Impact of land uses on soil quality and microbial dynamics in eastern Indian *Terai* region

ABSTRACT

Soil quality and microbial dynamics are major determining factors of soil's ecosystem functions. The eastern Indian Terai region, situated at the foothills of the Himalayas, is known for its diverse land uses and coarse alluvial fertile soils. This study examined the impact of two distinct land uses i.e. forests and croplands on soil quality and microbial dynamics in a part of this Terai region, located within the Indian state of West Bengal. Outcomes indicated that forest soils had higher total organic carbon and better microbial dynamics in terms of biomass carbon and activity. Regular addition of fresh organic matter (by leaf and litterfall) and higher residence time of carbon in undisturbed ecology may be the causes for this. In contrast, cropland soils showed higher presence of available nitrogen and phosphorus, possibly due to injudicious application of fertilizers. Leaching and runoff losses of these elements might cause environmental degradation like nitrate contamination in water and eutrophication. This study emphasized how natural ecology like forest improves soil quality and microbial dynamics while anthropogenic managements cause soil and environmental degradations.

Keywords: Terai region; Soil ecosystem functions; Land uses; Forests; Croplands

1. INTRODUCTION

Soil quality and microbial dynamics are key indicators of the terrestrial ecosystem health (Muñoz-Rojas, 2018). However, high population pressure, changes in land uses and land degradation cause their deterioration (Lal, 2018; Muñoz-Rojas, 2018). The eastern Indian Terai region, located at the foothills of Himalayas, is unique with its varied ecosystems and fertile lands. This region is characterized by undulating physiography, high rainfall, and coarse alluvial soils (Kar, 2018; Sharma et al., 2023). The diverse land use land cover (LULC) of this region have influenced the soil properties, amending soil quality and its ecosystem functions (Verburg et al., 2009; Smith et al., 2016).

This study focused on soil quality and microbial dynamics of the Terai region within the Indian state of West Bengal considering two distinct LULCs *viz*. forests and croplands. This area is home for a number of protected forests like Buxa Tiger Reserve, Jaldapara National Park, Garumara National Park, Chapramari Wildlife Sanctuary, Mahananda Wildlife Sanctuary, Baikunthapur forest etc. and they represent undisturbed ecosystem and soils. In contrast, this region also has vast croplands. The soils of these croplands face continuous tillage practices, anthropogenic perturbation, addition of organic matter and fertilizers, which changes the soil dynamics completely (Carvalho, 2006; Lal, 2007; Rastogi et al., 2023). In this context, the present study aims to find out the influence of these land uses on soil quality and microbial dynamics.

2. MATERIALS AND METHODS

2.1 STUDY AREA AND SOIL SAMPLING

Jalpaiguri district of the Indian state West Bengal was chosen as study area (Fig 1). This district represents diverse land uses and comes within the eastern Himalayan Terai region. The climate is warm subtropical and humid with annual temperature ranging between 8° to 38°C. In order to achieve the objective, soil samples were collected from forest areas and croplands. A total 60 surface soil samples were collected i.e. 30 soil samples from each of the land uses. Composite soil sampling was done for each of the soil samples. To mark the exact sampling locations, a hand-held GPS receiver (Gramin, Olathe, KS, USA) was used.

