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Carbon and nitrogen fractions and stocks under 41 years of chemical and organic fertilization in a sub-humid tropical rice soil

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ABSTRACT

Effects of different fertilizers and manure on dynamics of soil organic carbon (SOC) and nitrogen fractions and their stock changes remains unclear under intensively cultivated rice soil profile. Profile soil samples in six treatments viz. control, nitrogen (N), nitrogen-phosphorus-potassium (NPK), farm yard manure (FYM), N + FYM and NPK + FYM were collected from a long term fertilizer experiment continuing since 1969 at ICAR-NRRI, Cuttack, India to study the soil organic carbon and nitrogen fractions (particulate organic carbon, POC; microbial biomass carbon, MBC; particulate organic nitrogen, PON; and microbial biomass nitrogen, MBN) and SOC sequestration. Results from the study revealed that in the control treatment, where no manure or chemical fertilizer was applied,the bulk density was highest. Balanced fertilization and combined use of chemical fertilizers and manure for 41 years increased the SOC in all the plots except the unfertilized control as compared with the initial value (6.6 g/kg). Balanced fertilization (NPK) and integrated fertilization (NPK + FYM) resulted in similar increases in particulate organic carbon, carbon mineralization and microbial biomass carbon, whereas particulate organic nitrogen, nitrogen mineralization and microbial biomass nitrogen were more in integrated fertilization (NPK + FYM) compared with control treatment. Soil organic C and nitrogen stocks changed positively across the fertilizer and manure treatments over the control. In the control plot, at 0–15 cm depth the soil carbon and nitrogen stock was 15.1 and 1.77 Mg ha^{-1}, respectively which increased to the 19.5 Mg ha^{-1} in NPK + FYM for carbon and 2.25 Mg ha^{-1} in N + FYM for nitrogen. As compared to the initial (13.7 Mg ha^{-1}), the SOC stock in 0–15 cm depth increased under all the fertilized treatments during 41 year period in the order: NPK + FYM > N + FYM > NPK > FYM > N > control. The rate of increase in SOC (carbon sequestration) due to fertilizer application alone varied between 57 and 89 kg ha^{-1} yr^{-1}, while for FYM addition the rate of increase was 61 to 138 kg ha^{-1} yr^{-1}, highest being in NPK + FYM. Correlation coefficients between different soil organic C and N fractions indicate differential accumulation pattern of organic C and nitrogen in different depths. Based on crop yield and C storage, integrated fertilization of chemical fertilizers and manure proved to be the best for improving crop productivity and SOC sequestration.

1. Introduction

Rice is the most important human food crop in the world,which directly feeds more people than any other crop. Nearly half of the world's population (>3 billion people) relies on rice every day. It is the staple food of Asia including India, where over 90 percent of the world's rice is produced and consumed. Rice crop is spectacularly diverse and unique because it can grow in wet ecosystems where other crops cannot survive. Rice paddies account for a large fraction of the wetland ecosystem and most of them are in Asian countries (Redfern et al., 2012). The dynamics of soil carbon (C) and nitrogen (N) in submerged rice fields are different from those of aerobic, because submerged rice fields are maintained at lower redox potentials (Patrick and Delaune, 1972; Takai, 1970). In recent years, all around the world and particularly in India, stagnation or decline in yields has been observed under the intensive rice based cultivation systems; the reasons attributed to this phenomenon are loss in quality and quantity of SOC which impacts nutrient

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supply, particularly nitrogen (Bhandari et al., 2002; Dawe et al., 2000; Ladha et al., 2003; Singh et al., 2004). Inorganic fertilizer and organic manure are the most common resources applied in agricultural production system to improve soil quality and crop productivity (Rudrappa et al., 2006; Shahid et al., 2013). Many studies have concluded that balanced application of inorganic fertilizers with or without application of organic manure can increase SOC and maintain soil productivity (Gami et al., 2001, 2009; Jha et al., 2014; Manna et al., 2005; Purakayastha et al., 2008). Moreover, the addition of fertilizer on a regular basis leads to an increase in soil microbial biomass and also alters soil C and N dynamics (Smith et al., 1994). However, SOC is not a sensitive indicator of changes in soil quality along with different soil or crop management practices due to high background levels and natural variability in soil (Haynes, 2005; Liu et al., 2013).

Soil organic matter plays a vital role in maintaining soil quality because of its direct influence on physical, chemical and biological properties of the soil. There is an urgent need to increase our knowledge and understanding of the dynamics of SOC stock and the role that soil may play in the accumulation of atmospheric C through its sequestration. This need comes out of the fact that soil is a key reservoir of the terrestrial C, which contains globally about 1550 Pg C as organic C. It together with inorganic carbon constitutes about 3.3 times the size of the atmospheric pool and 4.5 times that of the biotic pool (Batjes, 1996). Any attempt that aims to enrich this reservoir through atmospheric C sequestration is likely to mitigate the harmful effects of the green house gases and also ensure global food security to a great extent (Lal, 2004).

