Management of soil quality and carbon sequestration with long-term application of organic amendments

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Abstract
Soil organic matter is of central importance in maintaining soil quality and is also now receiving attention due to the potential for carbon sequestration in soils. Here we aimed to assess the effects of organic and inorganic amendments on soil quality in a rice-wheat cropping system in the Indo-Gangetic plains of eastern India and to evaluate the carbon sequestration potential of such management approaches. Soil samples were collected from a 19 year old long-term fertility experiment in West Bengal and results showed that there were significant increases in nutrient availability with the application of farm yard manure (FYM @ 7.5 t/ha), paddy straw (PS @ 10 t/ha) and green manure (GM @ 8 t/ha) along with inorganic fertilizer. Microbial biomass C and mineralizable C were also increased by the addition of organic inputs. Continuous cultivation, without application of organic inputs, significantly depleted total C content by 39-43% when compared with the addition of organic amendments. There was a significant increase in non-labile C fraction by the amendments when compared with control. There was a net loss of C by 5.6% due to continuous cultivation without any amendment and 26.1%, 17.7% and 6.3% of the C applied through FYM, PS and GM respectively was sequestered.

Key Words
Soil quality, soil organic carbon, carbon pool, manure, paddy straw

Introduction
Soil quality is an integrated characteristic determined by biological, chemical and physical soil properties defining a soil's capacity to function (Karlen *et al.* 1997). Maintaining or increasing soil organic matter (SOM) is critical to achieving optimum soil function. In many parts of the world, organic wastes represent an inexpensive and plentiful resource for the treatment of soil quality. However, investigation of the options for the application of organic wastes and their efficacy in improving soil condition are needed to assess their potential to partially or fully replace inorganic fertilizers.
Soil organic carbon (SOC) is the most frequently reported soil attribute from long-term agricultural studies and is commonly selected as the key indicator of soil quality and agronomic sustainability because of its impact on other physical, chemical and biological elements of soil quality (Reeves, 1997). Long-term fertility experiments (LTFE) play an important role in understanding the complex interaction involving plants, soils, climate and management practices and are the primary source of information to determine the effects of cropping systems, soil management, fertilizer use, and residue utilization on the quantitative and mechanistic changes soil quality as well as on SOC pools (Leigh and Johnston, 1994; Rasmussen *et al.,* 1998).
Rice (*Oryza sativa* L.) - wheat (*Triticum aestivum* L.) cropping is the dominant cropping sequence in the Indo-Gangetic Plains, and occupies nearly 50% of its cropped area (Singh and Khan, 2000). Use of organic amendments such as FYM, rice straw and green manure is known to improve soil productivity in rice-wheat cropping (Ghosh *et al.,* 2009) and has the capacity to add SOC and to improve soil condition. However, little work has quantified the impact of long-term organic amendments on SOC quantity and pools in intensively managed Indian soils and such studies are particularly scarce in the Indo-Gangetic region. Therefore the present study was undertaken to assess the long term effect of different management practices on soil quality and carbon sequestration using a 19 years old LTFE with rice-wheat cropping systems in West Bengal, India.

Methods
Site description
A long-term field experiment was initiated in 1986 for the All India Coordinated Research Project on Cropping Systems at the University Teaching Farm, Bidhan Chandra Krishi Viswavidyalaya, West Bengal,

India (23˚N, 89˚E, 9.5 m msl); along the new alluvial soil zone in the hot humid sub-tropic Indo-Gangetic plains of eastern India. The experimental soil was characterised with pH 7.2, oxidisable organic C 8.8 g/kg, bulk density 1.2 Mg/m^3 and cation exchange capacity 22.0 $cmol_c/kg$.

Experimental design and treatments

The experiment was laid out in randomised block design with four replications with the following treatments: Fallow (no cultivation since the inception of the experiment) (T_1), Control (conventional cultivation without any fertilizer or amendments) (T_2), 100% recommended dose of inorganic fertilizer (NPK) (T_3), NPK + farm yard manure (FYM @ 7.5 t/ha) (T_4), NPK + paddy straw (PS @ 10 t/ha) (T_5) and NPK + green manure (*Sesbenia sesban*) (GM @ 8 t/ha) (T_6). Soil samples were collected from three different depths (0-.15, .15-.3 and .3-.45 m) 7-10 days after rice harvest, including the fallow and analysed for selected soil quality parameters (physical, chemical and microbiological).

