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Soil carbon dynamics in response to compost and poultry manure under rice (*Oryza sativa*)–wheat (*Triticum aestivum*) crop rotation

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ABSTRACT

An experiment was conducted during 2007–09 at New Delhi, to study effect of composted cereal wastes, poultry manure and chemical fertilizers on soil carbon pools under rice (*Oryza sativa* L.)–wheat (*Triticum aestivum*) crop rotation. Analysis was carried out for organic carbon, oxidizable carbon and its four fractions, microbial biomass carbon and dehydrogenase activity at harvest stage. Soil fertilization with half the recommended dose of NPK+ compost @ 3 Mg/ha or poultry manure @ 3 Mg/ha added separately, increased the soil organic carbon content significantly as compared to chemical fertilization after two cycles of rice–wheat cropping system. Compost + NPK amended soil not only resulted in improved harvest index (0.470) but also showed highest content of non-labile pool of carbon fractions (11.80 mg/g) and improved the grain yield by 33.24%. Therefore, integrated use of chemical fertilizer and compost at 3 Mg/ha to be a feasible option for storing and sequestering soil carbon at half of its recommended dose with improving crop productivity in rice–wheat crop rotation.

Key words: Carbon, Compost, Organic amendments, Poultry manure, Rice-wheat

Tropical Indian soils are under consistent threat of low fertility due to low organic carbon (Sharma *et al.* 2005). There is utter need to improve the soil quality by returning its lost share of organic matter. This may be possible only by adopting agricultural practices that help in either increasing the quantity of plant residues return or decrease the turnover rate of C inputs. Management systems that utilize organic amendments such as crop residues and animal manure can increase the level of soil C that may improve soil quality and increase the potential for C sequestration (Lal 1999). Due to low decomposition rate of organic materials, organic resources be first composted to improve their nutrient availability and decrease the C:N ratio, before application in the field. Cropping system could also influence soil organic carbon accumulation by influencing the carbon input and the rate of decomposition. Rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* emend. Fiori. & Paol.) are the two main cereals of Indian community, practiced on 13.5 m ha of Indo-Gangetic plains of South Asia (Ladha *et al.* 2003), thereby generating huge amount of crop residue after their respective crop harvest. Effective management of these wastes is a serious threat. An economical, low labour-intensive and environment-friendly strategy needs to be adopted to convert these wastes into value-added products. Both wheat and paddy straw are rich source of carbon but poor in nitrogen. Their supplementation with nitrogen-rich wastes of plant/animal origin is essential to lower their high C: N ratio to initiate the residue degradation and to get compost most suitable for organic farming (Gaind *et al*. 2009, Pandey *et al*. 2009). Poultry manure, an inexpensive source of nitrogen, can be explored for lowering the high C: N ratio of cereals straw as well as to sequester soil carbon. In order to improve the soil quality (in terms of soil organic carbon) and crop productivity using agricultural wastes, the present investigation was undertaken to (i) prepare compost from the respective crop harvest of rice and wheat crop using poultry manure as a nitrogen supplement, (ii) determine the contribution of added compost and poultry manure separately in improving the soil quality (in terms of carbon) in rice–wheat crop rotation under similar system of nutrient management and (iii) find a correlation between all the carbon pools and other tested parameters when subjected to different organic management practices under rice–wheat crop rotation. These results will help in selecting the optimal fertilization management practice in terms of soil carbon and improved crop productivity.

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MATERIALS AND METHODS

Wheat straw/paddy straw obtained after their respective crop harvest was amended with poultry manure in a ratio of 6.5:1 to reduce the initial high C:N to a ratio of 50:1, to

Table 1 Elemental composition of composting substrates and wheat and paddy straw compost

