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Management effect on soil organic carbon pools in lowland rain-fed paddy growing soil

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Abstract

Low and stagnant productivity of rainfed paddy farming is one of growing challenges in developing countries in the absence of management systems that enhance rice productivity and maintain soil health. To identify the effect of nutrient management practices on different pools of soil organic carbon (SOC) under rainfed paddy farming, dataset on on-farm fertilizer experiment plot from 2010 -2013 from Cachar district of Assam, India were utilized. Different pools of SOC viz. $C_{\text{Very Labile (VL)}}$, $C_{\text{Labile (L)}}$, $C_{\text{Less Labile (LL)}}$, $C_{\text{Non Labile (NL)}}$ were studied because of their sensitivity to the influence of agricultural management on soil quality. In surface soil C_{VL} and C_L dominated in organic and organic + inorganic plot, while C_{NL} was higher in control plots. The organic+inorganic treatment experienced 44% increase in C_{AP} (C_{VL}+C_L) over control in surface layer indicating the efficiency of C_{AP} in detecting changes for management systems. The study further revealed that the integrated use of organic with inorganic fertilizer enhanced the productivity and SOC over control treatment. The present study indicated that C_{VL}, C_L or C_{AP} can be important determinants of rice yield rather than total organic carbon.

Key words: Active pool, Passive pool, Total organic carbon, Yield

Introduction

Soil contains the largest organic carbon (C) pool, i.e., approximately 1550 Pg of C, in the global terrestrial ecosystems (Lal, 2007). The soil organic C pool is 2.2 times the size of the atmospheric C pool and 2.8 times the size of the biomass C pool (Lal, 2004; Schimel, 1995). Maintaining soil organic carbon (SOC) is particularly important for sustaining the productivity of agroecosystems, because SOC plays a central role in soil quality and its functioning by influencing soil physical, chemical, and biological properties (Lal et al., 1999; Carter, 2002). SOC levels are governed by the balance between carbon (C) input and output, and strongly influenced by soil management practices (Paustian et al., 2000). Studies have shown that maintenance of SOC at optimum level can be managed through crop rotation, reduced tillage, and fertilization practices (Verma and Sharma, 2007; Gong et al., 2009). Generally, changes in SOC induced by management practices occur slowly; these changes are relatively small as compared to the vast SOC pool size and also vary both spatially and temporally (Paustian et al., 1992; Salinas-Garcia et al., 1997). Therefore, SOC fractions with different stabilities and turnover rates are important variables to detect the influence of agricultural management on soil quality (Silveira et al., 2008; Chivhane and Bhattacharyya, 2010; Mandal et al., 2008). Changes in this fraction could provide a better indicator of soil management effects on soil organic matter (SOM) than changes in total C alone (Banger et al., 2009).

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Soil organic carbon (SOC) stock is comprised of labile or actively cycling pool and stable, resistant/ recalcitrant pools with varying residence time (Chan et al., 2001). Parton et al. (1987) defined soil labile carbon as the fraction of soil organic carbon with a turnover time of less than a few years as compared to recalcitrant carbon with a turnover time of several thousand years. The labile C pool of total organic carbon (TOC) has been the main source of nutrition which influences the quality and productivity of soil (Chan et al., 2001, Mandal et al., 2008). Highly recalcitrant or passive C pool is slowly altered by microbial activities (Weil et al., 2003) and due to this nature it may not be a good soil quality parameter but contributes towards overall TOC stock (Mandal et al., 2008). Soil labile organic carbon is constituted of amino acids, simple carbohydrates, a fraction of microbial biomass, and other simple organic compounds (Zou et al., 2005) and it changes substantially after disturbance and management (Chan et al., 2001). Changes in labile and non labile fraction of C in paddy field under different soil management practices including irrigation facilities have been studied in tropical and sub tropical regions in India (Rudrappa et al., 2006; Mandal et al., 2008). However studies on the changes in C fractions in lowland rainfed paddy with different management practices are lacking. In the present research effort we evaluated the changes in SOC and its fractions in an on farm experiment with different nutrient management regimes in rainfed paddy field and its relationship with productivity.

