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Research Paper

Carbon sequestration and yield of rice (*Oryza sativa*)–wheat (*Triticum aestivum*) soils amended with different organic manures and tillage practices

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ABSTRACT

A field experiment was conducted during 2 *kharif* and *rabi* seasons during 2006–08 with rice (*Oryza sativa* L.)–wheat [*Triticum aestivum* (L.) emend. Fiori & Paol.] cropping system at New Delhi. The main plots comprised 2 tillage treatments, viz. puddled and non-puddled in rice and with tillage and no-tillage in wheat. The subplots included 7 fertilizer treatments including recommended doses of urea (120 kg N/ha), urea + farmyard manure (FYM), urea + green manure (GM), urea + municipal solid waste (MSW) compost. Yields of rice and wheat were higher under puddled/conventional tilled condition compared to non-puddled/no-tillage conditions. Application of organic matter with recommended dose of mineral fertilizer gave the highest grain and straw yields compared to other treatments. The carbon sequestration potential was 0.146, 1.31, 1.165, 1.238, 0.728, 1.019 and 0.874 tonne C/ha under 120 kg N, 120 kg N + 6 tonnes FYM, 60 kg N + 6 tonnes FYM, 120 kg N+ 3 tonnes GM, 60 kg N + 3 tonnes GM, 120 kg N + 60 kg N (MSW compost) and 120 kg N + 60 kg N (MSW compost) treatments respectively, under puddle/tilled rice–wheat cropping system. However, under non-puddled/no-tilled crops carbon sequestration potential were 0.291, 1.601, 1.456, 1.529, 1.019, 1.31 and 1.048 tonnes C/ha under treatment having 120 kg N, 120 kg N + 6 tonnes FYM, 60 kg N + 6 tonnes FYM, 120 kg N+ 3 tonnes GM, 60 kg N + 3 tonnes GM, 120 kg N + 60 kg N (MSW compost) and 120 kg N + 60 kg N (MSW compost) respectively. The addition of organic manures resulted in sequestration of carbon in rice–wheat cropping system. The carbon sequestration increased under reduced tillage conditions of soil.

Key words: Carbon sequestration, Organic amendments, Rice–wheat system, Soil organic carbon, Tillage, Yield attributes

Judicious nutrient management is crucial to soil organic carbon sequestration in tropical soils (Bhattacharyya *et al.,* 2007; Mandal *et al.,* 2007). Adequate supply of nutrients in soil can enhance biomass production and soil organic carbon (SOC) content (Van Kessel and Hartley, 2000). Use of organic manure and compost enhances the SOC pool more than application of the same amount of nutrients as mineral fertilizers (Gregorich *et al.,* 2001). Besides the conventional organic sources, Indian cities generate 4.1 Million tonnes C/year from municipal solid waste (MSW) and it can be an important source of organic C (Pathak *et al.,* 2009). Long-term manure application increases the SOC pool (Gilley and Risse, 2000), which not only sequesters CO_2 but also enhances productivity of soil (Swarup *et al.,* 2000; Manna *et al.,* 2005). It is, however, argued that SOC sequestration is a major challenge in soils of the tropics and sub-tropics, where climate is harsh and the rate of C mineralization is high because of high temperature and low humification efficiency (Ladha *et al.,* 2003).

Rice–wheat cropping system (RWCS) of the Indo-Gangetic Plains (IGP) in South Asia is vital for food security and livelihood for millions of rural and urban people. The area under RWCS in the IGP is about 10 million ha (Prasad, 2005). In the IGP, the increased adoption of rice–wheat has resulted in a heavy usage of irrigation, fertilizer, electricity and diesel. Long-term experiments conducted in Indian IGP showed that there is a stagnating or declining trend in productivity at several locations even with application of N, P and K fertilizers under modern intensive farming (Sinha *et al.,* 1998). The decline or stagnation of crop yields has been attributed to changes in quantity and

