Indian Journal of Agricultural Sciences **87** (4): 444–54, April 2017/Article
https://doi.org/10.56093/ijas.v87i4.69310

Research Articles

Effect of *in-situ* recycling of sugarcane crop residues and its industrial wastes on different soil carbon pools under soybean (*Glycine max*) - maize (*Zea mays*) system

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Received: 28 June 2016; Accepted: 27 December 2016

ABSTRACT

A field experiment was conducted during summer 2011-12 at MPKV Farm, Rahuri to evaluate the effect of *in-situ* recycling of sugarcane crop residues and its industrial wastes on soil organic C fractions like labile carbon, microbial biomass C, particulate organic C, $KMnO_4$ extractable C, physically protected particulate organic matter carbon (POMC) and significantly improved water stable aggregates in the cultivated soil under maize (*Zea mays* L.)-soybean [*Glycine max* (L.) Merr.] system. The active carbon pools like soil microbial biomass carbon(SMBC), water soluble carbohydrates (WHC) and acid hydrolysable carbon (AHC) was significantly improved in the treatment receiving 100% recommended dose of fertilizer along with *in-situ* compost of crop residues, press mud cake and methanated spent wash compost compared to burning of residues. Application of *in-situ* sugarcane residues with pressmud incorporation retainedabout19.6%, 38.8% and 33% more amount of total organic carbon (TOC), SMBC, AHC respectively, over burning of sugarcane crop residues and removal of stubbles after harvest of maize. The mean values of WSC (43 mg/kg) and the physically protected carbon, i.e. POMC (2014 mg/kg) were greater by 47% and 6.6% respectively, in the treatment (T_7) receiving *in-situ* residue decomposition of sugarcane crop residues in combination with equal proportion (50%) of press mud cake and biomethanated spent wash over the burning of sugarcane crop residues and removal of stubbles after harvest of maize. After harvest of maize the maximum recalcitrant fraction (humic acid) of carbon was observed in the treatment T_7 (*in-situ* decomposition of sugarcane crop residues + 50% press-mud cake + 50% biomethenated spent wash). This study clearly indicated that resistant fraction of carbon might be accumulated more where decomposed organic matter was applied regularly. It clearly indicated that application of *in-situ* decomposed residues and by-products of industrial waste in combination with NPK enhanced the below and above ground biomass production, SOC stock and carbon pools.

Key words: Carbon sequestration, Industrial waste, *In- situ* compost, Soil carbon pools, Sugarcane residue

Conservation of soil organic matter (SOM) is considered a central component of sustainable soil health. Organic manure and chemical fertilizer are the most common resources applied in agricultural management to improve soil quality and crop productivity (Verma and Sharma, 2007). Many studies have shown that balanced application of chemical fertilizers or organic manure as in combination can enhance soil organic carbon (SOC) and maintain soil productivity (Powlson *et al.* 2012). However, total soil organic C is not sensitive to short-term changes of soil quality with different soil or crop management practices due to high background levels and natural soil variability (Haynes 2005). Labile soil organic C pools like dissolved organic C (DOC), microbial biomass C (MBC), and particulate organic matter C (POC) are the fine indicators of soil quality which influence soil function in specific ways (e.g. immobilization–mineralization) and are much more sensitive to change in soil management practices (Xu *et al.* 2011). Because these components can respond rapidly to change in C supply, they have been suggested as early indicators of the effects of land use on SOM quality (Gregorich *et al.* 1994). In this context, land use management systems along with crop residues or industrial wastes resulted in changing the dynamics of differentsoil pools in the soil.

Therefore, it is of paramount importance for farmers, small-scale and large, in both developing and developed

