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Total and labile pools of soil organic carbon in cultivated and undisturbed soils in northern India

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ABSTRACT

Labile fractions of soil organic matter (SOM) have been used as indicators for land use induced changes in soil quality. Differences in soil C pools under row crop production and uncultivated soils may provide information about soil C sequestration. The impact of agroforestry consisting of poplar with wheat, rice–wheat, maize–wheat and sugarcane agro-ecosystems on total organic carbon (TOC) and labile pools, viz. water-extractable (WEOC), hot water-soluble (HWC), $KMnO_4$-oxidizable, microbial biomass and mineralizable C; and organic C fractions of different oxidizability was studied at 22-sites for each land use. Cultivation resulted in decrease in TOC (21–36%) and dehydrogenase activity (by 2.8–3.4 mg kg^{-1} soil h^{-1}) compared to uncultivated soils. Labile C pools, except WEOC, were correlated ($P < 0.05$), though the amount extracted by different methods varied considerably suggesting that each method enumerated different fractions of TOC. Agroforestry and sugarcane systems were characterized by very labile C compared with uncultivated soils and the soils under rice–wheat and maize–wheat systems. Conversely, uncultivated soils and the soils under maize–wheat and rice–wheat held greater proportion of organic C in recalcitrant fractions. Results suggest that soil organic C (SOC) pools in agroforestry and sugarcane systems could be decomposed under land use alterations. However, no single soil C pool alone was suitable as a sensitive indicator for land use induced changes in SOM. A composite of soil indicators encompassing labile C, $KMnO_4$-oxidizable C, non-labile and recalcitrant C, mineralizable C, basal soil respiration, and dehydrogenase activity could distinguish different land use systems.

1. Introduction

Soil organic matter plays an important role in maintaining soil quality and ecosystem functionality. Land use and agricultural practices, such as tillage, irrigation and fertilization, all influence the storage of soil organic carbon (SOC) (Paustian et al., 1997). Cultivation of uncultivated soils leads to the loss of SOC due to rapid decomposition caused by disruption of soil structure (Davidson and Ackerman, 1993; Murty et al., 2002). Cropping intensity affects SOC storage through its effect on the rate of SOM decomposition, as the length of time that the soil supports a crop may increase the net annual C input. Improved management of agricultural lands, such as adoption of agroforestry systems, production of high-residue crops, low quality residue inputs, diversified crop rotations, and increased cropping intensity may result in greater soil C sequestration (Nieder and Benbi, 2008). Consequently, adoption of cropping practices that sequester soil C may help reduce greenhouse gas emissions.

Agroforestry, a land use system that involves growing woody perennials with agricultural crops, is considered an important option for C sequestration (Albrecht and Kandji, 2003; Nair et al., 2009). A review of literature on soil C sequestration under agroforestry systems showed widely varying estimates (1.3–173 Mg C ha^{-1}) in relation to tree species, climatic conditions, and age of plantation (Nair et al., 2009). Poplars (*Populus deltoides*) are among the fast growing tree species under appropriate climatic conditions and can be harvested at a short rotation of 6–7 years (Gera et al., 2006). Because of economic benefits associated with poplar-based agroforestry systems, this land use system is considered a viable option for irrigated agro-ecosystems in India (Pandey, 2007). Some reports on aboveground C sequestration potential of poplar-based agroforestry systems are available (Chauhan et al., 2011; Gera et al., 2006), however, the information on SOC pools and the quality of SOM under these systems are lacking.