Soil analyses

Soil pH, bulk density, total C, available N, extractable P and exchangeable K was analysed following standard methods. Carbon mineralization (Min-C) was evaluated by incubation using alkali traps (Anderson, 1982). A chloroform ($CHCl_3$) fumigation-extraction method was used to determine microbial biomass C (MBC) (Voroney and Paul, 1984).
Cumulative C inputs, during the 19 cropping cycles, were calculated from organic sources (FYM, PS and GM) as well as from crop contributions (roots, stubble and rhizodeposition) (Table 1). Fractions of SOC were estimated through a modified Walkely and Black method as described by Chan *et al.* (2001) which allowed separation of total C into the following four fractions of decreasing oxidizability: Fraction I ($C_{frac\ 1}$, very labile); Fraction II ($C_{frac\ 2}$, labile); Fraction III ($C_{frac\ 3}$, less labile) and Fraction IV ($C_{frac\ 4}$, non-labile).

Table 1. Cumulative C input from different treatments.

Treatment	Stubble biomass C	Root biomass C	Rhizode-position C	Aquatic biomass C	Crop C input	FYM/PS/GM C	Cumulative C input
	(Mg/ha)						
Control	1.52	10.6	11.8	13.3	37.2	0.0	37.2
100% NPK	3.04	24.5	29.6	13.3	70.4	0.0	70.4
NPK+FYM	3.42	27.0	34.2	13.3	77.9	9.49	87.4
NPK+ PS	3.42	26.4	33.3	13.3	76.4	7.98	84.4
NPK+GM	3.23	25.8	32.5	13.3	74.83	6.31	81.1

Results and discussion

Effect on soil quality

Results showed that upon cultivation with or without fertilizer, there was a little increase in pH over the fallow i.e. uncultivated soil. Soil bulk density (BD) under different treatments ranged between 1.13 to 1.25 Mg/m^3 and the highest value (1.25 Mg/m^3) was associated with fallow (T_1) and 100% NPK (T_3) (Table 2). Application of fertilizer with and/or without organic amendments caused significant increases in available N, P and K content in all the treatments over the control except for K under T_5. The increase in extractable P with T_4 treatment might be due to incorporation of FYM with inorganic fertilizer, since FYM upon decomposition produces some organic ligands, which helps to increase the availability of P to plants.

Table 2. Changes in soil quality parameters under different treatments after 19 years of cultivation.

Treatment	pH	BD (Mg/m^3)	Av. N (kg/ha)	Extrac. P (kg/ha)	Exch. K (kg/ha)	MBC (μg/g soil)	Min-C (mg CO_2/24 h. g soil)	Total C (%)
T_1	6.57^b	1.25^a	132^d	35.0^e	162^d	483^d	0.17^a	1.61^c
T_2	7.20^a	1.13^c	152^c	48.8^d	173^c	250^e	0.09^b	1.12^d
T_3	6.90^a	1.25^a	165^{ab}	95.9^a	199^a	486^d	0.15^{ab}	1.60^c
T_4	7.03^a	1.19^b	167^a	95.5^a	186^b	531^c	0.15^{ab}	1.95^{ab}
T_5	7.00^a	1.19^b	158^{bc}	73.7^c	159^d	776^a	0.13^{ab}	2.00^a
T_6	7.03^a	1.16^b	158^{bc}	90.1^b	191^b	565^b	0.11^{ab}	1.83^b
$SE_m(\pm)$	0.089	0.011	2.30	1.07	1.95	3.58	0.020	0.438

Means followed by common letter are not significantly different ($p<0.05$) by Duncan's Multiple Range Test (DMRT).

Changes in the physical and chemical properties of the soils were associated with changes in the soil biological properties. Microbial biomass carbon (MBC) content of the soils under different treatments (Table 2) varied from 250 to 776 µg/g soil constituting about 3.05% of the TOC content of the soil. The highest and the lowest values were associated with T_5 and T_2 treatment respectively. The greater magnitude of MBC with PS compared to GM or FYM might be due to the presence of decomposition resistant fibre fractions in the former compared with the latter. Similarly Rasmussen *et al*. (1998) reported that addition of organics caused a substantial increase in the MBC in soil. The relative amount of mineralizable C (Min-C) content of the soils under different treatments was as follows: $T_1 > T_3 > T_4 > T_5 > T_6 > T_2$ (Table 2). There was, however, no significant difference among the fertilizer treatments compared in the study. Because of intensive cultivation for the last 19 years, there was a significant decline in this form of C in soils, the magnitude of decrease in control treatment being 48.2% of the fallow.

Effect on C sequestration

Continuous cultivation, without application of organic inputs, significantly depleted total C content by 30% when compared with fallow (Table 2). Application of FYM, PS and GM as a supplement with NPK not only added C to the soil but also increased plant C input in the soil through root residue, stubble, rhizodeposition (Table 1).

