Impact of soil amendments on organic carbon pools under a rice-wheat cropping system

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Abstract
Rice-wheat cropping is the dominant cropping sequence in the Indo-Gangetic plains (IGP) of India. An experiment was conducted to study the impact of continuous application of farmyard manure (FYM) and rice straw (RS), either alone or in conjunction with fertilizer nitrogen (N), under a rice-wheat cropping system on i) total soil organic carbon (SOC) and slow pool C, and ii) stabilization of cumulative input C. Application of FYM, after seven years of rice-wheat cropping cycles, increased total SOC and slow pool C at 0-0.15 m soil depth by 6.7 t/ha and 1.5 t/ha, respectively, with the highest effect when FYM, RS and fertilizer N were applied together. Incorporation of RS increased total SOC by 4.1 t/ha, with an insignificant effect on the slow pool C. There was no significant effect of fertilizer N application on total SOC and slow pool C. The slow pool C was strongly correlated with the total SOC. About 18.5% and 4.2% of the cumulative input C were stabilized as total SOC and slow pool C, respectively, due to application of FYM; values for RS were 17.9% and 3.3%, respectively.

Key Words
Farmyard manure, rice straw, nitrogen, slow pool C, C stabilization

Introduction
Rice–wheat cropping systems are of immense importance for food security and livelihoods in South Asia. About 85% of the rice-wheat area in South Asia is located in the IGP. Since the late 1990s, rice and/or wheat yields have stagnated or declined across the IGP (Ladha *et al*., 2003). Regmi *et al*. (2002) attributed the reduced productivity of the rice-wheat system to the decline in soil organic matter (SOM) and decreased soil fertility. Terrestrial ecosystem models, such as CENTURY (Parton *et al*., 1988), partition SOC into an active pool with turnover time ranging from1-3 months, a slow pool with turnover time ranging from 10 to 50 years, and a passive pool with turnover time ranging from 400 to 4000 years. Most of the studies in the IGP are related to the management effect on the active or labile C pool and total SOC (Sekhon *et al.,* 2009; Benbi and Brar, 2009). Information about the impact of agricultural management practices on slow pool C, particularly under rice-wheat systems in the IGP, is very scanty. The present study was conducted to evaluate the impact of the application of FYM, RS and fertilizer N alone or in different combinations on (i) total SOC and slow pool C (particulate organic matter carbon [POM-C]), and ii) stabilization of cumulative C in the subtropical IGP of northern India after seven cycles of rice-wheat cropping systems.

Methods
Experimental Site
The experiment was set up in 1999 at the Punjab Agricultural University research farm, Ludhiana, India (30º 56' N, 75º 52' E). The experimental site is characterized by a semiarid sub-tropical climate. Soil texture is a sandy loam (60% sand, 17% clay and 23% silt) and the soil is classified as a Typic Ustorthents.

Treatments and Crop Management
The treatments viz. FYM (36.6% total C, 17% lignin and C:N ratio of 38.5), rice straw (46% total C,10% lignin and C:N ratio of 71.9) and fertilizer N, were laid out in a randomized block design with four replications in plots of 15 m x 3.3 m (Table 1). Cumulative C inputs, during the seven cropping cycles, were calculated from organic sources (FYM and RS) as well as from crop contributions (roots, stubble and rhizodeposition) (Table 2).

Soil sampling and analysis
Soil samples were collected from 0-0.15 m soil depth after seven cycles of a rice-wheat cropping system using a core sampler with internal diameter of 70 mm. Each sample was a composite of six cores within a plot. The samples were air-dried and passed through a 2 mm sieve for analysis.

Table 1. Details of FYM, RS and fertilizer N treatments applied to wheat and rice grown in sequence.