Rice (*Oryza sativa*)–wheat (*Triticum aestivum*) is the dominant cropping system in the Indo-Gangetic Plains (IGP) occupying around 13.6 million ha (mha) in Bangladesh, India, Nepal and Pakistan, and 13 mha in China (Timsina and Connor, 2001). This cropping system has contributed substantially towards food-grain production and its sustainability is of utmost importance for ensuring regional food security. Because of high irrigation water requirement for rice, this cropping system has adversely impacted the groundwater table depth in the North Indian state of Punjab. Efforts are being made to diversify to crops other than rice. Maize (*Zea mays*)–wheat, is considered an alternative

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to rice–wheat, it occupies an area of 8.26 mha in India and 0.14 mha in the state of Punjab (SAP, 2011). Rice and maize crops are grown under contrasting soil aeration conditions viz. anaerobic conditions in rice and aerobic conditions in maize fields that can significantly influence decomposition and accumulation of SOM. Besides rice– and maize–wheat cropping systems, sugarcane (*Saccharum officinarum*) is another important agro-industrial crop grown on 5.09 mha area of India, and has high biomass production (~70 Mg fresh matter ha^{-1}) (GOI, 2012). Being an annual crop, sugarcane occupies the field for 10–12 months in a year. Because of differences in production potential and the length of time various crops/cropping systems viz. rice–wheat, maize–wheat and sugarcane occupy the field, SOC dynamics and the quality of SOM tend to differ. So far there is almost no information available on the quality of SOM under different agro-ecosystems in comparison to uncultivated soils for the semiarid subtropical region of India. Studies from other regions of the world have shown that disturbance to the soil system, such as conversion of native vegetation to arable agriculture causes sizeable decreases in the size of both the labile and stabilized fractions of SOM (Guo and Gifford, 2002; Haynes, 2005; Saviozzi et al., 2001; Wei et al., 2013). In the Mediterranean area different land-uses viz. native undisturbed soil, intensively cultivated soil, and soil in set-aside are reported to influence the dynamics of organic matter mineralization and composition of SOM (Masciandaro et al., 1998).

Labile fractions of SOM, rather than total SOM, have been used as sensitive indicators of soils' quality and response to agricultural management changes (Haynes, 2005; Leifeld and Kögel-Knabner, 2005). Several physical, chemical, and biological methods have been used to distinguish between labile (or biologically active) and recalcitrant pools of SOM, with varying degrees of success. The significance of physical fractionation that involves separation of particulate organic matter and organo-mineral complexes has been recognized for some time (Cambardella and Elliott, 1993; Christensen, 2001; Jastrow, 1996) but that of extractable and mineralizable fractions is less well-known (Haynes, 2005). Commonly used extractable and mineralizable fractions include microbial biomass C (MBC), water-extractable organic C (WEOC), hot water-soluble C (HWC), $KMnO_4$-oxidizable C, organic-C fractions of different oxidizability, and mineralizable C (Benbi et al., 2012; Blair et al., 1995; Chan et al., 2001; Chantigny, 2003; Sparling et al., 1998). Besides labile pools of SOM, enzyme activities such as dehydrogenase have been used to understand processes of decomposition and C stabilization in soils. Dehydrogenases have a critical role in substrate oxidation and can be used as a measure of microbial metabolism rates in soils (Alef and Nannipieri, 1995; Skujins, 1973). Therefore, knowledge of different SOM pools and enzyme activities should render impacts of agricultural management and land use changes more transparent. Changes in labile pools of SOC due to different soil management practices have been studied in cool temperate regions of the world (Sherrod et al., 2005; Wu et al., 2003), with few studies conducted in tropical and subtropical regions, particularly comparing agroforestry, sole cropping systems and uncultivated soils.

Differences in SOM fractions between agricultural fields and uncultivated soils can yield information about mechanism of soil C sequestration (Del Galdo et al., 2003; Six et al., 2002). Furthermore, soil C fractions that are more sensitive to land-use changes than the total C may serve as early indicators of changes in soil C dynamics (Six et al., 2002). Our hypothesis is that land use practices with various carbon inputs (such as litter fall, crop residues, root production and root exudates) and losses (through decomposition of organic matter via soil disturbance and aeration conditions) influence the quantity and quality of SOM. Therefore, the present study was conducted to evaluate the impact of different cropping practices i.e., poplar-based agroforestry, rice–wheat, maize–wheat, and sugarcane agro-ecosystems on total organic C (TOC) and labile C pools in a semiarid, sub-tropical region of India. The results of the study will help us understand the influence of land use on SOM quality and soil C sequestration.