Materials and Methods

Site description

An on-farm field experiment in tropical humid climate was established in Dargakona village ($24^0$41’373”; $92^0$45’454”) of Cachar district Assam. Study area was originally low lying hillock with scattered forest which was cut down to make levelled field for agriculture around 70 years back. Experimental plot falls under lowland rainfed condition and characterized with single rice cropping system. Paddy field lay barren for six months (December to May) in a year. After crop harvest, residues were left in the field and grazed by domestic animals. The experimental site receives an annual rainfall of 2700 mm per annum. The mean annual minimum temperature ranges from 12^0 C to 25^0 C to mean annual maximum temperature 25.1^0 C to 37^0 C. The initial surface (0-10 cm) and sub-surface (10-30 cm) soil of the experimental site (estimated from control plot) had bulk density of 1.28 gm cm^{-3} and 1.48 gm cm^{-3} respectively; water holding capacity of 52% and 49% respectively; soil organic carbon of 1.3% and 0.70% respectively. The soil is loamy with pH (1:2.5 soil:water) 4.7.

Experimental design

The experiment was laid out in a randomized block design with the following treatments (a) control (without any organic and inorganic fertilizer) (b) village management (partially decomposed/ humified cow dung @ 70-80 Mg ha^{-1}) (c) Inorganic (NPK) fertilizer (130-100-60 kg/ha as recommended by Assam Agricultural University, Jorhat was used in the form of urea, single superphosphate and muriate of potash) (d) Organic (only phosphate solubilizing bio-fertilizer and Azotobacter biofertilizer were applied in two steps: seedling dip and soil application as recommended by Assam Agricultural University, Jorhat) (e) NPK + organic together. Each of the treatments was replicated thrice.

Choice of rice variety, seed bed preparation and field transplantation

A traditional rice variety called *lathma* (*Oryza sativa* L.) was used in the present investigation. *Lathma* variety was chosen because this variety was widely cultivated in the study area. For seed bed preparation, fields were ploughed twice using country plough. Seeds were broadcasted in the month of July. Seedlings were transplanted in rice field in August when the seedlings were around 30 days old. Ploughing with country plough was adopted to prepare the rice field. Rice field was ploughed five times, followed by laddering for levelling the land under partial submergence to create a soft layer for easy transplantation of rice seedlings. After four days of field preparation, rice seedlings were transplanted with a spacing of 10 cm X 10 cm.

Soil sampling strategy

Random soil samples to a depth of 0-10 cm and 10-30 cm were collected in January from each of the treatments. Three replicates for each depth were collected. A composite sample was prepared for each depth, air-dried, ground and passed through a 2 mm sieve and stored in plastic container for routine laboratory analysis. For OC fractionation 100 mesh soil samples were used.

Estimation of oxidizable soil organic carbon and its pool

The oxidizable total soil organic carbon (TOC) was determined by wet oxidation (Walkley and Black, 1934). This was approximated into different pools by the modified Walkley and Black method as described by Chan et al. (2001) using 5, 10 and 20 ml of concentrated (36N) H_2SO_4 that resulted in three acid-aqueous solution ratios of 0.5:1, 1:1 and 2:1 (corresponding to 12, 18 and 24N of H_2SO_4 respectively). The amount of C thus determined allowed the sub-fractionation of TOC into the following four different pools according to their decreasing order of oxidizability.

Pool I (C_{VL} very labile soil carbon): OC oxidizable by 12 N H_2SO_4.

Pool II (C_L labile soil carbon): The difference between C oxidizable by 18N and that by 12 N H_2SO_4.

Pool III (C_{LL} less labile soil carbon): the difference between C oxidizable by 24 N and that by 18 N H_2SO_4.

Pool IV (C_{NL} non labile soil carbon): the difference between TOC and oxidizable C by 24 N H_2SO_4.