Parameters	Paddy straw	Paddy straw compost	Wheat straw	Wheat straw compost	Poultry manure	*Sesbania rostrata*
*p*H	7.24	6.80	7.90	6.40	7.93	6.34
EC (dS/m)	1.00	3.72	0.9	1.10	4.32	
Cellulose (%)	41.4		24.1			
Hemicellulose(%)	20.4		39.6			
Lignin (%)	12.1		17.0			9.1
Moisture (%)	13.0	32.8	15.01	34.20	42.00	
OM (%)	63.44	48.15	91.38	44.80	17.24	72.41
TOC (%)	39.2	26.87	53.01	23.32	14.84	42.0
N (%)	0.50	1.60	0.48	1.52	2.12	2.5
C/N	78.4	10.54	110	14.57	7.00	16.8
Humus (%)		7.8		8.5		
P (%)	0.8	0.46	0.66	0.52	4.1	
K (%)	2.62		1.18		2.2	
E4/E6		0.35		0.52		
Cw (%)		0.48		0.42		
GI (%)		136		144		
			Available micronutrients (mg/kg)			
Cu	0.84	0.15	0.84	0. 23	3.50	8.50
Fe	98.2	2.10	2.14	2.45	5.05	
Zn	28.0	3.38	2.37	3.46	7.31	16.0
Mn	6.61	2.06	2.19	2.77	4.24	

OM, Organic matter; TOC, total organic carbon; GI, germination index; Cw, water-soluble carbon

initiate degradation. Substrate mixture was supplemented with 1% rock phosphate (w/w) to provide P nutrition. The material was filled in the above-ground perforated cemented pits of 1 m^2 dimension, moistened by adding 100% water (w/v) and left undisturbed for 12 hr to absorb moisture. Seed-based fungal inoculum developed by including *Aspergillus awamori* (F18), *Aspergillus nidulans* (ITCC 2011), *Trichoderma viride* (ITCC 2211) and *Phanerochaete chrysosporium* (NCIM 1073) was applied @ 300 g seed based mycelium/tonne substrate. Moisture was maintained at 50–60% throughout the composting duration that lasted for 60 days and manual turnings were given at fortnight intervals. On maturity, the fresh compost samples were analyzed for dehydrogenase activity and the air-dried and ground compost samples were subjected to chemical analyses.

Analysis involved the determination of moisture content by oven drying at 105°C and organic matter by ignition method. Total organic carbon was calculated from organic matter (Navarro *et al.* 1993).

Extraction of water-soluble carbon (Cw), total N, available P content, humus content, germination index and heavy metal content was estimated by the method of Walkley and Black (1934), Jackson (1973), Dickman and Bray (1940) and Konnonova (1966), Zucconi *et al.*(1981) and Lindsay and Norvell (1978) respectively. *p*H and electrical conductivity (EC) were measured in compost : water suspension (1: 5, w/v) using a digital *p*H meter and total dissolved solids (TDS) meter respectively.

The field experiment was conducted at experimental farm of the Indian Agricultural Research Institute, New Delhi during 2007-09. The farm soil had sandy loam texture with sand, silt and clay content of 69, 16 and 14% respectively. The soil was classified as Inceptisol (Typic haplustepts) and had a *p*H –8.7, EC–0.29 dS/m, TOC 0.44%, TKN 0.04%, available P 33.3 ppm, available K 330 kg/ha, available N 0.18 kg/ha, humus content –0.35-0.46%. The heavy metal content for Fe, Mn, Cu and Zn was 8.95, 6.15, 1.6 and 1.57 kg/ha. The mean maximum and minimum temperature for wheat and rice from December to March were 20° and 12° C and from July to October were 36° and 22° C respectively.

Sesbania rostrata Brem & Obrem (a green manuring crop) was grown each year (2007, 2008) for 55 days on the experimental site and applied to soil @ 2 Mg/ha (dry weight basis), 15 days prior to rice transplantation. Paddy straw compost was used for rice crop and wheat straw compost was used for wheat crop and was prepared at Microbiology Division, IARI, New Delhi as mentioned above.

Rice and wheat crops were grown annually for two consecutive years on 20 plots measuring 2.25 m × 2.12 m each. The experiment was laid down in randomized block design and the different nutrient regimes were: T_1, full recommended dose of NPK, T_2, compost, @ 6 Mg/ha, T_3, poultry manure @ 3 Mg/ha, T_4, ½ NPK+ compost @ 3 Mg/ha; T_5, ½ NPK + poultry manure @ 1.5 Mg/ha. All the treatments were replicated four times. Urea, super phosphate and muriate of potash were given @ 120, 80, 60 kg/ha respectively for rice crop. Recommended NPK fertilizers were evenly spread on to soil surface of each plot as per treatment schedule given in Table 2 and the organics (compost/ poultry manure) were mixed with soil using tiller, 2–5 days before puddling for rice. After 3–4 days, the land was leveled and after one week, 21 days old rice seedlings (var Pusa 1121) were transplanted. Other agronomic practices as weeding and irrigation were followed throughout the period of crop growth. Harvesting of rice transplanted in July was done in October. The same field was again pre irrigated in the first week of November and disked twice at field capacity moisture. It was ploughed the next day and thereafter planked once. Wheat was sown in the last week of November by applying seeds of wheat variety HD 2687@ 80 kg/ha. NPK fertilization for wheat was $N_{120}P_{60}K_{30}$ which was applied as a based dose. Experiment was repeated with the same treatments as for rice. The crop was harvested after four months of maturity. All the above-ground biomass for both the crops was harvested on a whole plot basis. Grain and straw yields for both the crops were also recorded.

