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Effects of carbon input on soil carbon stability and nitrogen dynamics

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ABSTRACT

Improved understanding of the process of carbon (C) stabilization is critical to managing emissions from agricultural soils and optimizing crop yield. We assessed soil organic C (SOC) stability and nitrogen (N) dynamics in a long-term fertilization experiment (started in 1972) conducted at three different locations in India (Jabalpur-Vertisol, Palampur-Alfisol and Ranchi-Alfisol). We measured soil organic C (SOC), C pools and stocks in the treatments of no fertilization as control, inorganic fertilization as NPK and integrated fertilization as NPK + farm yard manure (FYM). Quantification of different SOC pools was done by a procedure of acid hydrolysis followed by a long-term (247 days) incubation study. Based on crop yield and C storage, NPK + FYM was the best treatment for improving crop productivity and SOC sequestration. Integrated fertilization for 38 years increased SOC across sites. In the NPK treatment, additional C input (3–9 times higher) in the form of root biomass did not significantly change C pools. Application of FYM in addition to NPK enhanced the acid non-hydrolysable fraction of SOC across sites. Stability of SOC significantly influenced N dynamics in soil and the availability of N in soil is correlated with the amount of C in the acid-hydrolysable pool ($R^2 = 0.64$, $p = 0.01$) but not with SOC ($R^2 = 0.12$, $p = 0.01$). Long-term use of chemical fertilizers did not significantly affect soil total N content.

1. Introduction

Carbon (C) stabilization in soil is critical to influencing the global C cycle. Magnitude of the stable C pool of soil organic matter (SOM) must be increased to enhance soil C sequestration and increase its mean residence time (MRT) (Paul et al., 1997). While soil C pools with different stabilities and turnover rates are important indices to detect the influence of agricultural management on soil quality (Silveira et al., 2008), it is the physical protection of SOM that enhances the MRT (Dungait et al., 2012). Soil organic carbon (SOC) can be stabilized by different mechanisms including selective preservation of biochemically recalcitrant molecules, spatial inaccessibility of SOC for decomposers and enzymes (Dungait et al., 2012) and interactions of SOC with surfaces and metal ions (von Lützow et al., 2008).

Different methods exist to quantify stable forms of SOC (Six et al., 2002; Paul et al., 1997). Acid hydrolysis is used to preferentially remove young, potentially biodegradable compounds and assess the old or passive C fraction (Leavitt et al., 1996; Paul et al., 1997, 2001). The non-hydrolysable fraction in soil includes old C (Trumbore et al., 1996; Paul et al., 1999). Using ^{14}C dating, Paul et al. (1997, 2001) reported that non-hydrolysable C can be 1300 years older than total soil C in the surface soil layer. Therefore, determination of bio-chemically more stable C (acid non-hydrolysable pool or resistant C) would serve as an indicator for measuring the impact of long-term management interventions on soil C sequestration. In addition, changes in the acid hydrolysable fraction is an earlier indicator of management effects on SOM pool (Franzluebbers and Stuedemann, 2002; Banger et al., 2009). Hence, isolation and quantification of operationally measured fractions e.g. acid hydrolysable and non-hydrolysable (stable or resistant) C pools provide valuable information to understand SOC dynamics and the underlying mechanisms for specific management practices (Belay-Tedla et al., 2009).

Consumption of nitrogen (N) fertilizer in India has increased since 1960, along with a strong increase in crop yields. Response of soil C pools to long-term N fertilization is known for temperate agro-ecosystems (Neff et al., 2002; Swanston et al., 2004) and effects of long-term N fertilization on soil C and N dynamics are contradictory. While some have observed decline in soil C following long-term application of N fertilizer (Mulvaney et al., 2009),

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others have reported increase with balanced chemical fertilization (Bharadwaj and Omanwar, 1994; Schjonning et al., 1994; Hati et al., 2008). Paustian et al. (1997) described several mechanisms of SOC storage in response to crop residue incorporation and N fertilization, but concluded that much unexplained variation exists between field experiments. Soils of agro-ecosystems of India, inherently low in C and N concentrations, may respond differently to N fertilization than those of the temperate environment. Some studies have reported increase in C sequestration with the use of N fertilizer because of increase in C fixation with increase in photosynthesis (Bharadwaj and Omanwar, 1994; Schjonning et al., 1994; Jagadamma et al., 2007; Hati et al., 2008). Thus, judicious land management practices also enhance the SOC pool (Reay et al., 2007). However, the magnitude of increase and its allocation among different fractions is not understood. The long-term fertilizer experiments in India, initiated in 1972 under diverse climate and soil conditions, offer an opportunity to study the impact of chemical fertilization and manuring on soil C and N dynamics. The hypothesis tested in this study was that long-term fertilization and manuring increases SOC concentration and affects N availability. Therefore, the present study was conducted to assess the long-term impact of chemical fertilization and manuring on SOC and N pools in diverse agroecoregions.