Pool I and II together represent the active pool [Active pool = " (Pool I + Pool II)] while pool III and pool IV together constitute the passive pool [Passive pool = " (Pool III + Pool IV)] of TOC in soils (Chan et al., 2001).

Statistical analysis

Tucky's test was performed to determine the statistical significance of treatment effects. Simple correlation coefficient and regression equations were developed to evaluate the relationship between the response variables. The 5% probability level was considered as statistically significant.

Results and Discussion

Effect of treatments on TOC and its fractionation

TOC content for all the treatments was high in surface soil (0-10 cm) than in subsurface soil (10-30 cm). TOC in surface and sub-surface soil was in the order organic > organic + inorganic > VM > inorganic > control and organic > organic + inorganic > inorganic > VM > control respectively (Table 1). Build up of higher amount of TOC in surface soil over sub-surface soil is attributed to accumulation of organic matter from root biomass and left over crop residues in the former that decreased with soil depth. Addition of root biomass and root exudates results in such variation in soil depths (Kaur et al., 2008). Application of organic manure alone or in combination with inorganic fertilizer considerably increased TOC in 0-10 cm soil depth than control plot (Table 1). Reports from long term experiments suggests application of balanced fertilizer combined with manure (Rudrappa et al., 2006, Bhattacharyya et al., 2007, Brar et al,. 2013), paddy straw (Verma and Bhagat, 1992), and green manure (Yadav et al., 2000, Majumder et al., 2008) enhanced TOC in surface soil. C_{VL} and C_{NL} decreased with soil depth. In surface soil C_{VL} and C_L dominate in organic and organic + inorganic plot while C_{NL} is higher in control plots. Application of balanced fertilizer with manure increases polysaccharides (cellulose and hemi-cellulose) in soil that lead to production of higher amounts of C_{VL} (Seneviratne, 2000).

Distribution of active and passive pool of TOC

Passive pool (C_{pp}) dominated active pool (C_{AP}) of C in all the treatments for various soil depths. C_{AP} increased from 25% (in control) to 36% (in organic + inorganic) in surface soil. Marked changes in C_{AP} were not observed in sub-surface soil (Table 1). C_{AP} constituted about 88 % of the TOC after 19 yr long term fertilizer experiment of R-W cropping system in hot, humid subtropics of West Bengal (Majumder et al., 2008). Chan et al. (2001) reported 65% TOC confined to C_{AP} while working with different pasture species in semiarid areas of Australia. Distribution of various pools of TOC in horizon-wise soil samples showed C_{PP} (52-93% of TOC) remained dominant over C_{AP} (6-42% of TOC) in various land uses of shrink-swell soils of Maharashtra (Chivhane and Bhattacharyya, 2010). Comparing our results with the above reported works suggests C_{AP} for a given cropping system/land-use is governed by local management system adopted and also influenced by prevailing climatic condition. Figure 1 depicts that organic+inorganic treatment experienced 44% increase in C_{AP} over control in surface layer. Such an increase indicates that this pool of soil is more sensitive to change due to manuring and fertilization (Chan et al., 2001, Mandal et al., 2008, Moharana et al., 2012), therefore giving it a leading role in nutrient supply. Higher turnover of root biomass in combined application of organic and inorganic fertilizer is attributed for such increases in C_{AP} (Moharana et al., 2012). In sub-surface layers changes in active pool over control were meagre. Such a trend was also reported by Mandal et al. (2008) and Moharana et al. (2012). In both the soil depths together (i.e. 0-30cm), increase in C_{AP} ranged

Table 1 : Soil organic carbon (SOC) pools under different management regimes in surface soil (0-10 cm) and sub-surface (10-30 cm) paddy growing soils in fertilizer experiment at Barak Valley, Assam

