*Pedosphere* **25**(4): 534–545, 2015
ISSN 1002-0160/CN 32-1315/P

Published by Elsevier B.V. and Science Press

PEDOSPHERE

www.elsevier.com/locate/pedosphere

# Sensitivity of Labile Soil Organic Carbon Pools to Long-Term Fertilizer, Straw and Manure Management in Rice-Wheat System

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(Received November 20, 2014; revised April 30, 2015)

## ABSTRACT

Labile soil organic carbon (SOC) pools, estimated through chemical fractionation techniques, are considered sensitive indicators of management-induced changes in quality and composition of soil organic matter. Although the impacts of organic manure and crop residue applications on C sequestration in rice-wheat system are fairly well documented, their influence on labile SOC pools is relatively less known. Impacts of organic manure, rice straw, and inorganic fertilizer nitrogen (N) applications on soil total organic carbon (TOC) and SOC pools including water-extractable organic C (WEOC), hot water-soluble organic C (HWOC), potassium permanganate-oxidizable organic C ($KMnO_4$-C), microbial biomass C (MBC), mineralizable organic C ($C_{min}$), and the oxidizable fractions of decreasing oxidizability (easily-oxidizable, oxidizable, and weakly-oxidizable) were investigated in an 11-year field experiment under rice-wheat system. The field experiment included treatments of different combinations of farmyard manure, rice straw, and fertilizer N application rates, with C inputs estimated to be in the range from 23 to 127 Mg ha$^{-1}$. After 11 years of experiment, WEOC, HWOC, and $KMnO_4$-C were 0.32%–0.50%, 2.2%–3.3%, and 15.0%–20.6% of TOC, respectively. The easily-oxidizable, oxidizable, and weakly-oxidizable fractions were 43%–57%, 22%–27%, and 10%–19% of TOC, respectively. The applications of farmyard manure and rice straw improved WEOC, HWOC, $KMnO_4$-C, easily-oxidizable fraction, $C_{min}$, and MBC, though the rates of change varied considerably from −14% to 145% and −11% to 83% of TOC, respectively. At the C input levels between 29 and 78 Mg C ha$^{-1}$ during the 11-year period, the greatest increase was observed in WEOC and the minimum in $KMnO_4$-C. Water-extractable organic C exhibited a relatively greater sensitivity to management than TOC, suggesting that it may be used as a sensitive indicator of management-induced changes in soil organic matter under rice-wheat system. All the other labile SOC pools exhibited almost the same sensitivity to management as TOC. Most of the SOC pools investigated were positively correlated to each other though their amounts differed considerably. Long-term applications of farmyard manure and rice straw resulted in build-up of not only the labile but also the recalcitrant pool of SOC, emphasizing the need for continued application of organic amendments for permanence of the accrued C under the experimental conditions.

*Key Words*: metabolic quotient, mineralizable C, organic amendments, oxidizable C, soil microbial biomass, soil organic matter, water-soluble C

**Citation:** Benbi D K, Brar K, Toor A S, Sharma S. 2015. Sensitivity of labile soil organic carbon pools to long-term fertilizer, straw and manure management in rice-wheat system. *Pedosphere*. **25**(4): 534–535.

## INTRODUCTION

Soil organic carbon (SOC) is a key attribute of soil fertility and productivity because of its influence on the physical, chemical, and biological properties of soils (Johnston, 1986; Nieder and Benbi, 2008). Agricultural management practices that increase C input to the soil and decrease C loss or both lead to improvement in SOC. Because SOC represents a large reservoir of C and changes in its size are slow to occur, it is difficult to discern the short-term influence of management practices on overall SOC stock changes (Leifeld and Kögel-Knabner, 2005). Soil organic C is a heterogeneous mixture of organic substances and it is contemplated that different forms or pools of SOC may exhibit different sensitivity to management; certain pools are more sensitive than total organic C (TOC) (Carter *et al*., 1998; von Lützow *et al*., 2000). Generally, labile SOC pools are considered sensitive to changes in soil management and disturbance and have specific effects on soil functions (Haynes, 2005). The lability of SOC that refers to the relative ease and rate at which it is decomposed depends on chemical recalcitrance and physical protection from microorganisms (McLauchlan and Hobbie, 2004).