Treatment	Rice	Wheat
T_1	Nil	Nil
T_2	120 kg N/ha	120 kg N/ha
T_3	FYM at 10 t/ha	Nil
T_4	FYM at 10 t/ha+120 kg N/ha	120 kg N/ha
T_5	Nil	Rice straw incorporated before wheat sowing
T_6	Nil	Rice straw incorporated before wheat sowing+120 kg N/ha
T_7	FYM at 10 t/ha	Rice straw incorporated before wheat sowing
T_8	FYM at 10 t/ha+120 kg N/ha	Rice straw incorporated before wheat sowing+120 kg N/ha

Total organic C and slow pool C

The amount of total soil C was determined by CHNS Elemental Analyzer (Vario EL III, Germany). The amount of inorganic C was determined titrimetrically, by digesting the soil with dilute HCl following the method of Bundy and Bremner (1972). The amount of total SOC was estimated by subtracting the amount of inorganic C from the total C. The amount of the total SOC was computed by multiplying the % total SOC with bulk density (g cm^{-3}) and depth (cm), and was expressed as t/ha. Particulate organic matter is the measure of slow pool C (Cambardella and Elliott, 1992). This pool was determined by the method described by Cambardella and Elliott (1992). The C stabilization % was estimated as:

$$\text{C stabilized (\%)} = \frac{SOC_{treatment} - SOC_{control}}{SOC_{cumulative\ input\ in\ treatment} - SOC_{cumulative\ input\ in\ control}}$$

Table 2. Cumulative C input (t/ha) from seven years of rice-wheat cropping cycles through FYM, RS and additions from stubbles, roots and rhizodeposition.

Treatment	Rice straw C	FYM-C	Roots-C	Stubble-C	Rhizodeposition-C	Total input C
T_1	0	0	2.97	0.71	5.9	5.9
T_2	0	0	5.79	1.45	11.6	18.8
T_3	0	27.5	4.55	1.06	8.8	42.0
T_4	0	27.5	7.29	1.80	14.4	51.0
T_5	18.0	0	3.50	0.80	6.8	29.1
T_6	26.8	0	6.19	1.54	12.3	46.8
T_7	24.3	27.5	4.72	1.07	9.2	66.8
T_8	34.4	27.5	7.33	1.81	11.5	82.4

Results and Discussion

Total SOC

Application of both FYM and RS significantly increased the total SOC (Table 3). After seven cycles of a rice-wheat cropping system, application of FYM and RS increased the total SOC at the 0-0.15 m soil depth by 6.7 t/ha and 4.1 t/ha, respectively, with the highest increase in SOC (7.9 t/ha) when all the three treatments were applied together. There was no significant effect of fertilizer N application resulting in no significant difference when applied with FYM or RS or FYM+RS from their individual application. The highest amount of cumulative C input (Table 2) under FYM+RS+N treatment may be attributed to the highest increase in total SOC under that treatment. Positive effects of FYM and RS application on SOC have been reported by several researchers (Yang *et al.,* 2005; Singh *et al.,* 2005).

Slow pool C

After seven cycles of a rice-wheat cropping system, application of FYM increased the slow pool C, as estimated by POM-C, at the 0-0.15 m soil depth by 1.5 t/ha, with the highest effect (2.5 t/ha) when all three treatments (FYM+RS+fertilizer N) (T_8) were applied together (Table 3). There was no significant effect of RS incorporation on the slow pool C. Plant residual lignin directly flows to the slow pool (Parton *et al*., 1987). The insignificant effect of RS on slow pool C could be attributed to the lower lignin content of RS as compared to FYM. Application of fertilizer N did not influence this pool. Mando *et al*. (2005) reported in a similar fashion that manure was the most effective in increasing POM-C when compared with urea, and straw with or without urea. Averaged across different treatments the slow pool C constituted 35-58% of the total SOC, similar to the conceptual pool size described by the CENTURY model (Parton *et al*., 1988). Slow pool C was strongly correlated (r^2= 0.76) with the total SOC.

Table 3. Influence of FYM, RS and fertilizer N application on total SOC and slow pool C (POM-C) after seven cycles of rice-wheat cropping system at the 0-0.15 m soil depth.