The soil from different plots was sampled at the end of each crop harvest of rice–wheat crop rotation. The soil samples were collected from a depth of 0–15 cm, with auger from 3–4 places in the plot and composite soil samples for each plot of wheat/rice crop (2007–09) were prepared by mixing five soil samples. Carbon fractionation, microbial biomass carbon and enzyme activity were measured in wheat soil (2008-09) at the termination of two-year crop rotation experiment.

The moist soil samples were sieved through 2 mm mesh immediately and used for microbial biomass carbon (Cmic) and dehydrogenase activity. Another portion of the soil was air-dried ground and sieved through the same sieve. Moisture content was determined gravimetrically by drying the sample in oven at 105°C for 24 hr. The oven-dried soil samples of each crop harvest were analyzed for soil organic matter by ignition method. However, the soil organic carbon and oxidizable carbon in wheat (2008–09) was estimated by ignition and potassium dichromate method respectively (Walkley and Black 1934).

Carbon fractions were estimated by different concentrations of sulfuric acid (Chan *et al* 2001) and labile carbon was estimated using potassium permanganate (Blair *et al* 1995), microbial biomass carbon and dehydrogenase activity were determined by Nunan *et al* (1998) and Casida *et al.* (1964) respectively. Lability index was computed from different soil fractions as per details given by Majumdar *et al* (2007).

A labilty index for SOC was computed using all the three labile fractions. C frac1, C frac 2 and C frac3 designated as very labile, less labile and labile, respectively, and are given the weightage of 3, 2 and 1 respectively (Majumdar *et al* 2007). The index is computed according to the following equation.

$$\text{Labilty index} = \frac{\text{Cfrac } 1 \times 3}{\text{Coc}} + \frac{\text{C frac } 2 \times 2}{\text{Coc}} + \frac{\text{C frac } 3 \text{ x } 1}{\text{Coc}}$$

Soil pH and electrical conductivity (EC) was measured using digital pH meter and TDS scanner. All the determinations were performed in triplicate and results were expressed on dry-weight basis.

All the data (mean of determinations made on three replicates) were subjected to analysis of variance using least significance difference test and comparing the difference between specific treatments (Panse and Sukhatme 1978). Correlation analysis was used to test for relationship between different carbon fractions and other soil properties.

RESULTS AND DISCUSSION

Analysis of wheat and paddy straw compost

The composted product of paddy and wheat straw showed variation in their elemental composition that may be due to variability in the initial composition of substrate used for preparing compost (Table 1). Both wheat and paddy straw

Table 2 Changes in soil organic matter (%) and soil organic carbon (%) of rice and wheat soil during two years of crop rotation

Treatment	SOM Rice 2007	Wheat 2007	Rice 2008	Wheat 2008	SOC Rice 2007	Wheat 2007	Rice 2008	Wheat 2008
T_1	1.17	0.87	0.92	0.97	0.678	0.504	0.533	0.562
T_2	1.39	0.90	0.94	1.57	0.806	0.522	0.545	0.910
T_3	1.84	1.06	1.37	1.81	1.068	0.614	0.795	1.049
T_4	1.74	1.09	1.18	2.00	1.010	0.632	0.684	1.160
T_5	1.22	0.89	0.77	1.06	0.707	0.516	0.446	0.614
LSD ($P \leq 5$)	0.12	0.09	0.08	0.08	0.102	0.085	0.089	0.091