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countries, to employ appropriate crop management technologies that will not only generate cost-effective, stable crop production opportunities and yield performance but which will also conserve the integrity and sustainability of the soil resources for a long run. Investigation on soil organic matter (SOM) pools under different soil use and management systems play a key role for maintaining the soil health. During the last few decades, researchers have identified specific organic matter fractions with functional significance in the turnover of soil. Among these fractions, soil microbial biomass C and water–soluble C fractions are the most active and labile pools, which have short turnover times. Moreover, POMC can be used as an indicator of soil quality rather than total organic matter. Organo–mineral fractions of specific particle size (<0.053mm) can lead to development of stable microaggregates and slow decomposition rate within aggregates with respect to their composition and turnover. The microaggregate stability indices predict the soil erosion better than the macroaggregate counterparts (Igwe *et al.* 1999). An interrelationship between soil structures and soil organic carbon (SOC) is dynamic, where the level of decomposition of organic matter affects soil aggregate stability. Aggregate stability conserves soil moisture, maintain constant soil temperatures and improve water infiltration rates (Bhattacharyya *et al.* 2009). Impact of seasonal tillage alters biological activity, major nutrient transformation potential and crop yield. Impacts of tillage management on the relationships between chemical SOC pools and the physical indices of soil aggregation were investigated by Bhattacharyya *et al.* (2011). Greater SOC concentrations in macroaggregates suggested that the presence of decomposing roots and fungal hyphae within macroaggregates not only increased concentrations but also contributed to their stabilization. Puget *et al.* (1995) suggested the greater SOC concentration in macroaggregates could be due to lower decomposable soil organic matter associated with these aggregates, and also the direct contribution of SOM to the these aggregates. The breakdown of aggregate leads to more organic matter loss and increase soil erosion under intensive agriculture systems (Six *et al.* 2000).Currently sugarcane belts (2.5% of India cropped area) growers are facing problem such as decline in productivity, soil health deterioration, improper management of farm crop residues and indiscriminate waste disposal in sugar factory. Sugarcane upon harvest leaves behind 8 to 10 tonnes of sugarcane trash, 4 to 5 tonnes of stubbles and adequate amount of root mass, 4 to 5 tons of press mud cake and about 12 000 to 18 000 litres of biomethanated spent wash per hectare. With reference to this background information, it was felt not only to the farmers but for as a government policy issue that it urgently needs to develop suitable integrated technique for bio-conservation of sugarcane crop residues and its industrial wastes for recycling, improving soil physical properties and sustaining productivity by maintaining soil health. An effort was made for holistic recycling of sugarcane crop residues integrating with industrial wastes with objective of sustaining soil productivity, aggregate stability, soil fertility, to ascertain carbon sequestration and to reduce the cost besides solving environmental problems by effective use of management of sugarcane residues as converts into an eco-friendly sugarcane industry. Hence, present research investigation was to assess the effect of *in-situ* of sugarcane crop residues and its industrial wastes on soil carbon fractions, soil aggregate stability and SOC stock under soybean [*Glycine max* (L.) Merr.]- maize (*Zea mays* L.) system.

MATERIALS AND METHODS

A field experiment was carried out to evaluate the effect of *in- situ* recycling of sugarcane crop residues and its industrial wastes on soil carbon fractions and SOC stock at farms of MPKV, Rahuri (latitude 19° 47’ to 19° 57’ N and longitude 74° 18’ to 74° 19’E) during summer, 2011 to 2012. The analyses of various carbon fractions measured such as Total organic carbon by TOC analyzer (Nelson and Sommer 1982), Labile pool of carbon Permagnate oxidation method (Blair *et al.*1995), POMC by Wet sieving method (Camberdella and Elliott 1992), WSC by Water extraction method (Mc Gill *et al.* 1986), SMBC by Chloroform fumigation extraction method (Vance *et al.* 1987), AHC by Acid hydrolysis and chromatography method (Brink *et al.* 1960), Fractions of humic substances by 0.5 N NaOH extractant method (Stevenson 1994) and carbon stocks such as CMI, CPI and CLI by computation (Blair *et al.*1995). A newly harvested field of sugarcane ratoon (var. COM-0265) was selected for *in-situ* recycling of sugarcane crop residues and its industrial wastes. The sugarcane crop residues, viz. sugarcane trash, sugarcane stubbles produced after harvest of sugarcane ratoon from experimental field and sugarcane industrial wastes viz. pressmud, pressmud compost and biomethenated spent wash produced as a byproducts after crushing of sugarcane in sugar factory produced from experimental site was quantified and utilized for *in-situ* recycling in various techniques. The shredding of sugarcane trash by tractor drawn shredding machine and chapping of stubbles by rotavator into small pieces was carried out for increasing surface area of crop residues substrate. For enhancing decomposition process and adjustment of C:N ratio of sugarcane crop residues, 8 kg urea + 10 kg single super phosphate (SSP) + 1 kg decomposing culture consisting *Trichoderma herginum*, *Trichoderma viride*, *Penecillium digitatum*, *Chetonium* spp was used as per recommendation and phosphate solubilizing micro-organisms (PSM) @ 2.5 kg/ha was used for enhancing decomposition process. The required amount of these wastes (sugarcane crop residues and industrial byproducts) have been calculated and applied per plot as per availability basis for all these treatments. After two months period of decomposition the test crops, viz. soybean in *kharif* and maize in *rabi* were taken as a succeeding crops in sequence along with three graded levels of NPK on the same set of experiment without disturbing the original layout of each treatment which were super imposed. Each single plot (treatment) was sub-divided into three smaller plots with three replicates for soybean and maize was grown in sequence having plot size of 10 × 20 m^2. The treatment details have been given below:

The various treatment structure has been developed with respect to A. Main plot treatments consist of T1 (Burning of sugarcane trash and removal of stubbles), T2 (Removal of sugarcane trash), T3 (*In-situ* decomposition of sugarcane crop residues + cellulose decomposers+ PSM+ 8 kg urea +10 kg SSP),T4 (T3 + Press-mud Cake),T5 (T3 + biomethenated spent wash), T6 (T3 + Press-mud compost), T7 (T3 + 50% Press-mud cake + 50% biomethenated spent wash), and B. Sub plot treatments consist of F0 (Control without fertilizers), F1 (50% recommended dose of fertilizers), F2 (100% recommended dose of fertilizers).

Methodology adopted for analysis of soil carbon fractions: Standard analytical methods used for analysis of sugarcane crop residues, by-products, soil properties, plant and grain quality.

Computation of carbon management index (CMI): Calculation of CMI requires sample of the soils of interest and of reference site. Since continuity of (supply depend) upon both size and ability both are taken into account in during CMI. Various carbon indices were worked out as follows.

$$\text{Carbon pool index (CPI)} = \frac{\text{Total C in sample}}{\text{Total C in reference}} \qquad (1)$$

$$\text{Carbon pool index (CPI)} = \frac{\text{Liability of C in sample soil}}{\text{Liability of C in reference soil}} \qquad (2)$$

Where, liability of C represents the ratio of easily oxidized C to unoxidised C by $KMNO_4$.

$$\text{CMI} = \text{CPI} \times \text{CLI} \qquad (3)$$

Computation of soil organic carbon (SOC) stock (Mg/ha): The soil organic carbon for each depth was calculated from soil organic carbon (%) and bulk density as. Soil organic carbon = 100 cm/m × 100 cm/m × depth of soil (Mg/ha) (cm) × bulk density (g/cm) × 10 000/m/ha × 0.000001 Mg/g ×% SOC; Where, soil organic carbon content expressed in decimals (% SOC/100).

The experimental plots were ploughed and other tillage operations were carried out without disturbing the original layout followed by each treatment. The soybean in *kharif* and maize in *rabi* along with three graded levels of NPK fertilizers were compared with *in-situ* compost. All standard agronomical practices have been followed for both the crops and crops were harvest at grain filling stage. Post-harvest moist soil samples were collected for analysis of total organic carbon and other fractions of SOC. The initial soil samples were analyzed for physical, chemical and biological properties as detailed in Table 1. Standard analytical methods used for analysis of sugarcane crop residues, by-products, soil properties, plant and grain quality.

The experimental data on soil microbial and biochemical parameters were statistically analysed as per methods of randomized block design described by Panse and Sukhatme (1985).