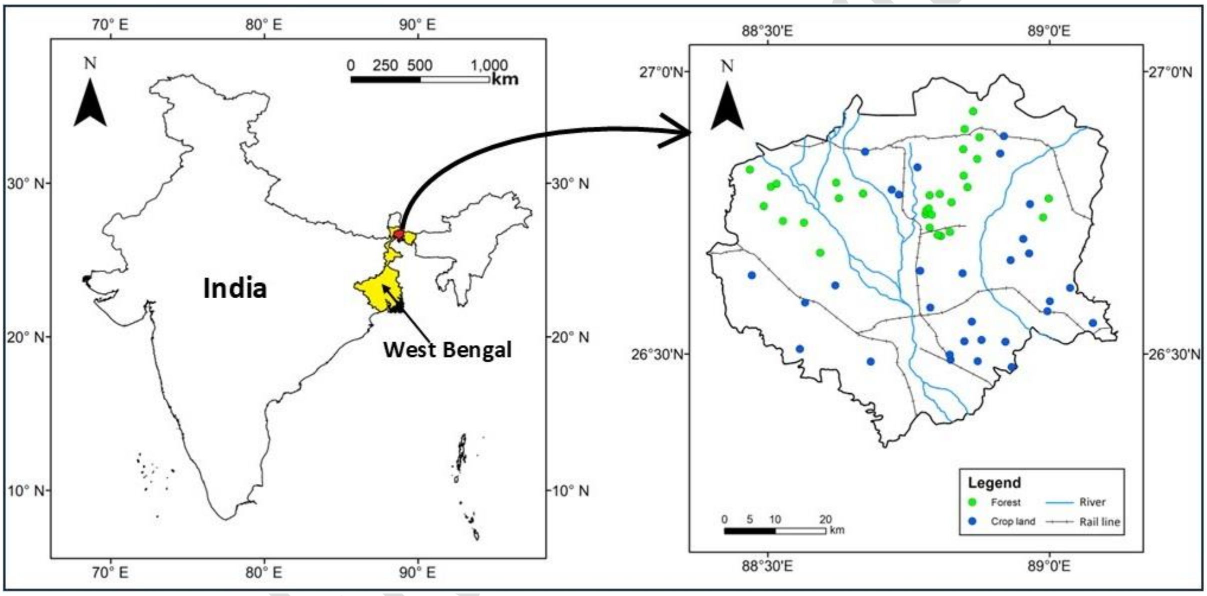

Fig. 1. Geographical location of the study area

2.2 ANALYSIS OF DIFFERENT SOIL PARAMETERS

The collected soil samples were air-dried and passed through a 2 mm sieve. Soil samples <2 mm size were used to measure soil physicochemical parameters. Bulk density was determined by tube core method (Blake and Hartge, 1986). Soil pH was measured using a pH meter with glass electrode (Jackson, 1973) while soil cation exchange capacity (CEC) was estimated using 1.0 *N* ammonium acetate at pH 7.0 (Deb et al., 2016). Exchangeable Al was estimated by KCl extraction and titration method (Black et al., 1983). Soil effective CEC was calculated by adding CEC values with exchangeable Al (Black et al., 1983). Soil texture was measured using international pipette method (Gee and Or, 2002). Soil total organic carbon (TOC) was estimated by oxidation method of Walkley and Black and then multiplying the value with 1.15 (Walkley & Black, 1934; Bhattacharyya et al., 2015). For estimation of available nitrogen and phosphorus, alkaline potassium permanganate method and spectrophotometer (Shimadzu UV–Vis 1800) after Bray and Kurtz extraction were used, respectively (Bray and Kurtz 1945; Subbiah & Asija 1956).

For the analysis of soil microbial parameters, field moist soil samples, stored at 4°C, were used. Soil microbial biomass carbon was measured using chloroform fumigation technique (Voroney and Paul, 1984) while soil respiration was measured by alkali trapping under incubation (Franzluebbers and Arshad, 1996).

2.3 STATISTICAL ANALYSIS

Statistical analysis was performed using Microsoft Excel software along with XLSTAT data analysis tool (version 2020.1.3, Addinsoft).

3. RESULTS AND DISCUSSION

Following the aim, this study implemented a stratified approach to understand the impact of LULCs on soil quality and microbial properties. Different soil indicators were analysed first to evaluate the soil quality status. Irrespective of the land uses, the soils were found acidic in nature (soil pH of forests: $\bar{x} = 5.69$ and croplands: $\bar{x} = 5.47$) (Table 1). Presence of exchangeable aluminium was also observed (forests: $\bar{x} = 0.73$ and croplands: $\bar{x} = 0.79$ cmol (p+) kg^{-1}). No significant impact of LULC was found on soil CEC (forests: $\bar{x} = 5.19$ and croplands: $\bar{x} = 5.04$ cmol (p+) kg^{-1}) and effective CEC (forests: $\bar{x} = 5.92$ cmol (p+) kg^{-1} and croplands: $\bar{x} = 5.82$ cmol (p+) kg^{-1}). Soils under both the land uses were found to be coarse in texture (loam, sandy loam, sandy clay loam) but clay percentage was slightly higher in forest soils ($\bar{x} = 17.33$ %) than in cropland soils ($\bar{x} = 14.01$ %).