T_1, Full recommended dose of NPK ($N_{120}P_{80}K_{60}$ for rice and $N_{120}P_{60}K_{30}$ for wheat); T_2, Compost @ 6 Mg/ha; T_3, poultry manure @ 3 Mg/ha, T_4, ½ NPK ($N_{60}P_{40}K_{30}$ for rice and $N_{120}P_{30}K_{15}$ for wheat) + compost @ 3 Mg/ha; T_5, ½ NPK + poultry manure @ 1.5 Mg/ha

SOM, Soil organic matter; SOC, soil organic carbon

Table 3. Total organic carbon (mg/g) fractionation, labile carbon, microbial biomass carbon and lability index of wheat soil after two years of rice–wheat crop rotation

Treatment	C_{Toc}	C_{OC}	C frac1	C frac2	C frac3	C frac4	LC	C_{mic}	C_{mic}/C_{Toc} x 100	LI
T_1	15.08	10.80	7.45	1.22	2.13	4.28	13.65	0.545	3.61	2.48
T_2	23.94	13.90	8.50	2.30	3.10	10.04	14.70	0.408	1.70	2.38
T_3	24.60	19.50	3.10	13.40	3.00	5.10	18.30	0.428	1.73	2.00
T_4	30.30	18.50	8.80	2.50	7.20	11.80	20.00	0.454	1.49	2.08
T_5	19.14	13.50	3.25	2.95	7.30	5.64	14.40	0.735	3.84	1.69
LSD ($P\leq$ 5)	3.21	1.81	1.96	0.98	1.12	0.83	1.89	0.134	0.31	0.23

T_1, Full recommended dose of NPK ($N_{120}P_{80}K_{60}$ for rice and $N_{120}P_{60}K_{30}$ for wheat); T_2, Compost @ 6 Mg/ha; T_3, poultry manure @ 3 Mg/ha, T_4, ½ NPK ($N_{60}P_{40}K_{30}$ for rice and $N_{120}P_{30}K_{15}$ for wheat) + compost @ 3 Mg/ha; T_5, ½ NPK + poultry manure @ 1.5 Mg/ha

SOM, Soil organic matter; SOC, soil organic carbon

C_{Toc}, total soil organic carbon; C_{oc}, oxidizable carbon; C $_{frac1}$, very labile carbon; C_{frac2}, labile C; $_{frac3}$-less labile C; C_{frac4}, non-labile C, LC, labile carbon; C_{mic}, microbial biomass carbon; LI, lability index

compost had a final *p*H near neutrality and EC ranging between 1.10 and 3.72 dS/m well within threshold values (< 4.0) of compost maturity. The decomposition resulted in loss of organic matter of both the substrate mixtures. However, a maximum reduction of 50.97% was recorded in poultry manure amended wheat straw mixture. The inoculated fungal consortium effectively degraded both the substrates to a final C: N ratio of 14.57: 1 and 10.54:1 for wheat and paddy straw compost respectively, within two months of composting. The final product of both the substrates had a germination index value of > 135%, humus content > 7% and heavy metal content within their permissible limits. The compost with these parameters values was considered safe for application to soil under rice–wheat crop cultivation.

Soil analysis

In the first year of growing rice (2007), soil organic matter content ranged between 1.17 and 1.84%. In the succeeding wheat crop (2007-08), it showed decreased values ranging from 0.87–1.09%. However, an improvement in organic matter content was recorded again in the following rice crop and that may be due to *in-situ* incorporation of *Sesbania rostrata*. Poultry manure application @ 3 Mg/ha to soil resulted in highest organic matter content for both the years of growing rice (Table 2). However, the positive effect of compost on organic matter status of wheat soil was observed in second cycle of wheat crop (wheat 2008–09). An increase of 14.94% in organic matter content was recorded under T_4 treatment of wheat soil (2008–09) compared to rice soil (2007), receiving same fertilization. Organically fertilized soils showed 2–2.2 fold increase in organic matter content compared to their chemically fertilized counterpart.