	Sub fractionation of organic carbon (%)						
Treatments	Very labile (C_{VL})	Labile (C_{L})	Less labile (C_{LL})	Non-labile (C_{NL})	TOC (%)	Active pool (C_{AP})	Passive pool (C_{PP})
				0-10 cm			
Control	0.28 (22%)	0.04 (3%)	0.10 (8%)	0.88 (67%)	1.30^{a}	25%	75%
VM	0.33 (24%)	0.10 (7%)	0.17 (12%)	0.76 (57%)	1.36^{b}	31%	69%
Inorganic	0.30 (23%)	0.10 (8%)	0.14 (11%)	0.79 (59%)	1.33^{a}	30%	70%
Organic	0.36 (25%)	0.13 (9%)	0.12 (8%)	0.85 (59%)	1.46^{ab}	34%	66%
Organic+Inorganic	0.37 (26%)	0.14 (10%)	0.05 (4%)	0.87 (60%)	1.43^{ab}	36%	64%
				10-30 cm			
Control	0.13 (19%)	0.06 (9%)	0.16 (23%)	0.35 (50%)	0.70^{a}	27%	73%
VM	0.15 (19%)	0.10 (13%)	0.15 (20%)	0.40 (49%)	0.80^{b}	31%	69%
Inorganic	0.13 (16%)	0.11 (14%)	0.17 (21%)	0.40 (49%)	0.81^{b}	30%	70%
Organic	0.14 (19%)	0.09 (12%)	0.10 (14%)	0.41 (55%)	0.74^{ab}	31%	69%
Organic+Inorganic	0.16 (19%)	0.09 (11%)	0.15 (18%)	0.45 (53%)	0.85^{b}	29%	71%
				0-30 cm			
Control	0.21 (21%)	0.05 (5%)	0.13 (13%)	0.61 (61%)	1.0^{a}	26%	74%
VM	0.24 (22%)	0.10 (9%)	0.16 (15%)	0.58 (54%)	1.08^{b}	31%	69%
Inorganic	0.22 (20%)	0.11 (10%)	0.16 (14%)	0.60 (56%)	1.07^{b}	30%	70%
Organic	0.25 (23%)	0.11 (10%)	0.11 (10%)	0.63 (57%)	1.24^{ab}	33%	67%
Organic+Inorganic	0.27 (23%)	0.12 (10%)	0.10 (9%)	0.66 (58%)	1.14^{ab}	33%	67%

Parentheses show percent of TOC; different letters superscripted refers to significant differences between the treatments at 5% level of significance. [Control: without any organic and inorganic fertilizer; VM: village management (partially decomposed cow dung applied @ 70-80 Mg ha^{-1}); Inorganic (NPK) fertilizer (130-100-60 was used in the form of urea, single superphosphate and muriate of potash); Organic manure (phosphate solubilizing biofertilizer and azobacter bio-fertilizer applied in two steps: seedlings dip and soil application; Organic+Inorganic: both organic and inorganic fertilizer applied together].

