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Long-term effects of NPK fertilizers and organic manures on carbon stabilization and management index under rice-wheat cropping system

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ABSTRACT

The potential of storing carbon (C) in soil and offsetting the atmospheric CO_2 depends on the management practices. This study investigated the long-term (15 years) effects of using nitrogen: phosphorous: potassium (NPK) fertilizers with and without organic manures namely farmyard manure (FYM), green manure (GM), and straw incorporation (SI) on soil C stabilization, and C management index (CMI) in intensive rice-wheat system in *Typic Ustochrepts* soil of a semiarid region in Punjab, India. The long-term effects of different fertilizer treatments as control, NPK, NPK + GM, NPK + SI, and NPK + FYM on soil organic carbon (SOC), labile fractions of SOC (LFSOC), C stabilization, C sequestration, and C management index (CMI) were determined. Prolonged application of NPK fertilizers alone or in combination with organic manures significantly decreased soil bulk density (from 7.3 to 16.6%) and increased total soil porosity of (from 11.7 to 26.2%) as compared to the control in surface soil (0–15 cm). Fertilizations had positive and variable effects on different LFSOC, namely water soluble C (WSC), labile carbon (LC), particulate organic C (POC), hot water soluble carbon (HWSC), and total organic carbon (TOC). Long-term intensive cultivation and fertilization significantly increased the SOC in surface soil (0–15 cm) up to 5.16 g kg^{-1} as compared with its antecedent value of 2.42 g kg^{-1} in 1999. The sensitivity index indicated that among LFSOC, LC (51–85%), WSC (67–131%), POC (64–159%), and HWSC (38–131%) were more sensitive compared with SOC (29–59%). NPK + SI (5.06 Mg C ha^{-1}) or NPK + FYM (5.31 Mg C ha^{-1}) along with NPK sequestered significantly higher C than the application of NPK (3.57 Mg C ha^{-1}) or NPK + GM (4.10 Mg C ha^{-1}). The fraction of C in stable fractions (C_{frac3} + C_{fract4}) increased from 7 to 29% with application of NPK fertilizers and organic manures compared with that of the control. The CMI indicated that the use of NPK + SI or NPK + FYM was statistically superior to the use of NPK + GM for improving the SOC status. The study concluded that a relatively high sensitivity index of LFSOC may be used as an early indicator for determining the potential of different management practices for improving SOC on short-term basis. The results indicated that the stability of SOC varies with the nature of the added organic manures, suggesting that the selection of organic manure is important for long-term C sequestration.

1. Introduction

Soil is an important reservoir of carbon (C), and a component of the global C cycle (Davidson et al., 2000). Maintenance of soil organic carbon (SOC) is essential to sustain soil fertility, productivity and quality (Katyal et al., 2001). The benefits of SOC for sustainable agriculture ecosystem is well recognized. Additionally, a major component of the global C pool of 2500 petagram (Pg = 10^{15}g = 1Gt), which includes about 1550 Pg of SOC and 950 Pg of soil inorganic carbon (SIC), the SOC pool is 3.1 times the atmospheric pool and 4.5 times the live biotic pool (Lal, 2004a). The capacity of a soil to act as sink or source of C depends upon management practices. Adoption of sustainable management practices has a potential to sequester 40–80 Pg of C in soils over the next 50 to 100 years (Houghton et al., 1996). Lack of optimum management practices deteriorated soil quality with the emission of C into the atmosphere (Lal, 2002).

Detection of short and medium term changes in losses or gains of SOC in soil is very difficult because of large variations in the geographical (spatial) and climatic (temporal) conditions

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(Bosatta and Argren, 1994). The degree of stabilization of various components of SOC is different due to variation in physico-chemical properties and turnover time. Labile fractions of SOC (LFSOC) are present in smaller size due to the rapid exhaustion of this pool as compared to non-labile pools (Paul et al., 2001). In agricultural soils, alteration in the SOC is very slow and can take a decade to centuries (Stevenson, 1965). The important LFSOC fractions include labile carbon (LC), water soluble carbon (WSC), hot water soluble carbon (HWSC), and particulate organic C (POC), which are much more sensitive to the change in the fertilization practices and can be used as an indicator of soil quality (Xu et al., 2011).

Conservation tillage, organic manures, crop residues, and mulch farming are commonly recommended practices, which helps to sequester C (Lal, 2004a). These practices have the ability to change the C storage capacity of agricultural soils depending upon regional climate and soil types (Halvorson et al., 2002; Russell et al., 2005). Therefore, it is important to assess C sequestration for specific climate/soil/crop systems/managements in order to draw site specific conclusions. The use of farmyard manure (FYM), green manure (GM), and incorporation of crop residues may be beneficial for C sequestration on long-term basis. Many studies have shown that regular fertilizer application influences SOC pools (Kundu et al., 2007), which might be related to the amount of biomass C returned into the soil and its humification rate (Lal, 2004b).

Carbon management index (CMI) evaluates the relative potential of different management strategies to influence SOC pool and C sequestration. The CMI provides a sensitive measure of the rate of change in the soil C dynamics of a system relative to a more stable reference soil (Blair et al., 1995). Basically, CMI is helpful in monitoring the differences in C dynamics between treatments with time on long-term basis. The higher value of CMI indicates that the system is being rehabilitated, improved and sustained as compared to lower CMI, which depicts that the system is declining.