Several physical, chemical, and biological methods for determining labile SOC pools have been used with varying degrees of success (Rosell *et al*., 2001; Haynes,

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2005; von Lützow *et al*., 2007). Physical fractionation involves use of size and density floatation techniques to isolate fractions based on the degree of physical protection or occlusion within aggregates and formation of organo-mineral complexes (Cambardella and Elliott, 1993; Golchin *et al*., 1994; Sollins *et al*., 1996; DeGryze *et al*., 2004; Benbi and Senapati, 2010; Benbi *et al*., 2012b). Though physical fractionation is well known to isolate multiple, spatially explicit pools (Jastrow, 1996; Christensen, 2001; Six *et al*., 2002), the method is complex and time consuming and lacks standard protocols. There is also a risk of redistribution and loss of soil organic matter (SOM) during fractionation, which may lead to misinterpretation of the results. Furthermore, adoption of physical fractionation to estimate soil C pools is limited due to additional resources required (Wander, 2004; Gil-Sotres *et al*., 2005). In contrast, chemical fractionation can provide relatively easy and quick estimates of management-induced changes in SOM composition. Chemical fractionation is based on extraction of labile SOC pools with reagents ranging from water and salt solutions to strong acids.

The labile SOC pools such as water-extractable organic C (WEOC), hot water-soluble organic C (HWOC), potassium permanganate oxidizable organic C ($KMnO_4$-C), and organic C fractions of different oxidizability are considered to respond to agricultural management rapidly than TOC (Blair *et al*., 1995; Sparling *et al*., 1998; Chan *et al*., 2001; Chantigny, 2003; Benbi *et al*., 2012a). The organic C fractions of different oxidizability and their ratios have been used to discern the effect of land use on C stabilization in soils (Loss *et al*., 2013). The biologically active SOC pools such as soil microbial biomass C (MBC) and mineralizable C ($C_{min}$) are recognized as sensitive indicators of management-induced changes in both SOC and biological properties of soils (Powlson *et al*., 1987; Anderson and Domsch, 1989; Haynes, 2005). Different studies have identified either of the aforementioned chemical or biological pools as sensitive indicators of management-induced changes under different soil, land use, and climatic conditions. However, most of the studies are confined to characterization of short- to medium-term management effects on labile SOC under temperate conditions. Information regarding long-term management-induced changes in chemical and biological pools of SOC and their sensitivity to management in rice-wheat cropping sequences under semiarid subtropical conditions is generally lacking. The SOC pools under rice-wheat system have been shown to be more stable than those under the other land use types (Benbi *et al*., 2012a); therefore, SOC pools under this cropping system may show different sensitivity to management than those under other land use types.

Rice-wheat cropping system is one of the world's largest agricultural production systems, occupying an area of 26 Mha, out of which 13.7 Mha occurs in the Indo-Gangetic Plains of India, Nepal, Pakistan, and Bangladesh (Timsina and Connor, 2001). This cropping system is of utmost importance for ensuring regional food security. It is imperative to maintain soil fertility and sustainability of rice-wheat cropping system. For maintaining the sustainability of rice-wheat system, it is important to improve soil C storage and the structural status of soil that is crucial for controlling soil microbial activity and functions. One of the options is the input of C through return of crop residues and addition of organic manures. The impacts of organic manure and crop residue application on C sequestration in rice-wheat system are fairly well-known, while their influences on labile SOC pools are relatively less known. We investigated the impacts of long-term agricultural management practices involving application of organic manure, crop residues, and fertilizer nitrogen (N) on soil TOC and labile pools of SOC in rice-wheat system in the subtropical Indo-Gangetic Plains of northern India. Our hypothesis is that one or more labile SOC pools could be more sensitive to management than TOC and may, therefore, be used as a sensitive indicator to characterize management-induced changes in SOM in rice-wheat system.

## METHODS AND MATERIALS

### *Study site*

A long-term field experiment, started in 1999, was conducted at the Punjab Agricultural University research farm in Ludhiana (30°56′ N, 75°52′ E, 247 m above sea level), India. The experimental area is characterized by a semiarid subtropical monsoonal climate. Annual rainfall ranges between 700 and 800 mm, more than 70% of which occurs during the monsoon months through July to September. The mean monthly minimum and maximum air temperatures average 18 and 35 °C during rice seasons (June–October) and 6.7 and 22.6 °C during wheat seasons (November–April), respectively. The soil of the experimental field was a Typic Ustorthent (Soil Survey Staff, 1999) developed on alluvial material with a sandy loam texture (59.8% sand and 16.5% clay). The field had been cultivated to rice-wheat for several years prior to the initiation of the experiment. At the start of the experiment, the field soil (0–15 cm) had a pH (1:2 soil to water ratio) of 8.0, electrical conductivity (1:2 soil:water suspension)