Nutrient regime for rice–wheat crops for both years followed the same pattern. However, *in-situ* incorporation of *Sesbania rostrata* was made only before rice transplantation (2007 and 2008). The organic carbon content of soil under rice crop (2007) was the highest under T_3 treatment, followed by T_4, statistically at par with each other and significant over other treatments. Organically amended soil showed higher value for soil organic carbon compared to mineral-fertilized soil. The carbon content of wheat soil that followed the rice crop in the first cycle showed declined values (Table 2). As the crop cultivation needs ploughing, this disturbs the stability of soil aggregates and exposes the organic carbon stock to rapid decomposition leading to carbon depletion. The magnitude of depletion was higher in organically fertilized treatment compared to mineral fertilized soil. Organic carbon values for rice soil (2008) showed some improvement in the second crop cycle and were again highest in poultry-amended treatment (T_3). An increase in organic carbon of rice soil in second crop cycle may be due to the soil remaining under flooded moisture regime. Moreover, the decomposition rate also decreases with increasingly anaerobic conditions as is the case in rice based cropping system. The values though improved in succeeding wheat soil but T_1 and T_3 treatments of wheat soil (2008-09) showed an overall decrease of 1.71 and 1.77% at the end of two years of crop cultivation when compared to their values in rice (2007). This showed that two years period was not enough for the carbon build up in poultry manure-amnended soil.

Soil under half the recommended dose of NPK + 3 Mg/ha compost amendments (T_4) resulted in highest organic carbon concentration of 1.16%. Organic inputs in the form of compost might have improved the soil physical environment in addition to valuable nutrients and might have added to improved moisture regime of soil that resulted in higher above-ground plant biomass (Table 4). Improved SOC values of T_3 and T_4 treatments may be due to high nitrogen content added through poultry manure/compost that inhibited the soil carbon decomposition (Bradford *et al.* 2008).

The amount of oxidizable carbon extracted from soil showed little variation between T_2 and T_5 and T_3 and T_4 treatments (Table 3), though all the values were significantly higher than T_1 treatment. The magnitude of different fractions

Table 4 Dehydrogenase activity, *p*H, electrical conductivity (EC) and harvest index of wheat soil after two years of rice – wheat crop rotation

Treatment	Dehydrogenase (μg TPF/g/d)	*p*H	EC (dS/m)	Biomass yield (Mg/ha)	Grain yield (Mg/ha)	Harvest index
T_1	231.81	8.4	0.30	9.43	3.79	0.401
T_2	234.15	7.9	0.40	9.81	4.29	0.437
T_3	261.83	8.2	0.30	9.43	3.81	0.404
T_4	299.81	8.2	0.30	10.73	5.05	0.470
T_5	214.34	8.2	0.30	9.43	3.24	0.343
LSD ($P \leq 5$)	36.06	0.04	0.02	0.84	0.32	0.045

T_1, Full recommended dose of NPK ($N_{120}P_{80}K_{60}$ for rice and $N_{120}P_{60}K_{30}$ for wheat); T_2, Compost @ 6 Mg/ha; T_3, poultry manure @ 3 Mg/ha, T_4, ½ NPK ($N_{60}P_{40}K_{30}$ for rice and $N_{120}P_{30}K_{15}$ for wheat) + compost @ 3 Mg/ha; T_5, ½ NPK + poultry manure @ 1.5 Mg/ha
SOM, Soil organic matter; SOC, soil organic carbon

of oxidizable carbon extracted under a gradient of sulphuric acid was different for different treatments. However, majority of the differences were compared with T_1 treatment. The NPK fertilization had higher amount of very labile carbon ($frac_1$ 57.5%), whereas in compost-amended treatments, (T_2 and T_4) higher content was in non-labile carbon pool (Table 3).

Most of the carbon added through compost was most resistant to decomposition, whereas that applied through mineral fertilization was least resistant. As compost was prepared from wheat and paddy straw that contained lignin content of 12 and 17% respectively, this along with poly phenols contribute to the formation of stable complexes with protein of plant origin and added to the stability of carbon. Input of compost to soil, can have long-term effect on soil properties. The results indicate that both quality and quantity of carbon input in soil have a significant role in building of soil organic carbon. The carbon added through organic amendments was particularly important in maintaining soil organic carbon.

Microbial biomass carbon (C_{mic}) content varied from 0.408 to 0.735 mg/g soil and was in the order of $T_5 > T_1 > T_4 > T_3 > T_2$ (Table 3). The higher C_{mic} under T_5 treatment may be attributed to the incorporation of exogenous microorganisms through poultry manure. Xiao *et al.* (2009) and Majumdar *et al.* (2008) also reported higher microbial biomass carbon in NPK+ FYM-amended soil. The balanced fertilization in the form of NPK resulted in higher microbial activity under T_1 treatment.