Table 1. Soil physicochemical parameters of the study area

Soil Parameters		**Types of Land Use**	
		Forest	**Crop land**
Soil pH	**Mean**	**5.69**	**5.47**
	Range	*(5.34 – 6.16)*	*(5.32 – 5.59)*
Clay (%)	**Mean**	**17.33**	**14.01**
	Range	*(10.00 – 26.00)*	*(8.00 – 22.00)*
Silt (%)	**Mean**	**27.87**	**24.27**
	Range	*(16.00 – 42.00)*	*(10.00 – 36.00)*
Sand (%)	**Mean**	**54.80**	**61.72**
	Range	*(46.00 – 62.00)*	*(54.00 – 72.00)*
Textural class		Loam, Sandy Loam, Sandy Clay Loam	
CEC (cmol (p+) kg^{-1})	**Mean**	**5.19**	**5.04**
	Range	*(4.31 – 6.52)*	*(4.23 – 6.21)*
Exchangeable Al (cmol (p+) kg^{-1})	**Mean**	**0.73**	**0.78**
	Range	*(0.46 – 1.14)*	*(0.47 – 1.34)*
Effective CEC (cmol (p+) kg^{-1})	**Mean**	**5.92**	**5.82**
	Range	*(4.98 – 7.45)*	*(4.86 – 7.05)*

The forest soils were found to be very high in TOC ($\bar{x} = 22.47$ g kg^{-1}) while cropland soils had much lower TOC ($\bar{x} = 9.04$ g kg^{-1}) (Fig 2a). This was possibly due to continuous addition of fresh organic matter in forest ecology through leaf and litter fall and high turnover time of carbon in undisturbed forest soils (Prescott, 2010; Zhang et al., 2024). Low carbon status of cropland soils was associated with regular anthropogenic disturbances, break-down of soil aggregates and low residence time carbon within (Jacinthe et al., 2001; Pouyat et al., 2002; Murindangabo et al., 2023). However, even the cropland soils also had higher TOC in comparison to the Indian national average (Bhattacharyya et al., 2000; Velayutham et al., 2019). This is possibly due to the subtropical cooler climate of the study area (Bhattacharyya et al., 2000). Soil available nitrogen was found low in all the soils (Baruah and Borthakur, 1997; Wiesmeier et al., 2013). However, cropland soils were found to have the comparatively higher available nitrogen ($\bar{x}$ = 199.92 kg ha^{-1}) than forest soils ($\bar{x}$ = 178.49 kg ha^{-1}) (Fig 2b). Soil available phosphorus (in P_2O_5 form) was also found to be significantly high in cropland soils ($\bar{x}$ = 48.97 kg ha^{-1}) in comparison to forest soils ($\bar{x}$ = 9.00 kg ha^{-1}) (Fig 2c). These high presence of available nitrogen and phosphorus in croplands were probably associated with high applications of nitrogenous and phosphatic fertilizers in croplands (Bouwman et al., 2017; Huang et al., 2017).

The occurrence of microbial biomass carbon was observed higher in the forest soils ($\bar{x}$ = 547.05 µg g^{-1}) in comparison to the cropland soils ($\bar{x}$ = 330.26 µg g^{-1}) (Fig 2d). The possible reason was undisturbed soil ecology, high organic carbon and regular addition of fresh organic matter (leaf and litter), which served as the food and energy source of soil microbes (Wang and Lin, 2023). The comparatively lesser presence of soil microbes in cropland soils might be due to lower presence of organic carbon. Extensive use of pesticides might also have negatively impacted the soil microbial population (Lo, 2010; Kalia and Gosal, 2011). Irrespective of land uses, soil respiration reached its peak in the 6th day (under controlled laboratory condition) (Fig 3) and then declined towards basal soil respiration (Fig 2e). A comparison of 6th day's soil respiration indicated higher CO_2 emission from forest soils in comparison to the cropland soils. The cumulative soil respiration was also higher in forest soils ($\bar{x}$ = 339.52 µg CO_2 24 h^{-1} g^{-1}) than cropland soils ($\bar{x}$ = 162.22 µg CO_2 24 h^{-1} g^{-1}) (Fig 2f), which indicated the similar trend of microbial biomass carbon. The huge amount of leaf and litter deposition possibly boosted availability of labile carbon in forest soils, supporting good microbial activity there (Leno and Sudharmaidevi, 2021). However, these possibilities need farther confirmation through substrate chemistry analysis.