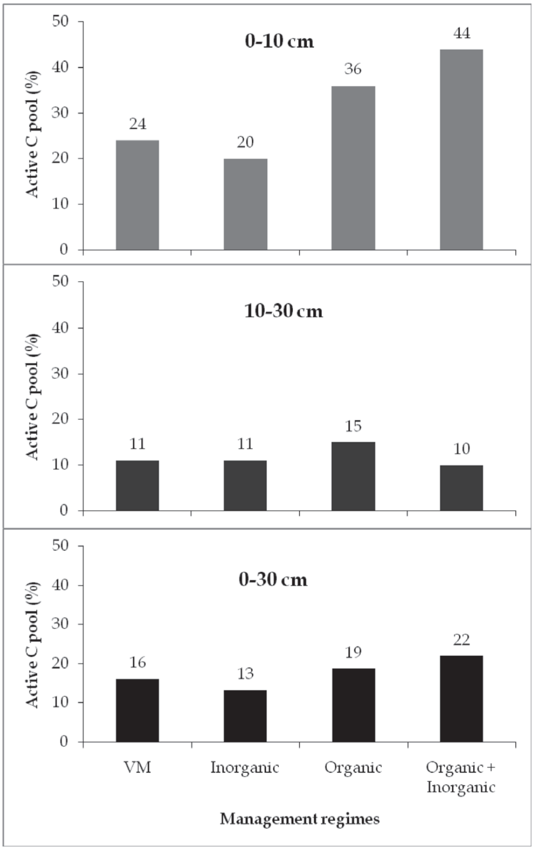

Figure 1. Active C pool over control in different management regimes in various soil depths. [Control: without any organic and inorganic fertilizer; VM: village management (partially decomposed cow dung applied @ 70-80 Mg ha^{-1}); Inorganic (NPK) fertilizer (130-100-60 was used in the form of urea, single superphosphate and muriate of potash); Organic manure (phosphate solubilizing biofertilizer and azobacter bio-fertilizer applied in two steps: seedlings dip and soil application; Organic+Inorganic: both organic and inorganic fertilizer applied together].

from 13% (in inorganic) to 22% (Organic+ Inorganic). As the C_{AP} generally includes light fraction of organic matter, microbial biomass and mineralizable organic matter (Chan et al., 2001, Chivhane and Bhattacharyya 2010, Moharana et al., 2012) organic+inorganic treatment can play pivotal role in enhancing soil fertility and nutrient availability for crop productivity (Bhattacharyya et al., 2007, Mandal et al., 2008).

Analysis of experimental traits and relationship of grain yield with TOC fractionations

Mean comparison of experimental traits showed higher plant height in inorganic treatment. True grain production and grain yield was highest in organic+inorganic (Table 2). Grain yield was 45 and 66% higher in inorganic and organic+inorganic plot respectively over control plot. Organic treatment recognized an increase of 31% over control plot signifying that organic treatment alone cannot enhance productivity like inorganic and organic+ inorganic treatment or replace application of inorganic fertilizer. The integrated use of organic manure with inorganic fertilizer enhances the availability of the nutrients for a longer period (Rani and Srivastava, 1997), increases nutrient use efficiency of the crops (Narwal and Chaudhary, 2006) and enhances the activities of N fixers (Ladha et al., 1989). Integrated use also enhances inherent nutrient supplying capacity of the soil and improved soil physical properties (Hati et al., 2006), rooting and water absorption by crops (Reicosky and Deaton, 1979; Zhang et al., 1998). Better synchrony of nutrient availability to the wheat crop increased grain yield, biomass production and nutrient use efficiency under integrated use of organic and inorganic fertilizer (Moharana et al., 2012). Bhattacharyya et al. (2011) reported that combination of inorganic and organic doses increased TOC as well as crop yield in rice-wheat (R-W) cropping system in typical black soil regions of India. Present study corroborates the above reported studies showing the superiority of organic + inorganic application in enhancing grain yield and increasing TOC stock. Increased soil TOC has important implication in global climate change mitigation through sequestration of atmospheric C is soil and also ensures global food security (Lal, 2004) through sustained yield production from increased soil nutrient status.

To evaluate the influence of TOC and its pool fractionations on grain yield simple correlation coefficient was computed (Figure 2-5). Study

Table 2. Mean comparison of experimental traits (for the period 2013)

Treatment	Plant height (cm)	Panicle number/ rice hill	No. of true grains/panicle	No. of false grains/panicle	Grain yield (kg ha^{-1})
A	78.90^a	7^a	137^a	40^a	860^a
B	80.94^a	7^a	165^b	45^a	934^b
C	89.62^b	8^a	192^a	47^a	1247^b
D	80.96^a	7^a	178^c	35^b	1130^c
E	86.76^b	8^a	198^d	38^b	1425^d

Means with the same letter in each column have no significant difference [A (Control): without any organic and inorganic fertilizer; B (village management): partially decomposed cow dung applied @ 70-80 Mg ha^{-1}; C: Inorganic (NPK) fertilizer (130-100-60 was used in the form of urea, single superphosphate and muriate of potash); D (Organic manure): phosphate solubilizing biofertilizer and azobacter bio-fertilizer applied in two steps: seedlings dip and soil application; E (Organic+Inorganic): both organic and inorganic fertilizer applied together].