2. Materials and methods

2.1. Sampling sites

Soil samples were collected from farmers' fields in agro-ecological sub-region 4.1 located between 30°32′–31°24′N and 76°18′–76°–55′E (Fig. 1). The climate is characterized as semiarid sub-tropical with monsoonal influence. Annual bimodal rainfall ranges between 700 and 800 mm. Mean monthly minimum and maximum air temperature averages 18 °C and 35 °C during summer (rice/maize growth season, June–October) and 6.7° C and 22.6 °C during winter (wheat season, November–April), respectively (Kaur and Hundal, 2008).

For each given land use (i.e., uncultivated, agroforestry, rice–wheat, maize–wheat, and sugarcane agro-ecosystems), 22 different sites were selected in such a manner that the different agro-ecosystems were within the same agro-ecological sub-region (4.1), had similar basic soil properties such as pH, electrical conductivity and texture (Table 1), and each occupied a minimum area of 0.4 ha. The uncultivated sites had not been disturbed for more than four decades and were under mixed scrub and unmanaged volunteer grass species. The cultivated soils were under a given agro-ecosystem for at least 10 continuous years. The agroforestry systems consisted of poplar plantation with wheat during winter and a pulse crop either mung (*Vigna radiata*) or black gram (*Vigna mungo*) during summer. Poplar trees were planted on 5.3 m rows and 2.0 m plant spacing. Rice–wheat and maize–wheat were annual crop rotations with rice or maize grown in summer and wheat during winter. Rice and maize were fertilized with mineral fertilizers at 120 kg N and 30 kg P_2O_5 ha^{-1}. Farmyard manure (FYM) obtained from dairy cattle was added at 7.5 t ha^{-1} (moisture content ~30%) to maize every alternate year; the latest application being in May, 2008. Wheat, both under agroforestry and sole cropping systems, was fertilized at 140–160 kg N and 55 kg P_2O_5 ha^{-1}. The summer pulse crop was fertilized with 25–30 kg N and 50 kg P_2O_5 ha^{-1}. Sugarcane was planted in February and harvested during December/January or planted in November and harvested during October in the following year. Generally, a planted crop was followed by one or two ratoon crops of sugarcane. Sugarcane was fertilized at 180–190 kg N, 105 kg P_2O_5 and 55 kg K_2O ha^{-1}. An application of 7.5 Mg FYM ha^{-1} (moisture content ~30%) was made to the planted sugarcane crop. The N, P and K were supplied through urea, diammonium phosphate and muriate of potash, respectively. Crop residues post-harvest were removed from the field. All the agro-ecosystems were adequately irrigated with groundwater. An irrigation of about 7.5 cm was applied to maize, wheat, and sugarcane crops when required depending on visual inspection of the field. Rice was kept submerged during the first month after transplanting and thereafter flood irrigation was applied after the standing water from previous irrigation had drained.

2.2. Soil sampling

Surface soil samples (0–15 cm) were collected from 110 sites under five different land uses viz. uncultivated sites, and agroforestry, rice–wheat, maize–wheat, and sugarcane agro-ecosystems. Soil samples from agroforestry, maize–wheat, and rice–wheat agro-ecosystems were collected after the harvest of wheat crop (end of crop cycle) in April/May 2009. Soil samples from sugarcane based agro-ecosystem were collected after the harvest of sugarcane, which was either in November 2009 or January 2010. Four soil samples were taken with a soil core sampler (inner diameter 7 cm) and composited at a site. In the agroforestry systems, samples were collected between tree rows.

2.3. Sample preparation

Soil samples were air-dried and each sample was divided into two portions. One portion of the sample was passed through a 2 mm sieve and was used for analysis of soil chemical and biological properties.