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Soil properties and organic carbon distribution under different land uses in reclaimed sodic soils of North-West India

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ABSTRACT

Land use changes have caused emission of ~20% greenhouse gases (GHGs) globally that leads to shrinkage of carbon (C)-storage in the potential areas. Soil carbon pools change rapidly in response to land use change. However, in-depth understanding of C-dynamics is needed with respect to eco-systems variability. Suitable land use systems can help in sequestering C and reduce GHGs' adverse effect. Therefore, seven land uses namely Guava (*Psidium guajava*), Litchi (*Litchi chinensis*), Mango (*Mangifera indica*), Jamun (*Syzygium cumini*), Eucalyptus (*Eucalyptus tereticornis*), Prosopis (*Prosopis alba*) and Rice–wheat cropping system were selected to study their impact on soil properties and distribution of soil organic carbon (SOC) in soil layers in a reclaimed sodic soil (*Typic Natrustalf*, Alfisols). Soil samples were collected up to a depth of 2 m i.e. 0–0.2, 0.2–0.4, 0.4–0.6, 0.6–0.8, 0.8–1.0, 1.0–1.5 and 1.5–2.0 m. Results showed that soil pH and bulk density increased with depth in all the land uses. Minimum and maximum soil pH was associated with Litchi (6.81) at 0–0.2 m and Eucalyptus (9.52) at 1.5–2.0 m depth, respectively. Eucalyptus recorded minimum and maximum (1.41 and 1.76 Mg m^{-3}) bulk density at 0–0.2 and 1.5–2.0 m soil depth, respectively. Carbon content in passive pool along with its recalcitrant nature was increased with depth in all the land uses. Depth-wise maximum decreasing tendency of lability index in Jamun plantation (0.44 at 1.0 to 1.5 m and 0.72 at 1.5 to 2.0 m soil depth) reiterated more recalcitrant nature of SOC. However, overall highest SOC storage (133 Mg C ha^{-1}) as well as maximum passive pool C (76 Mg C ha^{-1}) was maintained in Guava land use.

1. Introduction

Ever since the Industrial Revolution began about 250 years ago, man-made activities have added significant quantities of greenhouse gases to the atmosphere. The atmospheric concentrations of CO_2, CH_4 and N_2O have grown by about 31, 151 and 17%, respectively, between 1750 and 2000 (IPCC, 2001). Last year for the first time in human history, the global atmospheric CO_2 concentration passed 400 ppm and will continue to rise (Kodaira, 2014). The increasing greenhouse gas (GHG) concentration in the atmosphere indicates clear evidence of human influence on the climate system (IPCC, 2013). Soil is a major reservoir of terrestrial C and contains a stock of carbon to the tune of 2500 Gt (1 Gt $= 10^9$ t), out of which soil organic and inorganic carbon constitute about 1550 Gt and 950 Gt, respectively up to 1-m depth (Lal, 2004). Small losses from this large pool would have a significant impact on future atmospheric carbon di-oxide concentration in the atmosphere (Smith et al., 2008). Soil organic carbon (SOC) is an important component in soil that contributes to soil fertility, soil tilth, crop production and soil sustainability.

Soil C pools change rapidly in response to land use change (Guo and Gifford, 2002) and contributes to nearly 20% of GHG emissions (UN REDD, 2009). Information on global and regional SOC pools is available. However, data on vertical distribution of the SOC pools in relation to vegetation and land use is scanty (Jobbagy and Jackson, 2000). Soil C sequestration research has historically focused on the top 0–30 cm of the soil profile, ignoring deeper portions that might also respond to management (Syswerda et al., 2011). It has been showed that important amounts of stable SOC are also stored at greater depth (Meersmans et al., 2012). There is a 60% increase in the global SOC budget when the second meter of soil was included (Batjes, 1996). Despite their low C content, most subsoil horizons contribute to more than half of the total soil C stocks, and therefore need to be considered in the global C cycle.

The knowledge of SOC distribution and controls on C sequestration within soil profiles is used to predict the effect of land use changes on C emission (Jobbagy and Jackson, 2000). The importance of SOC sequestration in subsoil to mitigate the greenhouse effect is related to the increase turnover time of SOM with increase in depth, and to the fact

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that subsoil SOC occurs in fairly stable and most probably highly recalcitrant forms to biodegradation (Nierop and Verstraten, 2003). Subsoil SOC stocks become additionally important because they primarily constitute the intermediate and passive SOM pools (Lutzow et al., 2008). It has been showed that vertical distribution of C in the soil is much deeper than the vertical distribution of roots, suggesting a decrease of SOC decomposition rate with depth (Gill et al., 1999; Gill and Burke, 2002).

In the Miombo Woodlands ecosystem of south central Africa, roughly 60% of the total C stock is found below ground (Campbell et al., 1998) which is common in drier systems (Woomer et al., 1997). Information on C stock or oxidizable organic carbon content of the soil under land uses of fruit trees such as Guava, Litchi, Mango, Jamun or forest trees such as Eucalyptus, Prosopis are very limited. Moreover, most of the studies are restricted to the surface soil or hardly up to 60 cm depth. Also there has been little research on the distribution of organic carbon onto different pools of their oxidizability up to 2.0 m depth of soil. So this study builds on our understanding of how different land uses impact soil carbon levels and the soil carbon vertical structure by comparing soil C stocks within the land uses.

There is great variation on the vegetation dynamics of the land uses and biomass litter levels reaching the soil (Laganiere et al., 2010). The balance between C inputs in the form of litter (aboveground and belowground) and losses through decomposition determines whether the ecosystem is a sink or a source of C. Evaluating the C dynamics of this type of system requires data on the size of the C pool, the magnitude of the C input and output fluxes, as well as information about the mechanisms involved in controlling flux dynamics. To promote the C sink status of tree plantations, it is therefore imperative to determine the mechanisms involved in controlling SOC dynamics and more specifically in the storage of C in soil.

Soil organic carbon (SOC) pool up to 30 cm of soil layer was maximum and statistically significant in the forest lands followed by grasslands, orchards (Mango, Guava, Litchi) and plantation (Eucalyptus) areas (Gupta and Sharma, 2011). Gupta and Sharma (2013) also studied SOC pools up to 30 cm soil depth under different orchards in Uttarakhand state of India and found that maximum SOC pool was estimated under apple orchard followed by Mango, Litchi and Guava and they significantly differed from each other.

Research dealing with SOC depth distribution is gaining interest as the identification of a stable SOC reservoir at greater depths is essential for understanding the influences of climate and human activities on the terrestrial C cycle (Wang et al., 2004). Land-use change impact on SOC was not restricted to the surface soil, but relative changes were equally high in the subsoil, stressing the importance of sufficiently deep sampling (Don et al., 2011). Values on above ground biomass stocks are available for most ecosystems but below ground C associated with roots and soil as well as different pools of their oxidizability are not well characterized particularly up to a depth of 2.0 m. Soil physical and chemical properties have been proposed as suitable indicators for assessing the effect of land-use changes and management (Janzen et al., 1992; Bremer et al., 1994; Alvarez and Alvarez, 2000). This approach has been used extensively by several authors to monitor land-cover and land-use change patterns (Schroth et al., 2002; Walker and Desanker, 2004; Michel et al., 2010). Similarly, a lot of studies have been carried out on the soil physicochemical and biological changes over the humid tropical regions of the world (Awotoye et al., 2013). Though these horticultural and forestry land uses are economically important for the livelihood security of the farmers, earlier studies on the effects of different land-use types on soil properties as well as SOC distribution in different soil layers in South Asia are still inadequate. For this purpose, seven land uses namely Guava (*P. guajava*), Litchi (*L. chinensis*), Mango (*M. indica*), Jamun (*S. cumini*), Eucalyptus (*E. tereticornis*), Prosopis (*P. alba*) and Rice–wheat cropping system were selected to study their impact on distribution of organic carbon (OC) in soil layers as well as changes in selected soil properties in a reclaimed sodic soil of North-West India. Accordingly, we hypothesize that i) soil organic carbon stock may vary with land-use types and ii) soil organic carbon content in different pools as well as soil properties may differ with depth increment across the land-use systems in a reclaimed sodic soil. To test these hypotheses, this study aims to i) determine the effect of different land uses on soil organic carbon stock and selected soil properties in soil layers and ii) find out preponderance of SOC into pools of different oxidizability with depth increment under different land uses in a reclaimed sodic soil and iii) screen out land use systems best for soil carbon storage.

2. Materials and methods

2.1. Study site

Seven land uses namely Guava (*P. guajava*), Litchi (*L. chinensis*), Mango (*M. indica*), Jamun (*S. cumini*), Eucalyptus (*E. tereticornis*), Prosopis (*P. alba*) and Rice–wheat cropping system located at the research farm of ICAR-Central Soil Salinity Research Institute, Karnal (latitude 29° 43′ N, longitude 76° 58′ E, altitude 245 m msl) in Haryana State, India (Fig. 1) were selected for the study.

Guava plantation is about 31 years of age. Mango seedlings were planted about 34 years back whereas Litchi is 12 years old. Jamun plantation is of 23 years old. Eucalyptus is the youngest plantation having 11 years period followed by Prosopis with 13 years old. Rice–wheat cropping system has been continuing for the last 28 years. Rice–wheat cropping system was selected as a reference and it is continuing for the last 28 years with normal recommended doses of fertilizers. In Litchi, Mango and Guava, about 500 g di-ammonium phosphate (DAP) was applied per plant in every year and about 12 number of irrigations per year was given. Generally, 5 to 6 plowing were followed in a year. In Jamun, fertilizer was not applied and about 4 to 5 irrigations were given every year. Whereas in the case of Eucalyptus and Prosopis plantations 6 to 7 plowing were followed and during initial years, Eucalyptus and Prosopis plantations were irrigated 2 times and 4 times in a year, respectively.

2.2. Soil

The soil comes under the Zarifa Viran soil series. It is a member of the fine-loamy mixed hyperthermic family of *Typic Natrustalf*. The soil was highly sodic with high pH (1:2.5) of 10.3 and exchangeable sodium percentage of 97% at 0–5 cm depth; organic C and $CaCO_3$ contents were 0.30 and 0.5%, respectively. The moisture regime is ustic (Murthy et al., 1982). Due to the intervention of the reclamation technologies particularly addition of gypsum and adaptation of optimum packages of practice developed by ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, India (Sidhu et al., 2014), the soils were reclaimed and cultivation of field crops as well as plantation of horticultural and forest trees started. Before establishing those land uses/orchards, we presume that the soil texture was the same as it comes under the same great group level classification "*Typic Natrustalf*".

2.3. Sampling and laboratory analysis

Three soil profiles (2 m × 2 m × 2 m) in each land uses were excavated. Soil samples were collected up to a depth of 2 m i.e. 0–0.2, 0.2–0.4, 0.4–0.6, 0.6–0.8, 0.8–1.0, 1.0–1.5 and 1.5–2.0 m from all the land-uses. Then the samples were dried, grinded and sieved with a 2.0 mm sieve and stored. Depth-wise soil samples were collected using a metal core sampler for bulk density analysis (Blake and Hartage, 1986). Soil pH (soil:water 1:2) and electrical conductivity(EC) were determined by following standard methods (Jackson, 1967). Soil textural analysis was performed by following the International Pipette Method (Baruah and Barthakur, 1999). Calcium carbonate was determined by a manometric method using Collin's calcimeter (Allison and Moodie, 1965). SOC content of the soils under different land uses was