Treatment	Total SOC (t/ha)	Slow Pool C (POM-C) (t/ha)	C stabilization % (as slow pool C)	C stabilization % (as total SOC)
T_1	6.18a	3.58 (58)ab		
T_2	5.96a	3.27 (55)a	-2.4	-1.7
T_3	12.83c	5.08 (40)c	4.2	18.5
T_4	12.68c	4.45 (35)bc	1.9	14.4
T_5	10.32b	4.34 (42)bc	3.3	17.9
T_6	10.39b	4.35 (42)bc	1.9	10.3
T_7	13.79d	5.17 (37)c	2.6	12.5
T_8	14.11d	6.10 (43)d	3.3	10.4
LSD(0.05)	0.349	0.967		

Different small letters between rows indicate significant differences (P<0.05)
Values in parentheses indicate percentage of total organic C

Carbon stabilization

In the FYM treated plots, after seven cycles of a rice-wheat cropping system, 18.5% and 4.2% of the cumulative input C was stabilized as total SOC and slow pool C at the 0-0.15 m soil depth. Similarly, in the RS incorporated plots, 17.9% and 3.3% of the cumulative input C was stabilized as total SOC and slow pool C at the 0-0.15 m soil depth. The results suggest that FYM was slightly more effective, when compared to RS, in term of stabilization of C in the slow C pool. This may be attributed to the higher lignin content of FYM as compared to RS, as lignin directly enters into the slow pool (Parton *et al*., 1987). The N fertilization stimulates microbial activity and enhances C turnover (Raiesi, 2004), which explains the negative values of C stabilization in the fertilizer N applied plots.

Conclusion

Application of FYM at 10 t/ha/yr significantly increased total SOC stock (108%) and the slow pool C (42%), after seven years under the rice-wheat system. Although incorporation of RS alone had no effect on slow pool C, the combined application of RS with FYM and fertilizer N significantly increased slow pool C (70%) that would contribute to improving soil fertility as well as improve the total SOC stock under rice-wheat systems.

References

Benbi DK, Brar JS (2009) A 25-year record of carbon sequestration and soil properties in intensive agriculture. *Agronomy for Sustainable Development* **29,** 257-265.

Bundy LC, Bremner JM (1972) A simple titrimetric method for determination of inorganic carbon in soil. *Soil Science Society of America Proceeding* **36,** 273-275.

Cambardella CA, Elliott ET (1992) Particulate soil organic matter changes across a grassland cultivation sequence. *Soil Science Society of America Journal* **56,** 777-783.

Ladha JK, Dawe D, Pathak H, Padre AT, Yadav RL, Singh B, Singh Y, Singh P, Kundu AL, Sakal R, Ram N, Regmi AP, Gami SK, Bhandari AL, Amin R, Yadav CR, Bhattarai EM, Das S, Aggrawal HP, Gupta RK, Hobbs PR (2003) How extensive are yield declines in long-term rice-wheat experiments in Asia? *Field Crops Research* **81,** 159-180.

Mando A, Bonzi M, Wopereis MCS, Lompo F, Stroosnijder L (2005) Long-term effects of mineral and organic fertilization on soil organic matter fractions and sorghum yield under Sudano– Sahelian conditions. *Soil Use and Management* **21,** 396–401.

Parton WJ, Schimel DS, Cole CV, Ojima DS (1987) Analysis of factors controlling soil organic matter levels in Great Plains grasslands. *Soil Science Society of American Journal* **51,** 1173-1179.

Parton WJ, Stewart JBW, Cole CV (1988) Dynamics of C, N, P and S in grassland soils: a model. *Biogeochemistry* **5,** 109-131.

Raiesi F (2004) Soil properties and N application effects on microbial activities in two winter wheat cropping systems. *Biology and Fertility of Soils* **40**, 88-92.

Regmi AP, Ladha JK, Pathak H, Pasquin E, Bueno C, Dawe D, Hobbs PR, Joshy D, Maskey SL, Pandey SP (2002) Yield and soil fertility trends in 20-year rice-rice-wheat experiment in Nepal. *Soil Science Society of America Journal* **66,** 857-867.

Sekhon KS, Sing JP, Mehla DS (2009). Soil organic carbon pools after seven years of manures and mineral fertilizers application in a rice-wheat rotation. *Archives of Agronomy and Soil Science* **55,** 197-206.

Singh G, Jalota SK, Sidhu BS (2005) Soil physical and hydraulic properties in a rice-wheat cropping system in India: effect of rice straw management. *Soil Use and Management* **21**, 17-21.

Yang C, Yang L, Ouyang Z (2005) Organic carbon and its fractions in paddy soil as affected by different nutrient and water regimes. *Geoderma* **124,** 133-142.