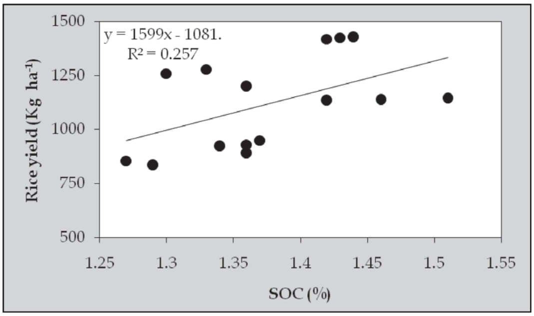

Figure 2: Relationship between rice yield and soil organic carbon pool in the experimental field

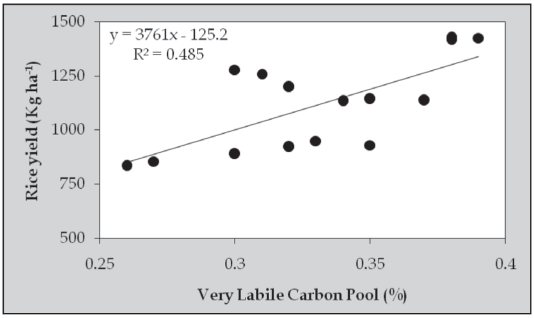

Figure 3: Relationship between rice yield and very labile carbon pool of soil in the experimental field

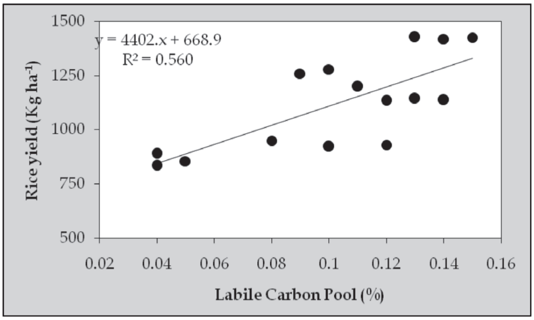

Figure 4: Relationship between rice yield and labile carbon pool of soil in the experimental field

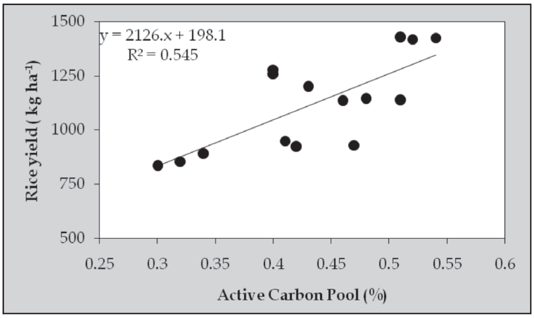

Figure 5: Relationship between rice yield and active carbon pool of soil in the experimental field

showed TOC is weakly related with grain yield ($R^2 = 0.257$, $p>0.05$). Grain yield was highly correlated with C_L ($R^2 = 0.560$, $p<0.05$) and C_{VL+L} ($R^2 = 0.545$, $p<0.05$). Similar result was also reported by Majumder et al. (2008) while working with R-W cropping system of West Bengal, India who suggested that by maintaining better soil quality, C_{VL} and C_L influences crop yield. Chivhane and Bhattacharyya (2010) further suggested that C_{VL} and C_L should be considered as the more logical soil quality parameters as these vary with climate and land use. Present study confirmed that $C_{VL,}$ C_L or C_{AP} are the important determinants of yield over TOC. Because of ease of estimation and low cost, these fractions can reasonably be used as good indicators for assessing soil health and its productivity (Majumder et al., 2008).

To conclude, dominance of C_{PP} over C_{AP} in rainfed paddy soils, as observed in the present study, can act as a mitigative measure of climate change through storing more C in recalcitrant pool. This is because passive pool carbon does not easily oxidize with marginal increase in temperature under climate change scenario. Furthermore, we recommend the promotion of combined application of organic and inorganic fertilizer for enhancing TOC stock and crop productivity in rainfed paddy soils.

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