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quality of soil organic matter (SOM) and a gradual decline in the supply of soil nutrients, causing macro-and micro-nutrient imbalances (Ladha *et al.,* 2003). Conservation tillage, besides reduction in fossil fuel use for ploughing and puddling, may enhance SOC concentration in these soils (Lal, 2004). Benbi and Brar (2009) in their 25-year study found that intensive cultivation of a rice–wheat system resulted in 38% increased C sequestration from 2.9 g/ kg in 1981-82 to 4.0 g/ kg in 2005-06, a favourable pH environment and amelioration of the soil salinity(pH declined by 0.8 pH units from 8.5 to 7.7). Increased productivity of rice and wheat resulted in enhanced C sequestration in the plough layer by 0.8 tonne C/ha/tonne of increased grain production. Swarup (1998) reported that integrated nutrient management enhanced SOC concentration of rice soils from <5 g/kg in 1973 to about 8 g/kg in 1994. Manuring and application of crop residue or compost also enhanced soil aggregation. So there is a need to identify good carbon management strategies that may be needed for sustainable crop production. With this background a field experiment was conducted to determine the effect of different nutrient management and tillage practices on yield attributes, yield and carbon sequestration of soils in rice–wheat system.

MATERIALS AND METHODS

The experiment growing rice and wheat for rainy (*kharif*) and winter (*rabi*) seasons for 2 years (2006–2008) was conducted at the farm of Indian Agricultural Research Institute (IARI), New Delhi (28°40' N, 77°12' E, 228.6 m above the mean sea-level). The climate of Delhi is sub-tropical semi-arid with hot and dry summers and cold winters under average climatic conditions. The area receives 750 mm annual rainfall, about 80% of which occurs from June to September. The mean annual maximum temperature is 35°C, while the mean annual minimum temperature is 18°C. The soils are well drained with the groundwater table at 6.6 and 10 m depth during the rainy and summer seasons, respectively. The alluvial soil of experimental site had 7.82 pH and sandy clay loam texture. At the beginning of experiment, composite soil sample had 250.0 kg/ha total N, 13.2 mg/kg NH_4-N, 31.0 mg/kg NO_3-N, 56.5 mg/kg available P and 406.0 mg/kg available K.

The field experiment was conducted with rice variety 'Pusa Sugandh 5' during *kharif* seasons of 2006 and 2007. The experiments was laid out in a split-plot design. The main plots comprised 2 tillage treatment, viz. puddled and non-puddled. The subplots included 7 treatments each with 3 replications in plots of 7.5 m long and 7.00 m wide. In puddling treatments, cross-ploughing was done with disc plough and then water was filled 12 hrs before puddling. Transplanting was done 8 hr after puddling. In non-puddled treatments, water was filled after cross-ploughing of field and then transplanting was done. The C, N, P and K contents of the applied organic manures are provided in Table 1. In 2006 and 2007, transplanting was carried out on 22 and 18 July respectively, and row-to-row spacing of 20 cm and plant-to-plant spacing of 15 cm were maintained. Details of the treatments are given in Table 2. Urea was used as a source of mineral nitrogen and applied in 3 equal splits as per the treatment. Phosphorus (60 kg P/ha) and potassium (50 kg N/ha) were applied basal. Irrigations were provided at every 2 days throughout the cropping period to maintain the saturation moisture regime. Farmyard manure (FYM) was incorporated in soil 2 weeks before transplanting @ 6 tonnes/ha. On dry- weight basis it contained 0.96% N, 0.29% P and 0.48% K. Green-manuring crop *(Sesbania aculeata)* was incorporated (3 tonnes/ ha) in soil before transplanting. Municipal solid wastes (MSW) compost was incorporated @ 60 kg N/ha 2 weeks before transplanting. Wheat variety 'PBW 343' was sown in the last week of November at a row spacing of 22.5 cm. Urea was applied as per the treatment in 3 splits, half at 24 days after sowing (DAS) and the remaining half in 2 equal splits at 40 and 90 DAS. Phosphorus (60 kg P/ha) and potassium (50 kg N/ha) were applied basal. Five irrigations were applied at 20, 41, 63, 83 and 107 days after sowing (DAS). The FYM, green manure and MSW compost were applied in the same way as in rice. The experiment was laid out in a split-plot design. The main plots included 2 tillage treatments, viz. conventional tillage and no-tillage. In conventional tillage treatments, two times cross ploughing was done with disc plough and once by cultivator and then sowing was done. In no-tillage treatments, sowing was done with no-tillage seed drill. The subplots included 7 treatments as done in rice crop. Each treatment was replicated thrice. Plots size in rice as well as wheat was 7.5 m × 7.00 m and same layout was used for 2 years in both the crops. Wheat crop was harvested in the third week of April.

