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Land use changes: Strategies to improve soil carbon and nitrogen storage pattern in the mid-Himalaya ecosystem, India

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ABSTRACT

A thorough knowledge of the effects of land use systems (LUS) on the soil carbon pool and soil total nitrogen (STN) are critical to planning effective strategies for adaptation and mitigation in future scenarios of global climate and land use systems. This study conducted with the objectives of investigating soil carbon, nitrogen storage and carbon management index (CMI) in different LUS under middle Indian Himalayan ecosystem, four LUS: barren land (BL), cultivated land (CL), grass land (GL) and forest land (FL) were selected in Indian mid-Himalaya. A total of 111 composite soil samples [4 treatment (land use systems) 3- soil depths (0–15, 15–30 and 30–45 cm) and 8, 11, 8 and 10 replication for BL, CL, GL and FL systems, respectively] were collected for laboratory analyses. Forest land use system has the highest Walkley-Black Carbon (WBC), total carbon (TC), total nitrogen (TN), carbon and nitrogen (C and N)-storage and CMI values while barren land use system having least amount of WBC, TC, TN, CN-storage and CMI. Land use system had minimum effect on non-labile carbon (NLC), lability of carbon (LC), lability index (LI) and carbon pool index (CPI) of the ecosystem. Moreover, TC and TN were increase in the grass and forest land as compared to barren and cultivated land. The TC concentration was highly correlated with TN ($R^2 = 0.88$, $p < 0.01$) and soil N-sequestration ($R^2 = 0.93$, $p < 0.01$) concentrations. However, carbon storage and NSP relationship ($p < 0.01$) was NSP = 0.0916× + 0.7088 ($R^2 = 0.93$). Overall results indicated that LUS and C-storage were associated with N-storage and CMI. These results suggest restoration of degraded barren and cultivated land to grass and forest land and decrease in intensity of land use could increase carbon and nitrogen storage in the study area as well as other similar mountainous regions of Indian mid-Himalayas.

1. Introduction

Agricultural expansion in the Himalayan ecosystem resulted in plant and soil degradation due to the intensive use, climate conditions, and rugged terrain (Palni et al., 1998). Global increase of carbon di-oxide (CO_2) in the atmosphere is the attracting point from climate change (CC) point of view. This increasing concentration of atmospheric CO_2 can be reduced either by low emission or by trapping it in aquatic and terrestrial ecosystems. Among the terrestrial ecosystem, soils are the biggest carbon reservoir (Lal, 2015; Wang et al., 2016). The source of carbon stored in the soil is vegetation and its growth. The residence time of the carbon in the soil is higher as compared to carbon stored in vegetation (Lal, 2015). Soil organic carbon (SOC) is one of the five major carbon pools categorized by Intergovernmental Panel on Climate Change (IPCC) under the Land Use, Land Use Change and Forestry (LULUCF). The potential of agricultural best management practices (BMPs) towards offsetting greenhouse gas emission (GHG) emissions is estimated at 0.3 to 1.17 Pg C year^{-1} (Neufeldt et al., 2013; Neufeldt et al., 2015) and represents 2.7 to 10.4% of the global GHG emissions (Houghton, 2014; Le Quere et al., 2015). The contribution of land use types and its management to mitigate climate change by carbon (C) and nitrogen (N) sequestration is perceived to be low presumably because: (i) the capacity for soil carbon and nitrogen sinks are finite (Adenle et al., 2015; Corbeels et al., 2016; Powlson et al., 2016); (ii) diverse crop sequences or combinations with worldwide adoption of conservation agriculture promote variable effects on crop yields worldwide (Pittelkow et al., 2014); (iii) difficulty of obtaining credible estimates of total carbon (TC) and total nitrogen (TN) along with carbon management index (CMI) in the different land use system and requiring a complex framework encompassing a wide range of climate, soils

Abbreviations: NLC, non-labile C; LC, lability of carbon; LI, lability index; CPI, carbon pool index; CMI, carbon management index; LUS, land use system; BL, barren land; CL, cultivated land; GL, grass land; FL, forest land; WBC, Walkley-Black Carbon; TC, total carbon; TN, total nitrogen; CSP, carbon sequestration potential; NSP, nitrogen sequestration potential

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(texture, mineralogy), crops and cropping systems which exacerbate uncertainties in assessing carbon and nitrogen sequestration (Lam et al., 2013; Adenle et al., 2015); (iv) high risks of re-emission of SOC sequestered because even a single crop cultivation through modern agricultural practices in a long-term soil may negate previous gains in TC and TN stock (Lal, 2015); (v) a high variation and uncertainties of the carbon and nitrogen sequestration rates in grass and forest land (FAO and Agriculture Organization of the United Nations, 2015; Kassam et al., 2015); and vi) low amount of the input of biomass carbon and nitrogen return because of extreme weather events (e.g., long dry period or excessive rainfall). At the global level ~1500 Pg carbon is stored in the soil (Batjes, 1996) and ~ 9 Pg soil carbons in India (Bhattacharya et al., 2000). Soil plays vital role in mitigating climate change through sequestering carbon and nitrogen in it. Sequestration of carbon (C) from atmosphere in the soil provides long term removal of CO_2 from the atmosphere (Gupta and Sharma, 2011).