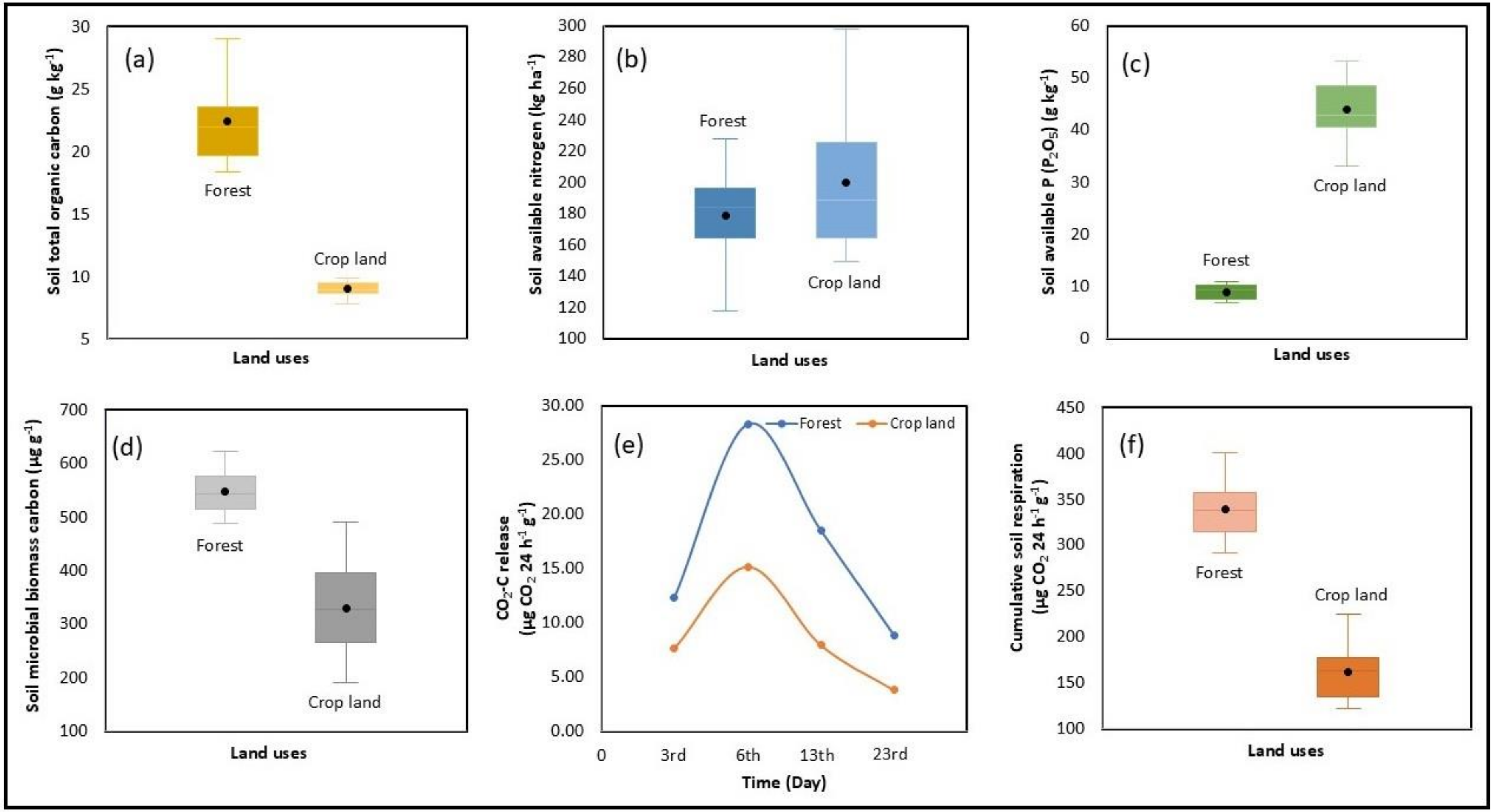

Fig. 2. Status of (a) total organic carbon, (b) available nitrogen, (c) available phosphorus (in P_2O_5 form), (d) microbial biomass carbon in soils and (e) cumulative soil respiration and (f) day wise soil respiration in the study area

4. CONCLUSION

This study found that land uses impacted very clearly on soil quality and microbial properties in eastern Indian Terai soils. The undisturbed ecology of forests and continuous addition of fresh organic matter in their soils caused an increase in organic carbon, microbial biomass and activity. On the contrary, injudicious fertilizer application resulted in high available nitrogen and phosphorus in cropland soils. Leaching and runoff of these elements might cause environmental pollution like nitrate contamination in groundwater, eutrophication etc. This study clearly indicated how anthropogenic management degrades soils in the long run.

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