Soil samples from 0–15 cm and 15–30 cm depth were collected in 3 locations from each plot at different crop growth stages like sowing, tillering, flowering and harvesting. The soil samples were analysed for soil organic carbon and microbial biomass carbon (MBC) at different stages of crops. The C sequestration was calculated only in terms of increase in C stock in soil. Data on initial and

Table 1. Composition of different organic amendments (dry weight basis)

Organic source	C (g/kg)	N (g/kg)	P (g/kg)	K (g/kg)
FYM	318	9.6	2.9	4.8
GM *(Sesbania aculeata)*	410	20.7	1.9	18.5
Compost (MSW)	35	2.5	4.0	1.56

final SOC concentration in the mineral and organic amended treatments were obtained from the field experiments carried out in rice and wheat for 2 years. The mass of SOC in the surface layer (0–15 cm) of soil was calculated (Pathak *et al.,* 2011) as follows:

$$MSOC = SOC \times BD \times T$$

where MSOC is mass of soil organic carbon (Mg/ha), SOC is organic C concentration in soil (%), BD is bulk density (Mg/m^3) and T is thickness of surface layer (cm).

Carbon sequestration potential (CSP) of a treatment was calculated as

$$CSP_{\text{treatment}} = MSOC_{\text{treatment}} - MSOC_{\text{initial control}}$$

$MSOC_{\text{treatment}}$ was final SOC in the mineral or mineral + organic treatment (Mg/ha) and $MSOC_{\text{control}}$ was initial SOC in the unfertilized soil at the beginning of the experiment in Mg/ha.

The data on various parameters were statistically analysed using MSTAT-C (version 1.41). The critical difference (CD) between the treatment means was used to assess the level of significance.

RESULTS AND DISCUSSION

Yield attributes and yields of rice and wheat

The yield attributes of rice and wheat, viz. number of effective tillers and test weight were positively influenced by the addition of organic amendments, viz. FYM, GM and MSW compost along with the mineral N in rice over sole mineral N (Tables 2 and 3). In non-puddled rice on an average 9% less number of panicles/hill were recorded in the control treatment compared to puddled rice. In other treatments also, all the yield attributes were lower in non-puddled rice treatments compared to puddled rice. In wheat also, all the yield attributes were lower in non-tillage condition compared to conventionally tilled wheat. Yield attributes of rice and wheat showed higher values when FYM, GM and MSW compost were added with recommended dose of mineral nitrogen. However, yield attributes of rice and wheat declined when 50% of mineral nitrogen was substituted with organic sources, i.e. FYM, GM and MSW. The number in tillers of wheat increased by 17% in conventional tilled plots over the no-tilled plots. In rice crop there was reduction in number of productive tillers by 16.5 and 16.4% under treatments T_7 and T_3 compared with T_2 treatment in puddled rice. Thus there was reduction in tillering in non-puddled rice and no-tilled wheat in both the years compared to conventional tillage. Test weight (1,000-grain weight) of rice and wheat was lower in non-puddled/ no-tillage rice/wheat compared to conventionally puddled/ tilled conditions. Improvement in yield attributes of rice with application of manures was reported by Singh *et al.* (2011).

Yields of rice as well as wheat were significantly affected by integrated application of organic amendment in both the tillage conditions. In puddled conditions, grain yields of rice ranged from 4.60 to 5.96 tonnes/ha and 4.80 to 5.89 tonnes/ha and in non-puddled conditions from 3.91 to 4.85 tonnes/ha and 3.85 to 4.80 tonnes/ha (Tables 2, 3). In conventionally tilled conditions, grain yield of wheat ranged from 4.42 to 5.87 tonnes/ha and 4.63 to 5.78 tonnes/ha and in no-tillage condition from 3.75 to 5.02 tonnes/ha and 3.82 to 4.95 tonnes/ha. Grain and straw yields of rice and wheat were increased when FYM, GM and MSW compost were added with recommended dose of mineral nitrogen. However, yields of rice and wheat declined when 50% of mineral nitrogen was substituted with organic sources, i.e. FYM, GM and MSW. Treatments with addition of organic manures along with mineral N (urea) resulted in higher yields in both rice and wheat owing to rapid and higher nutrient availability compared to the mineral fertilizer treatment. Singh *et al.* (2011) also reported positive effects with the addition of organic manures along with urea on the yield of rice and wheat. The yield attributes and yields in the MSW compost treatments were at par with the farmyard manure and green-manure treatments in both rice and wheat. The yield data obtained clearly demonstrated the superiority of the integrated use of FYM, GM, compost and chemical fertilizers. The beneficial effect of integrated use of N with organic amendments was more pronounced and effective in enhancing the productivity. This could be due to other benefits of organics apart from N supply, such as improvements in microbial activities; better supply of macro- and micronutrients such as S, Zn, Cu and B which are not supplied by mineral fertilizers; and less losses of nutrients from the soil (Yadav *et al.,* 2000). The higher wheat yields obtained from FYM, GM and compost-amended plots in both conventionally tilled and no-tilled wheat attributed possibly to the better supply pattern of N, P and K and improved soil physical conditions (Yadvinder-Singh *et al.,* 2004).