Worldwide research on organic carbon in the soil has been focused due to its potential to store a large amount of atmospheric carbon which in turn helps in functioning of soils besides mitigating climate change (Mc Bratney et al., 2014). The SOC varies with land use types (Gupta et al., 2015) due to difference in source material. Among vegetative ecosystems tree based ecosystem are paramount to reduce the atmospheric CO_2 which is stored in parts of the trees (Yadav et al., 2016) and returned to the soil via litter fall and root decomposition. Natural forests, forest plantation, agroforestry, grasslands and cultivated lands are the major ecosystems whose soil store huge amount of the soil organic carbon (SOC) and soil total nitrogen (STN). The quantity as well as quality of organic matter (OM) besides ability of the soil for retaining organic carbon determines the storage of organic carbon in the soil (Grace et al., 2005). Soils of the forest are the main carbon and nitrogen sinks as these soils have higher OM due to continuous addition of source of carbon and nitrogen in the form of roots and litter by trees. Global forest ecosystems soil store ~40% of total C-stock of the soils (Lal, 2015) and Indian Himalayan forests soils reserves ~ 33% of total soil C-stock of India (Bhattacharyya et al., 2016).

The information regarding quantity and quality of SOC and STN in the soil is crucial for sustaining soil functioning and its quality. The globally various estimate has been made for stock of SOC and STN in the soil in the context of worldwide warming (Todd-Brown et al., 2013; Tian et al., 2015). The investigation related to SOC and STN stock in different land uses types in the Indian mid-Himalaya is scanty though available for various forest types. The hypothesis set for our study was that the accumulation of different fractions of carbon and total nitrogen might be influenced by the different land use systems in the mid-Himalaya of India. To test this hypotheses, objectives of this study were (i) to determine the effect of land use types {forest (FL), grass (GL), cultivated (CL) and barren land (BL)} and soil depths (0–15, 15–30 and 30–45 cm) on SOC pools (physical) and TC/TN ratio in the middle Indian mid-Himalayas ecosystem, (ii) to assess the best land use systems and quantitative soil degradation status compare to reference site, and (iii) to find the relationships between TC and TN, soil carbon and nitrogen stock under different land use systems.

2. Materials and methods

2.1. Site description

This study was conducted at Hawalbagh cluster in Almora district of Uttarakhand in the middle Indian Himalaya. The soil samples were collected representing different sites/elevations (900–1800 m a.s.l.) of concerned land use and made a composite sample. The location of the different land use systems of experimental site in the mid-Himalaya ecosystem of India is presented in the Fig. 1. The average temperature of the last 53 years of a mid-Himalayan hill station, viz., Almora, located at 29°35′N and 79°35′E at an elevation of 1640 m from the m.s.l., showed an increasing trend. The average temperature of Almora, i.e. 17.55 °C, has increased up to 0.46 °C during the last 53 years. This preliminary observation suggests that the average temperature is rising in the state (Bhatt et al., 2015).

2.2. Experimental design

Soils were sampled from four land use systems viz., barren land (BL), cultivated land (CL), grass land (GL) and forest land (FL). Cultivated site is dominated by finger millet-fallow; pulse-fallow; finger millet-lentil cropping systems and inter/mixed cropping with wheat + mustard; wheat + lentil with no history of chemical fertilizer use. Under cultivated land, there was no heavy tillage machinery system, sowing is accomplished through hand sowing with farm yard manure (FYM) application @ 5–20 t ha^{-1} (Mahanta et al., 2015). Forest (natural) is higher than 90 years old, dominated with pine (*Pinus roxburghii*) followed by oak (*Quercus* spp.) with no history of disturbances. The grass-dominated rangelands harbour a variety of grass species. Grassland site is dominated by Ulla Grass {*Themeda anathera* (Nees)} with no history of plowing except mowing. The land which was lying unutilized for higher than 15 yrs. was considered as barren and/or fallow land. Forest land was government owned whereas community was the owner/user of grass land and barren land was private land.

2.3. Soil sampling and processing

The size of natural forest was varied between 8 and 13 ha, grassland 3 to 6 ha, barren land 2 to 4 ha and cultivated land ranged from 7 to 9 ha. On the basis of availability of land use systems in the cluster number of sites were determined, though we sampled soil from fifteen different points and made a composite sample for each site. Soil sampling of study area from four land use systems {barren (n = 8), cultivated (n = 11), grass (n = 8) and forest (n = 10) land) in the month of November 2016 undisturbed soil cores were collected in the 0–15, 15–30 and 30–45 cm soil depth with a core sampler (7.5 cm diameter). Bulk density was determined from oven-dried core mass divided by the core volume using one sample set. Samples from individual land use systems (the second set) were thoroughly mixed, air-dried, and passed through a 4.75 mm sieve. Thereafter, these soil samples were kept in labeled sample bottles for analysis.

2.4. Carbon fractionation

In part one, soil clods were crushed, roots and visible plant remains were removed, and then fresh samples were gently grounded and sieved (2 mm) for Walkley-Black Carbon (WBC), labile organic carbon (LOC) and soil reaction. In part two, bulk soil samples were air-dried, gently grounded for macro-aggregates (2 mm). A subsample of ~5 g was grounded by mortar and pestle and passed through 0.2 mm sieve. The total soil organic carbon and nitrogen concentration was determined using a CHN analyzer (model FOSS Hareus; CHNO rapid) following the dry combustion method (Nelson and Sommers, 1982). Since the samples were free of inorganic C (carbonates), the total soil carbon measured was taken as equivalent to the TOC. Labile organic carbon (LOC) pool was determined 333 mM $KMnO_4$ extraction following the procedure of Blair et al. (1995). Non-labile carbon (NLC) poll was estimated by deducting the LBC from TOC (TOC-LOC) and bulk SOC was determined following the procedure of Walkley-Black (1934) using $KCr_2O_7 + H_2SO_4$ as oxidizing agents.

2.5. Soil carbon and nitrogen stock

The soil carbon and nitrogen (stock) (Mg ha^{-1}) in a single land use system was calculated as follows: