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Total and labile forms of soil organic carbon as affected by land use change in southwestern Iran

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ABSTRACT

The labile pools of soil organic matter enable assessment of the variation in land use changes and other management practices. This study aims to: (1) examine the effect of forest (F) and pasture (P) conversion on total and labile forms of soil organic C (SOC), (2) quantify the relationship among different labile SOC, and (3) determine whether labile SOC fractions are more sensitive indicators of soil quality than total organic C (TOC) after F and P conversion to agricultural use (forests converted (F to A) and pasture converted (P to A) soils) in southwestern Iran. Accordingly, composite soil samples with eight replicates were collected from 0–15 cm of each land use in December 2014. The samples were then analyzed for TOC, microbial biomass C, permanganate oxidizable C, and cold- and hot-water extractable organic C. The results illustrated that the TOC and all labile pools of soil organic carbon followed the trend: F > P > F to A > P to A. However, from the four land uses studied, P soils showed a better and different quality of organic C than other land use systems, which was indicated by the highest proportion of microbial biomass C (3.3%), permanganate oxidizable C (4.8%), and cold- (0.55%) and hot-water extractable organic C (3.7%), but the lowest proportion of non-labile C (95.2%) to the TOC contents of the soils. The highest amounts of SOC stocks were spotted in the F soils (42.1 Mg ha^{-1}) followed by P (29.7 Mg ha^{-1}), F to A (26.7 Mg ha^{-1}) and P to A (19.5 Mg ha^{-1}) land use systems. Accordingly, organic carbon storage of the soils decreased by land use conversion from F (36.6%) and P (34.3%) to agriculture. The carbon management index, whose variation was mainly caused by carbon pool index, was higher in P to A soils than F to A soils suggesting that organic C compounds are less degraded and contain higher amounts of labile C than F to A soils. The results also showed that labile organic carbon pools are more sensitive to changes in management practices than TOC contents of the soils. However, a single carbon pool cannot be used as the most sensitive indicator of soil quality to reflect land use differences. The permanganate oxidizable C, hot water extractable organic C and microbial biomass C demonstrated the highest sensitivity to the land use induced changes in forest soils and cold water extractable organic C and microbial biomass C were realized as the most sensitive parameters in pasture conversion to arable lands. In conclusion, it seems that the quality of both F and P soils was decreased with adoption of agriculture and therefore sustainable management practices should be employed in order to achieve soil stability and biological productivity in the area.

1. Introduction

Soils are the largest terrestrial pool of organic C with estimates ranging from 1115 to 2200 Pg in a meter soil profile (Batjes, 1996). It is estimated that global cultivated soils released about 50 Pg C into the atmosphere through the mineralization of soil organic carbon (Paustian et al., 1997). In view of that, soils can be considered as both a significant source and a sink of atmospheric CO_2 (Smith et al., 2000; Llorente et al., 2010; Mujuru et al., 2013). It is believed that land use change is the second main cause of carbon emissions after fuel consumption (Watson et al., 2000). Globally, land use change is responsible for estimated net emissions of 1.1 ± 0.7 Pg C per year of the first decade of the 2000s (Poeplau and Don, 2013). However, the most dramatic impact of the agricultural practices occurs when soils under native vegetation are converted to arable agriculture (Haynes, 2005).

It should be mentioned that the SOC is also essential for enhancing soil quality, sustaining and improving food production, and maintaining clean water (Singh et al., 2007). Changes in total soil organic matter content, in response to the alterations in soil management practices, are difficult to detect because of the generally high background levels and natural soil variability (Haynes and Beare, 1996). Moreover, soil organic matter is a heterogeneous mixture of materials, ranging from active or labile fractions (e.g. microbial biomass, particulate organic matter, and

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soluble organic matter) decomposing in a matter of months and the more resistant or non-labile fractions remaining in the soil with turnover rates measured in millennia (Christensen and Johnston, 1997).

In order to estimate the effects of land use change on the total carbon stocks of the soils, it is important to quantify and reasonably understand the sensitivity of different functional SOC pools to disruptions such as land use change (Martin et al., 1990). It has been suggested that hot water-extractable C and N could be used as a sensitive indicator of the fertility status of soils (Haynes, 2005). Ghani et al. (2000) observed that 45–60% of C extractable with hot water were carbohydrates. Leinweber et al. (1995) utilized solid state ^{13}C NMR and pyrolysis-field ionization mass spectrometry to show that the hot water-extractable organic matter is largely comprised of carbohydrates and N-containing compounds, and especially amino-N species amides. Soil microbial biomass is another sensitive indicator, which is applied to identify the changes in total soil organic matter, since it more readily responds to the alterations in plant vegetation or land use (Saffigna et al., 1989; Warembourg et al., 2003). Blair et al. (1995) proposed that organic C oxidizable with $KMnO_4$ is a useful index of labile soil C. Permanganate oxidizable organic C fraction includes labile humic material and polysaccharides and has been proved to be sensitive to land use conversion from grassland to arable agriculture (Blair et al., 1995).

It is believed 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) would influence on the quantity and quality of soil organic matter (Benbi et al., 2015). Therefore, this study intends to: 1) understand how land use conversion from forest to agriculture and from pasture to agriculture is affecting soil carbon pools, 2) compare the differences in labile soil carbon pools between the four land uses studied, and 3) determine whether labile SOC fractions are more sensitive indicators of soil quality than total organic C (TOC) after F and P conversion to agricultural use in southwestern Iran. The information help understand the processes involved in soil C sequestration and the accumulation patterns of labile- and non-labile C fractions in relation to land use changes from forest and pasture to agriculture.

2. Materials and methods

2.1. Description of the study area

The study area is located in Rakaat Basin, east of Izeh city in Khuzestan Province (UTM: longitudes 417994 to 436996 E and latitudes 3503013 to 3522340 N). The region has a typical temperate continental climate, characterized by dry summers and cold winters. The mean annual rainfall is 680 mm. The mean annual temperature (MAT) is 13.6 °C, and the mean monthly air temperature varies from 1.6 °C in January to 24.6 °C in July. The mean annual relative humidity ranges between 29.6% in August and 60.7% in January. According to the USDA soil taxonomy, the soil moisture and temperature regimes in the study area are estimated as *xeric* and *mesic*, respectively. The soils of the study area are also classified as Calcic Haploxeralfs in native forests, Humic Haploxerepts in undisturbed pastures, and Typic Calcixerepts in agricultural land uses based on the criteria of USDA soil taxonomy (Soil Survey Staff, 2014).

2.2. Soil sampling

Soil sampling was carried out with eight replicates in four different land uses including native forests (F), forests converted to croplands (F to A), pastures (P), and pastures converted to croplands (P to A) (Fig. 1). The main forest community of the region is *Quercus brantii*, and the other species are *Pistacia atlantica* and *Amygdalus orientalis*. The main pasture vegetation communities of the region consist of *Astragalus fasciculifolius* and annual grasses. Both croplands have experienced more than twenty years of cultivation and at the time of sampling were under wheat cultivation.

Composite soil samples were collected from surface layers (0–15 cm) of each land use in December 2014. The composite samples were combined and mixed thoroughly, placed in polyethylene bags, and immediately transported to the laboratory. In the laboratory, the visible roots and plant fragments were first removed and the composite samples were passed through a 2-mm sieve and physico-chemical characteristics of the soils including carbonate contents (Tiessen et al., 1983), texture (Gee and Bauder, 1986), EC (Rhoades, 1986) and pH (in a 1:1 soil: water suspension using pH meter) were determined.

2.3. Total organic carbon and nitrogen

Total organic C (TOC) content of the soils was measured by the Walkley–Black method (Walkley and Black, 1934) and the total nitrogen (TN) by the Kjeldahl procedure as described by Bremner and Mulvaney (1982).

2.4. Water-extractable organic carbon

There are two functional pools of water- extractable organic C that are normally studied: cold water extractable organic C and hot water extractible organic C (Ghani et al., 2003). The cold water extractable organic C was determined by shaking 5 g of soil with 50 ml of distilled water (20 °C ± 2) at 30 rpm for 1 h. Afterwards, the suspension was centrifuged at 3500 rpm for 20 min and the organic carbon contents in the extracts were determined by the wet digestion method. In order to determine the hot water extractible organic C of samples, 40 ml of distilled water was added to the centrifuge tubes containing 5 g air-dried soil samples, and shaken vigorously for 10 s and placed into a water bath at 80 °C for 16 h. The suspension was then centrifuged, filtered and the organic carbon content of the extracts was determined by the wet combustion method as described before (Ghani et al., 2003).

2.5. Potassium permanganate-oxidizable C

The permanganate-oxidizable C content of the soils was determined by oxidation with 0.33 M of $KMnO_4$ solution (Blair et al., 1995). The amount of C which was not oxidized by $KMnO_4$ and is referred to as non-labile C was determined from the difference between total organic carbon content and $KMnO_4$-C (Benbi et al., 2015).

2.6. Microbial biomass carbon

Microbial biomass carbon was determined by the chloroform fumigation-extraction method (Vance et al., 1987) using a recovery factor (K_{EC}) of 0.41 (Voroney and Paul, 1984). All the results are expressed on an oven-dry soil basis.

2.7. Determination of soil organic carbon and total nitrogen stocks

The soil organic C stocks (SOC, Mg ha^{-1}) were calculated based on the following equation:

$$\text{SOC or TN stock}\left(\text{Mg ha}^{-1}\right) = \text{SOC or TN contents}\left(\text{g kg}^{-1}\right) \times \text{Bulk density}\left(\text{g cm}^{-3}\right) \times D(\text{m}) \times 10^4 \quad (5)$$

where D is the depth of soil which was used for determination of soil organic carbon.