The straw yields of rice and wheat were significantly influenced by different manure treatments compared with control (Tables 2, 3). Higher tiller production owing to favourable N availability at the different growth stages increased the photosynthetic assimilation, resulting in enhanced dry matter in organic amended treatments. Application of organic amendments caused appreciable improvement in vegetative growth as evident by significantly more number of tillers/hill that ultimately resulted in higher dry-matter production. Harvest index also showed the same trend as grain and straw yield. As harvest index is dependent on these 2 parameters, same trend could be

Table 2. Effect of different nutrition and tillage practices on yield attributes and yield of rice in puddled and non-puddled conditions

Treatment	Conventional puddled rice										Non-puddled rice									
	Effective tillers/hill		1,000-grain weight (g)		Grain yield (tonnes/ha)		Straw yield (tonnes/ha)		Harvest index (%)		Effective tillers/hill		1,000-grain weight (g)		Grain yield (tonnes/ha)		Straw yield (tonnes/ha)		Harvest index (%)	
	2006	2007	2007	2006	2007	2006	2007	2006	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007
T_1	18.1	19.2	23.9	24.1	5.18	5.30	11.86	12.43	44	43	16.1	18.1	22.9	23.0	4.21	4.10	9.87	10.76	43	38
T_2	23.0	20.2	24.1	25.2	5.96	5.89	12.75	13.91	47	42	20.6	20.0	24.2	24.1	4.76	4.80	10.93	11.92	44	40
T_3	18.0	17.1	23.2	24.1	4.95	4.90	11.89	11.64	42	42	16.4	18.5	22.0	23.5	4.08	4.20	10.56	11.14	39	38
T_4	21.4	24.2	24.8	25.0	5.58	5.70	12.02	13.50	46	42	19.4	19.3	24.1	25.2	4.85	4.80	10.95	11.53	44	42
T_5	17.1	18.2	19.5	20.2	4.78	4.80	10.80	12.52	44	38	15.1	18.2	19.2	21.2	4.23	4.07	10.12	10.52	42	39
T_6	19.9	19.5	24.2	25.1	5.65	5.80	12.58	13.75	45	42	18.1	18.2	23.9	24.0	4.62	4.55	10.70	11.24	43	41
T_7	16.5	18.9	22.1	20.2	4.60	4.95	10.86	11.65	42	42	14.2	17.2	21.9	21.6	3.91	3.85	10.35	10.15	38	38
SEm±	1.0	1.4	1.1	0.9	0.12	0.08	0.41	0.42	1	1	1.0	1.3	1.1	0.9	0.12	0.08	0.20	0.07	1	1
CD (P=0.05)	3.0	4.1	3.4	2.9	0.35	0.26	1.19	1.21	3	3	3.0	4.1	3.4	2.9	0.35	0.26	0.59	0.21	3	3

T_1, 120 kg mineral N/ha (control); T_2, 120 kg mineral N/ha + 6000 kg FYM/ha; T_3, 60 kg mineral N/ha + 6000 kg FYM/ha; T_4, 120 kg mineral N/ha + 3000 kg GM/ha; T_5, 60 kg mineral N/ha + 3000 kg GM/ha; T_6, 120 kg mineral N/ha + 60 kg N/ha (MSW compost); T_7, 60 kg mineral N/ha + 60 kg N/ha (MSW compost)

Table 3. Effect of different nutrition and tillage practices on yield attributes and yield of wheat in conventional tilled and no-tillage conditions

Treatment	Conventional tilled wheat										No-tillage wheat									
	Effective tillers/hill		1,000-grain weight (g)		Grain yield (tonnes/ha)		Straw yield (tonnes/ha)		Harvest index (%)		Effective tillers/hill		1,000-grain weight (g)		Grain yield (tonnes/ha)		Straw yield (tonnes/ha)		Harvest index (%)	
	2006–07	2007–08	2006–07	2007–08	2006–07	2007–08	2006–07	2007–08	2006–07	2007–08	2006–07	2007–08	2006–07	2007–08	2006–07	2007–08	2006–07	2007–08	2006–07	2007–08
T_1	12.3	12.9	29.7	32.1	5.11	5.29	11.59	13.50	44	39	11.9	12.1	26.0	30.0	4.19	3.97	10.86	10.90	39	36
T_2	13.0	13.2	31.3	32.2	5.87	5.59	13.12	13.50	45	41	12.7	12.5	31.3	30.8	4.92	4.59	11.75	11.46	42	40
T_3	12.0	12.2	26.6	31.0	4.42	4.67	11.42	10.85	39	43	11.6	10.2	31.3	28.1	3.75	3.86	10.89	9.77	34	40
T_4	13.2	13.5	32.7	32.2	5.62	5.78	13.60	13.12	41	44	12.9	12.5	32.5	31.0	4.56	4.40	11.02	11.06	41	40
T_5	12.7	12.2	27.9	31.4	4.73	4.86	10.97	10.90	43	45	11.6	11.3	27.8	29.2	4.03	3.97	10.30	10.08	39	39
T_6	12.4	13.2	30.1	32.1	5.37	5.47	12.86	12.85	42	43	12.1	12.3	28.4	30.6	5.02	4.38	11.98	10.99	42	40
T_7	11.5	11.1	24.5	28.6	4.63	4.63	10.76	10.37	43	45	9.2	9.8	23.2	27.6	3.98	3.82	10.86	9.86	37	39
SEm±	0.6	0.5	0.7	0.6	0.08	0.38	0.43	0.45	1	1	0.6	0.5	0.7	0.6	0.08	0.40	0.42	0.35	1	1
CD (P=0.05)	1.7	1.5	2.2	1.7	0.26	1.16	1.26	1.34	3	3	1.7	1.5	2.2	1.7	0.26	1.10	1.16	1.04	3	3

T_1, 120 kg mineral N/ha (control); T_2, 120 kg mineral N/ha + 6000 kg FYM/ha; T_3, 60 kg mineral N/ha + 6000 kg FYM/ha; T_4, 120 kg mineral N/ha + 3000 kg GM/ha; T_5, 60 kg mineral N/ha + 3000 kg GM/ha; T_6, 120 kg mineral N/ha + 60 kg N/ha (MSW compost); T_7, 60 kg mineral N/ha + 60 kg N/ha (MSW compost) seen in this parameter. The decline in harvest index was more in case of non-puddled rice and no-tilled wheat compared to conventional tillage. Improvement in the physico-chemical properties of soil with addition of organic matter such as FYM and GM thereby improving water and nutrient-use efficiency were the reasons for higher yield in the NPK+FYM treatment compared to the NPK treatment (Ladha *et al.,* 2003). Addition of organic matter corrected unrecognized nutrient deficiency (Swarup *et al.,* 2000; Manna *et al.,* 2005) and thus increased yield in rice–wheat system.

