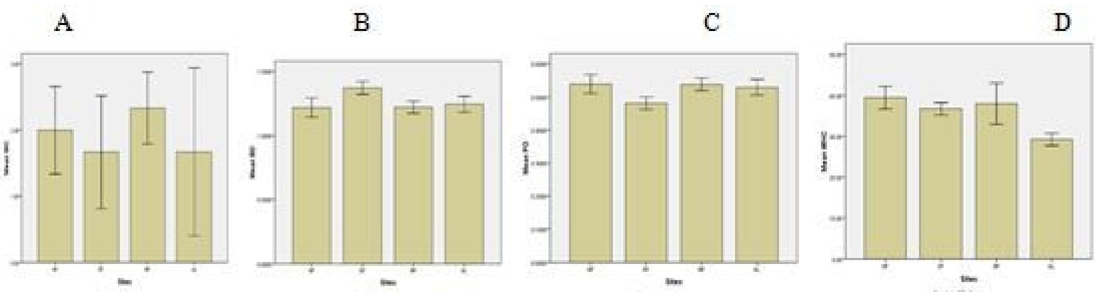

Figure 2

Comparison of MC, BD, porosity and WHC under different land use types: Natural Forest (NF), Degraded Forest (DF), Bamboo Plantation (BP) and agricultural Land (AL)