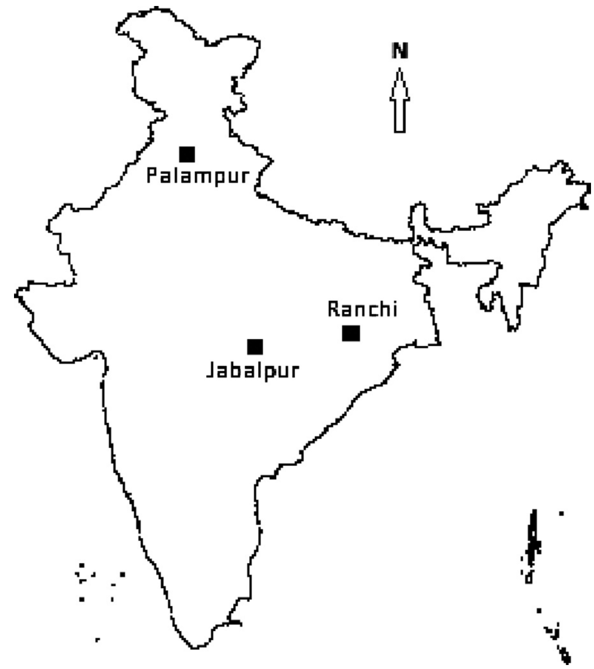

Fig. 1. Location of sampling sites.

2. Materials and methods

2.1. Description of long-term fertilizer experiment

A long-term fertilization experiment (LTFE) on arable land in India was established in 1972 in different agro-climatic regions of north and central India under sub-humid climatic conditions (Fig. 1 and Table 1). The Palampur site is located in the mid hills of the western Himalayas under the mountain climatic zone. The other two sites are located in typically sub-tropical climate with hot and wet summer and mild winter. The LTFE at Jabalpur (Vertisol), Ranchi (Alfisol) and Palampur (Alfisol) sites have 10 treatments replicated 4 times and laid out in a randomized block design. However, the present study focused on 3 treatments: no fertilization as control, inorganic fertilization as NPK and integrated fertilization as NPK + farm yard manure (FYM). Response to these treatments was assessed for a double cropping system. Soybean (*Glycine max.*) and maize (*Zea mays*) were grown as rain-fed crops during the rainy season while wheat (*Triticum aestivum*) w cultivated as an irrigated crop during the winter. Soybean-wheat was the cropping sequence studied at Jabalpur and Ranchi; and maize-wheat was the cropping sequence at Palampur. Tillage systems for these sites were those practiced in each region, and are conventional tillage involving a plough-based system is widely practiced under these conditions.

NPK was applied at the recommended rate for each site and crop. The annual application rate of N ranged from 105 to 270 kg ha^{-1} across sites (Table 2). Manure was applied before seeding of the maize or soybean crop once a year for all sites. The Vertisol at Jabalpur was clayey in texture having neutral to slightly alkaline pH. It is classified as fine montmorillonitic hyperthermic family of Typic Haplusterts (Soil Survey Staff, 2010). The Alfisol at Ranchi is acidic red loam (dominant clay 1:1 type, Kaolinite) and classified as hyperthermic mixed Typic Paleustalfs. However, the Alfisol at Palampur (Alfisol) is acidic silty loam and taxonomically classified as Typic Hapludalfs.

2.2. Sampling and analysis

Soil samples from each replicate were collected from 0 to 15 cm depth for each site during May–June 2010. Samples collected from several locations in each replicate were composited, air-dried,

Table 1
Main site characteristics of the three long-term fertilizer experiments in India.

Site characteristics	Jabalpur (Vertisols)	Palampur (Alfisols)	Ranchi (Alfisols)
State	Madhya Pradesh	Himachal Pradesh	Jharkhand
Latitude/longitude	23° N 10′ E, 79° N 57′ E	32° N, 76′ E	23° N 17′ E, 85° N 19′ E
Climate	Humid subtropical	Montane	Humid subtropical
Altitude (m)	411	1280	625
Mean annual temperature (°C)	25	18	23
Mean annual rainfall (MAR)	1386	2157	1450
Experiment start year (duration)	1972 (38)	1972 (38)	1972 (38)
Plot size (m^2)	184	15	100
Soil classification	Typic Haplusterts (Vertisol)	Typic Hapludalf (Alfisol)	Typic paleustalf (Alfisol)
pH (1.2.5)	7.6	5.8	5.3
Initial organic C (g kg^{-1})	5.7	7.9	4.5
Available N (kg ha^{-1})	193	736	295
Total N (mg kg^{-1})	845	–	500
Sand (g 100 g^{-1})	25	30	66
Silt (g 100 g^{-1})	18	46	9
Clay (g 100 g^{-1})	57	24	25
Textural class	Clay	Silty loam	Sandy clay loam
Bulk density (Mg m^{-3})	1.30	1.31	1.36