Carbon sequestration in soil

Estimation made after taking 4 crops showed that final SOC contents in both conventional tilled/ puddled and non-puddled/ no-tilled rice and wheat were higher under organic substitution and addition treatment than sole mineral N application (control) treatment (Table 4). The carbon sequestration potential, i.e. the annual build up of SOC content in our experiment over the initial soil condition was 0.146, 1.310, 1.165, 1.238, 0.728, 1.019 and 0.874 tonne C/ha at the treatment with 120 kg N, 120 kg N + 6.0 tonnes FYM, 60 kg N + 6 tonnes FYM, 120 kg N+ 3 tonnes GM, 60 kg N + 3 tonnes GM, 120 kg N + 60 kg N (MSW compost) and 120 kg N + 60 kg N (MSW compost) under puddled-tilled rice–wheat cropping system. The SOC build up in soil also increased under the non-puddled and no-tilled rice–wheat cropping system. The annual build up of SOC over the initial soil condition was 0.291, 1.601, 1.456, 1.529, 1.019, 1.310 and 1.048 tonnes C/ha at treatment having 120 kg N, 120 kg N + 6 tonnes FYM, 60 kg N + 6 tonnes FYM, 120 kg N+3 tonnes GM, 60 kg N+3 tonnes GM, 120 kg N+60 kg N (MSW compost) and 120 kg N+60 kg N (MSW compost) treatments, respectively under non-puddled/no tilled rice–wheat system. In a multi-location study conducted all over India regarding the carbon sequestration potential of organic manures, Pathak *et al.* (2011) reported that compared to the control treatment the NPK + FYM treatment sequestered 0.33 Mg C/ha/year, whereas the NPK treatments alone sequestered 0.16 Mg C/ha/year. The carbon sequestration potential in different nutrient management scenarios ranged from 2.1 to 4.8 Mg C/ha. Regular application of FYM, GM and compost combination with N resulted in considerable build up of SOC. The higher concentration of C in the fertilizer + organic manure treated plots was a result of increased yields of roots and plant residues and the application of organic C through FYM, GM and compost (Singh *et al.,* 1997). Organic sources of nutrient such as FYM decompose slowly, resulting in more SOC accumulation in soil (Mandal *et al.,* 2007). Considerably higher build up of SOC in 120 kg N+FYM treated plots compared to the plots with 60 kg N+FYM-indicated the beneficial effect of balanced fertilization in improving SOC status of the soil. Manna *et al.* (2005) observed that application of fertilizer NPK, either alone or in combination with FYM maintained active and slow-release pools of C, sequestered C and improved soil quality and productivity. Increased biological yield in organically amended plots resulted in addition of C through large amount of root and crop residues (Mandal *et al.,* 2007). Majumder *et al.* (2008) also observed that balanced fertilization caused a net enrichment of both the total carbon and SOC of the soils in rice–wheat–jute rotation owing to the addition of large amount of crop residues and root biomass C in soil.

It was concluded that integrated use of FYM, green manure or municipal solid waste compost with mineral nitrogen improved agronomic/biomass productivity and C sequestration in rice-wheat system. The carbon stock and

Table 4. Carbon Sequestration potential of different organic amendments during 2006–08 in rice–wheat system

Treatment	Soil organic carbon				Carbon build up in Soil		Carbon sequestration potential	
	Puddled/ CT* %	Non-puddled/ no-tillage %	Puddled/ CT* Mg C/ha	Non-puddled/ no-tillage Mg C/ha	Puddled/ CT* Mg C/ha	Non-puddled/ no-tillage Mg C/ha	Puddled/ CT* Mg C/ha/year	Non-puddled/ no-tillage Mg C/ha/year
T_1	0.60	0.62	17.47	18.05	0.29	0.58	0.146	0.291
T_2	0.68	0.71	19.80	20.68	2.62	3.20	1.310	1.602
T_3	0.67	0.70	19.51	20.38	2.33	2.91	1.165	1.456
T_4	0.67	0.70	19.51	20.53	2.33	3.06	1.165	1.529
T_5	0.64	0.67	18.64	19.51	1.46	2.04	0.728	1.019
T_6	0.66	0.69	19.22	20.09	2.04	2.62	1.019	1.310
T_7	0.65	0.67	18.93	19.51	1.75	2.04	0.874	1.019

*Conventional tillage

T_1, 120 kg mineral N/ha (control); T_2, 120 kg mineral N/ha + 6000 kg FYM/ha; T_3, 60 kg mineral N/ha + 6000 kg FYM/ha; T_4, 120 kg mineral N/ha + 3000 kg GM/ha; T_5, 60 kg mineral N/ha + 3000 kg GM/ha; T_6, 120 kg mineral N/ha + 60 kg N/ha (MSW compost); T_7, 60 kg mineral N/ha + 60 kg N/ha (MSW compost) carbon sequestration potential in soil was higher under the non-puddled and no-tilled fields compared to conventional tillage in rice–wheat cropping system.

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