The fractions of OC extracted, were significantly different among the treatments. Both PS and GM significantly increased the more labile $C_{frac\ 1}$ by 28% and 25%, respectively; and both PS and FYM increased labile $C_{frac\ 2}$ significantly by 97% and 69%, respectively, when compared with control. All the treatments increased $C_{frac\ 4}$ significantly when compared with control, with the highest increase under T_4 (136%) followed by T_6 (101%) > T_5 (80%) > T_3 (71%). When compared with fallow, continuous cultivation, without any amendment (T_1), decreased the $C_{frac\ 1}$, $C_{frac\ 2}$ and $C_{frac\ 4}$ significantly by 17-43%. Among the organic treatments, only T_4 and T_6 significantly increased the $C_{frac\ 4}$ by 35% and 15% respectively (Table 3).

Table 3. Fractions of SOC (g/kg) under different treatments.

Treatment	Soil organic carbon fraction (g/kg)											
	$C_{frac\ 1}$			$C_{frac\ 2}$			$C_{frac\ 3}$			$C_{frac\ 4}$		
	0-.15	.15-.3	.3-.45	0-.15	.15-.3	.3-.45	0-.15	.15-.3	.3-.45	0-.15	.15-.3	.3-.45
T_1	4.30	2.43	1.89	1.77	1.41	1.43	1.13	2.23	0.33	2.72	3.69	5.54
T_2	3.77	2.00	1.30	0.83	0.54	1.37	1.60	1.10	1.37	1.78	3.47	1.59
T_3	4.17	1.63	1.37	1.07	1.39	1.39	1.50	0.89	1.93	2.98	5.13	3.55
T_4	4.43	1.76	1.50	1.70	1.88	1.04	2.00	1.00	1.95	3.04	7.59	5.49
T_5	4.23	3.45	1.37	2.44	0.98	1.95	1.86	1.82	0.85	2.05	5.29	4.96
T_6	4.77	2.15	1.95	1.50	0.85	1.17	1.73	0.91	1.50	2.48	6.79	4.48
T X D		***			**			**			***	
LSD (0.05)		0.249			0.365			0.401			0.350	

Higher values of labile fractions under NPK+PS (T_5) may be ascribed to the higher polysaccharides (cellulose and hemicelluloses) content of PS that could lead to the higher production of that fraction as compared to that of FYM and GM. The largest effect of NPK+FYM (T_4) treatment on less labile/non labile fraction may be attributed to the higher lignin and polyphenol content of FYM that could lead to formation of more stable complex with protein of plant origin and thus made FYM-C more resistant to decomposition (Tian *et al.,* 1992). The significant increase in MBC with application of organic amendments along with inorganic fertilizer probably resulted from a more conducive environment for microbial growth (Grego *et al.* 1998). When compared with fallow, the amount of sequestered C was higher (2.47 Mg/ha) under T_4 followed by T_5 (1.41 Mg/ha) > T_6 (0.4 Mg/ha). There was a net loss of C by 5.57 due to continuous cultivation without any amendment. The result showed that 26.1%, 17.7% and 6.3% of the C applied through FYM, PS and GM were sequestered. This indicates that among the organic amendments, C applied through FYM was sequestered more than that of PS, followed by GM. This may be attributed to the higher lignin and polyphenol content of FYM (17.5% and 1.08%) than that of PS (11% and 0.60%) and GM (8.9% and 0.32%). Addition of these organic amendments also increased plant C input in the soil (Table 1) and when the plant C inputs were included with C inputs through organic amendments, then the percentage of C sequestration reduced to 14.5%, 10.0% and 3.7 % due to the FYM, PS and GM application, respectively. After 19 years cropping cycles, the existence of a strong positive linear relationship ($R^2 = 0.98$) between stable C ($C_{frac\ 4}$) and cumulative C input indicates that soil of the present study still has the capacity to sequestered more C with the increase of C input through organic amendment as well as crop C input.

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

Conclusion

Management practices such as application of fertilizer and organic amendments played important roles in maintaining soil quality and C sequestration and thereby greenhouse gas mitigation in the Indo-Gangetic plains of eastern India. Addition of organic residues with inorganic NPK fertilizers significantly increased the nutrient content of the soil. Continuous cropping decreased total C as well as its labile and non-labile fractions. The labile C fractions dominated in the near surface soil layers, but decreased significantly in the deeper layers where the recalcitrant C fraction was significantly dominated down to .45 m depth. The result has clearly shown that even in intensive cropping, application of NPK + organic amendments could build up more C as compared to that of fallow and among the organic inputs, FYM is proved more beneficial than PS and GM.

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1 – 6 August 2010, Brisbane, Australia. Published on DVD.