Climate change poses many threats to agriculture, including the reduction of agricultural productivity and production stability. Rice-wheat is a dominant cropping system in the Indo-Gangetic Plains (IGP) and it occupies 2845 thousand hectares area of the Punjab during 2012–13 (Anonymous, 2015). The major practice followed by the farmers in this region is burning of crop residues especially rice straw. The straw burning results in environmental degradation because it leads to release of soot particles and smoke causing human health problems, emission of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) causing global warming and loss of essential plant nutrients.

Incorporation of different organic manures adds C into the soil, and a part of their C is stabilized into SOC and distributed among different pools or fractions. This process is carried out by various reactions and interactions in soils. Various organic manures differentially affect the amount of C stabilized, size and dynamics of SOC pools (Majumdar et al., 2008). The SOC pool at any time reflects the long-term balance between additions of organic C from different sources and its losses through different pathways. Continuous soil disturbance in the cropping systems modify the long-term balance between oxidative losses of C, while it also leads to a large-scale addition of C to the soil through crop residues and other amendments. This may cause either a net build-up or a net depletion of the SOC pool (Rasmussen et al., 1980; Cole et al., 1993; Kong et al., 2005). Cropping systems and management practices that ensure greater amounts of crop residues returned to the soil are expected to cause a net build-up of the SOC pool.

Soil is a complex system, and the measurement of a single LFSOC does not adequately reflect management-induced changes in soil quality. In contrast, the simultaneous measurement of several LFSOC is required for better assessment of the effects of management on soil properties (Iovieno et al., 2009). Thus, there is a great need to fully quantify and understand the way by which C is lost or stabilized in the soil. The highly recalcitrant or passive pool of SOC is very slowly altered by microbial activities and hence hardly serves as a good indicator for judging soil quality. The addition of FYM contributes more to the passive pool of C as compared to GM (Majumdar et al., 2008). Fractionation of SOC into active and passive pools is helpful in detecting even very small changes in the SOC (Mandal et al., 2013). However, little information was quantified on the basis of these pools.

Assessment of SOC dynamics is important for drawing conclusions regarding sequestration of C in soil, which has the capacity to reduce the atmospheric load of CO_2. Therefore, to understand the interactions of various pools of C, an attempt has been made to determine the long-term effects of NPK fertilizers and organic manures on; (1) labile fractions of soil organic carbon (e.g. LC, WSC, HWSC, and POC) and its sensitivity to management-induced changes (2) fractionation of SOC based on oxidizability (very labile, labile, less labile, and non-labile) (3) identifying a fertilizer management practice for the system that would improve SOC pool and to assess the soil quality based on CMI.

2. Materials and methods

2.1. Site description

A long-term fertilizer experiment was initiated in 1999 on rice–wheat cropping system at Research Farm, Department of Soil Science, Punjab Agricultural University, Punjab, India. The geo-spatial location of this experiment is 30°54′27″ N, 75°46′59″ E at an altitude of 274 m above mean sea level. The climate of the region is characterized by semi-arid, sub-tropical with cold winters and hot summers. The soils of the experimental site are alluvial soils with sandy loam texture and classified as *Typic Ustochrept*.

2.2. Experimental design and treatments

The experiment comprised of 12 combinations of mineral fertilizers and organic manures laid out in a randomized complete block design. Each treatment was replicated three times in a plot size of 108 m^2 (12 m × 9 m). The treatments selected for the present study are presented in Table 1.

The recommended dose of nitrogen (N), phosphorous (P) and potassium (K) in the region for rice was N:120 kg ha^{-1}, P:13.1 kg ha^{-1}, K:25 kg ha^{-1}, and for wheat was N:120 kg ha^{-1}, P:26.2 kg ha^{-1}, K:25 kg ha^{-1}. In this experiment, N was supplied through urea, P through di-ammonium phosphate (DAP), and K from muriate of potash (MOP). In rice, N was applied in three equal splits (1/3rd at the time of transplanting, 1/3rd after 3 weeks of transplanting and remaining 1/3rd after 6 weeks of transplanting). In wheat, 1/2 of the recommended dose of N was applied at the time of sowing and remaining N was broadcasted at the time of first irrigation. The full amount of P and K was applied at the time of transplanting of rice and sowing of wheat. Rice was transplanted in

Table 1
Details of fertilizers and organic manures treatment.

Treatment description
Control (absolute control)
NPK[#]
NPK+ Green manure (GM: *Sesbenia Sp*)
NPK+ Straw incorporation (SI at the rate12 Mg ha^{-1})
NPK+ Farmyard manure (FYM at the rate10 Mg ha^{-1})

[#] The recommended dose of N (nitrogen), P (phosphorous) and K (potassium) for rice was N:120 kg ha^{-1}, P:13.1 kg ha^{-1}, K:25 kg ha^{-1} and for wheat was N:120 kg ha^{-1}, P:26.2 kg ha^{-1}, K:25 kg ha^{-1}. GM: green manure, SI: straw incorporation, FYM: farmyard manure.