The ratio of Cmic:Ctoc(%) under different treatments ranged between 1.49 and 3.84 being highest for chemically fertilized soil. The difference in soil management, crop rotation, variation in sampling line and analytical methods may be responsible for this variation in Cmic:Ctoc ratio, in agreement with the findings of Anderson and Domsch (1989).

The labilty index value was significantly high for chemically fertilized soil. The high lability index with application of NPK may be related to high content of labile carbon. However, the lability index values were lowest for half the recommended dose of NPK + 1.5 Mg/ha of poultry manure amended soil, supported by the reports of Majumdar *et al.* (2007).

The dehydrogenase activity was highest for T_4 treatment followed by poultry manure amended treatment (Table 4). The high level of dehydrogenase activity in the soils treated with organic wastes suggests the existence of a high quantity of biodegradable substrates in these soils, stimulating soil microbial activity.

A relation between microbial biomass carbon and dehydrogenase activity could not be established. Microbial biomass carbon was highest in T_5 treatment but dehydrogenase activity was lowest in this treatment. This showed that poultry manure amended soil may contain higher microbial flora but that may not be in an active state to reduce the substrate.

Amendment of soil with compost and poultry manure could not bring about significant changes in soil *p*H and electrical conductivity (Table 4). Though, the crop yield improved significantly in compost amended soil. An increase of 13 and 33.15% in grain yield was noted in T_2 and T_4 treatment respectively, compared to chemically fertilized soil. Biomass yield was also highest in T_4 treatment. Higher soil organic carbon under wheat (2008–09) might have resulted in high above ground biomass production in compost amended soil (Table 4), in agreement with the findings of Kukal *et al* (2009). Application of poultry manure did not show encouraging results as far as the biomass and grain yields were concerned.

Harvest index (HI) refers to the ratio of grain yield by total biomass yield and serves as quality index for comparing the nutrient management in cropping system. Harvest Index of compost amended treatment was certainly higher compared to all other treatments especially T_4 treatment (Table 4). This suggests that nutrient availability during crop maturing stage was higher in compost treated plots. These results indicate that combined application of NPK at half its recommended dose and compost @ 3 Mg/ha sustain higher yield under rice-wheat crop rotation in alkaline soils of IARI farm. T_1 and T_3 treatments did not differ significantly among themselves as far as the yield related parameters were concerned.

Table 5 Values of correlation coefficients among different soil organic pools

Pools of carbon	C frac1	C frac2	C frac3	C frac4	Coc	Ctoc	Cmic
C frac1	1.00						
C frac2	-0.39	1.00					
C frac3	-0.62	0.33	1.00				
C frac4	0.70	-0.43	-0.19	1.00			
Coc	0.50	0.55	-0.03	0.32	1.00		
Ctoc	0.79	-0.39	-0.21	0.99	0.42	1.00	
Cmic	-0.77	-0.22	0.65	-0.34	-0.78	-0.43	1.00

C_{frac1}- very labile carbon, C_{frac2} - labile C, $_{frac3}$- less labile C, C_{frac4} – non labile C, C_{oc}- oxidizable carbon, C_{toc-}- total soil organic carbon, C_{mic-}- microbial biomass carbon

Relationship among different carbon pools

Data showed the relationship of some of the carbon pools with each other (Table 5). Fraction 3 of carbon was marginally related with fraction 2. However, fraction 4 was highly correlated with fraction 1. Total organic carbon was strongly related with fraction 1 and fraction 4. No correlation could be established between microbial biomass carbon and different carbon fractions.

An overall analysis of results showed that ½ NPK+ compost @ 3 Mg/ha is the most suitable fertilization for rice–wheat crop rotation in tropical area of north India for improving the soil organic carbon and sustaining crop productivity. The preparation of compost from cereal wastes (paddy straw/wheat straw) and its application to soil in conjunction with chemical fertilizers is a sound technology to conserve the natural resources as well as for combating soil degradation. It will also help to reverse the process of yield stagnation thereby alleviating crop yield. This technology is environment friendly and quite economical due to low input of chemical fertilizers. However, socio-ecological constraints need to be mitigated to increase the adoption of compost technology at a large scale.

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