Active C and N fractions, such as microbial biomass carbon and nitrogen (MBC and MBN), potentially mineralizable C and N, particulate organic C and N (POC and PON) which respond rapidly to changes in management practices, can better reflect changes in soil quality and productivity by altering the nutrient dynamics through immobilization–mineralization processes (Dong et al., 2012a, 2012b). Particulate organic C and N that contain coarse fraction of organic matter, are considered intermediate between active and slow fractions of SOC and total nitrogen (TN) which change rapidly due to management practices (Cambardella and Elliott, 1992). These soil C and N fractions are likely to be more sensitive to management practices than the total SOC and total N (Awale et al., 2013) and are the fine indicators of soil quality which influence soil function in specific ways (*e.g.*, immobilization–mineralization). Thus, these soil C and N fractions may serve as indicators of future changes in total SOC and TN that are presently undetectable (Dalal et al., 2011; Spargo et al., 2012; Xu et al., 2011). The pool sizes of labile C and N fractions provide an insight into the consequences of management practices that could not be garner from studies of total SOC or TN alone. More resistant fractions of SOC generally have much longer turnover times, and thus have the long-term potential for SOC sequestration (Lal, 2016).

Investigation on changes in soil organic carbon (SOC) and total nitrogen (TN) contents and other soil physical, chemical and microbiological properties resulting from various long-term inorganic fertilizer and organic manure management practices have been done in many regions around the world on intensive lowland-rice cropping (Dong et al., 2012b; Liu et al., 2013; Nayak et al., 2012; Pampolino et al., 2008; Tong et al., 2009; Tripathi et al., 2014) in the humid-subtropical and sub-humid tropical regions. Some of the earlier findings have shown a buildup of soil organic matter stock in rice-based cropping system with farm yard manure (FYM), rice straw or green manure in tropical or subtropical Asian countries (Ghosh et al., 2012; Nayak et al., 2012; Tirol-Padre et al., 2007). But scanty information is available regarding the magnitude of such buildup, its allocation into different soil C and N fractions and their residence time under different management practices. In the recent years, several studies have reported responses of labile SOC pools to management practices (Laudicina et al., 2014; Mandal et al., 2007; Manna et al., 2005; Moharana et al., 2012; Purakayastha et al., 2008; Sainju et al., 2013), however, these studies for soil carbon and nitrogen; and their fractions mostly focused on shallow surface soil. Because of the inadequate information on the distribution of total SOC and TN fractions in soil profile, conclusive identification of beneficial effects after long-term fertilizer application could not be ascertained. Thus, to elucidate the impacts of inorganic fertilizer and manure applications on total SOC and TN; and their fractions for the entire soil profile, more research is needed. An attempt has, therefore, been made in this study (i) to determine the effects of long-term application of chemical fertilizer and manure on soil organic carbon and nitrogen fractions and (ii) to measure the role fertilization on SOC sequestration and yield sustainability in sub-humid tropical intensively cultivated rice soil with a view to assess their aggrading/degrading influences on C and N balance in soils for maintaining soil health and curbing global warming.

2. Material and methods

2.1. Study site

The long term field experimental site is located at the research farm of the ICAR-National Rice Research Institute, Cuttack, India (20°25′N,85°55′E; elevation 24 m above mean sea level) with rice (*Oryza sativa* L.) as mono-crop in wet (June–November) and dry (January–May) seasons of the year. The climate is sub-humid tropical with mean annual precipitation 1500 mm, of which 75–80% is received during June to September and the mean annual temperature is 27.6 °C. The mean temperatures of wet and dry season are 28.0 °C and 27.1 °C, respectively. The difference between mean summer and winter soil temperature is more than 5 °C, thus qualifying for the hyperthermic temperature class. The soil on the farm has developed in recent times from deltaic sediments of the Mahanadi River. The soil of the experimental site is an Aeric Endoaquept with a sandy clay loam texture (31% clay, 17% silt and 52% sand). Other soil physical and chemical properties of the surface soil (0–15 cm) at the start of the study were bulk density 1.4 Mg/m^3, cation-exchange capacity 15.2 cmol(p$^+$)/kg, pH 6.6 (using 1:2.5, soil:water suspension), organic carbon 6.6 g/kg, total N 0.8 g/kg, exchangeable K 0.26 cmol(p$^+$)/kg and available P 13.0 mg/kg.

2.2. Field experiment

The field experiment started in 1969 comprises of two crops per year with rice (*Oryza sativa* L.) as a mono-crop in wet (July–November) and dry (January–May) seasons. The experiment with ten treatments, arranged in a randomized complete block design with three replications include unfertilized control and different combinations of chemical fertilizers (nitrogen, N; phosphorus, P and potassium, K) and farm yard manure (FYM) *viz.* control, N, NP, NK, NPK, FYM, N + FYM, NP + FYM, NK + FYM and NPK + FYM. The FYM used in this experiment is prepared from the wastes collected from the Institute dairy farm which contained 171–189 g total organic C and 4–16 g total N per kg. The FYM (5 Mg/ha) was applied uniformly in the treatments with FYM during the last week of May every year. The chemical fertilizer schedules were 60-40-40 and 80-40-40 kg/ha N-P_2O_5-K_2O for wet and dry seasons, respectively and the fertilizers were applied according to the treatment requirement. All the treatments were followed in the same replicate field plots since the beginning of the experiment.