Table 1 Initial soil characteristics of the experimental field

Soil properties	Value
Taxonomic classification	
Soil order	Vertisol
Soil classification	Typic Haplusterts
Soil series	Babhulgaon
Physical properties	
Particle size distribution	
Sand (%)	20.0
Silt (%)	21.8
Clay (%)	58.2
Soil textural class	Clayey
Water holding capacity (%)	59
Bulk density (Mg/m^3)	1.32
Chemical properties	
pH(1:2.5)	8.1
EC(1:2.5) (dS/m)	0.52
Total organic carbon (%)	0.59
Available N (kg/ha)	146
Available P (kg/ha)	12
Available K (kg/ha)	527
Soil carbon fractions	
Total soil organic carbon (%)	0.59
Water soluble carbon (mg/kg)	60
Particulate soil organic carbon (mg/kg)	756
Potassium permanganateoxidisable organic carbon (mg/kg)	603
Acid hydrolizable carbohydrates (mg/kg)	988
Soil microbial Biomass Carbon (mg/kg)	175
Humic acid (%)	36.5
Fulvic acid (%)	28.4
Biological Properties	
Soil respiration (mgCO_2-C/kg/d)	18.3
Enzyme activities	
DHA (µg TPF/g/24h)	73.5
FDA(µgfluorescien/g/2h)	11.2
Alkaline phospatase (µg PNP/g/2h)	499

RESULTS AND DISCUSSION

Effect on TOC, TN and SMBC

Soil microbial biomass C, total organic C and nitrogen have also been analyzed from post-harvest soil of maize system (Table 2). The data shows that the content of TOC (%) varied from 0.68 to 1.10. The highest % TOC was observed in the treatment (T_6) receiving *in-situ* decomposition of sugarcane crop residues + cellulose decomposer +PSM+ 8 kg urea + 10 kg SSP (T_3) + press mud compost whereas lowest TOC was found in treatment (T_2) having removal of sugarcane trash. The total nitrogen (TN) varied among

Table 2 Effect of *in-situ* recycling of sugarcane crop residues and its industrial wastes on TOC, TN, SMBC (active pools of C) after harvest of maize (0 - 30 cm soil depth)

Treatment	TOC (%)				TN (%)				SMBC				SMBC/TOC			
	F0	F1	F2	Mean	F0	F1	F2	Mean	F0	F1	F2	Mean	F0	F1	F2	Mean
T1	0.76	0.83	1.18	0.92	0.06	0.06	0.06	0.06	228	274	415	306	3.00	3.28	3.53	3.27
T2	0.66	0.68	0.69	0.68	0.05	0.06	0.06	0.06	226	231	233	230	3.43	3.39	3.40	3.41
T3	0.68	0.69	0.77	0.71	0.06	0.07	0.07	0.06	281	297	356	311	4.10	4.30	4.60	4.33
T4	0.61	0.84	0.99	0.81	0.06	0.06	0.08	0.07	240	298	368	302	3.91	3.54	3.72	3.72
T5	0.69	1.01	1.06	0.92	0.07	0.07	0.08	0.07	256	382	390	343	3.70	3.82	3.70	3.74
T6	0.77	0.99	1.55	1.10	0.05	0.07	0.10	0.07	288	382	603	425	3.72	3.86	3.90	3.83
T7	0.89	0.91	0.98	0.93	0.07	0.07	0.08	0.07	387	410	431	409	4.32	4.52	4.40	4.41
Mean	0.72	0.85	1.03	0.87	0.06	0.07	0.08		272	325	399		3.74	3.82	3.89	
CD (P=0.05) (T)	0.12				0.007				45.8				0.006			
CD (P=0.05) (F)	0.07				0.004				26.2				NS			
T × F	0.21				0.012				78.9				0.24			

the treatment from 0.06 to 0.07%; the higher side found in treatment (T_7) receiving T_3+ 50% pressmud compost + 50% biomethanated spent wash. The SMBC was varied significantly among the treatment the highest values was observed in treatment T_7 and lowest in T_2. The SMBC/TOC ratio was ranges from 3.2 to 4.4, similar to SMBC the highest was found in T_7 and lowest values in T_1. Application of increased level of fertilizers significantly improved TOC, TN, SMBC and SMBC/TOC ratios. It was observed that application of 100% NPK, TOC content, TN and SMBC were increased about 21.3, 15.2 and 22.96% greater over 50% recommended dose of fertilizer level respectively (Table 2). Further, it was observed that the combined use of chemical fertilizers with *in-situ* decomposition of sugarcane crop residues and its industrial waste application had significantly improved these parameters.

For efficient management of soil and plant nutrients an integrated approach to plant nutrition must be adopted. Efficient use of crop residues, industrial and animal wastes along with nutrients reserves soil carbon, nitrogen and soil microbial biomass carbon. Thus, off-farm and *in-situ* organic sources need for facilitating nutrient generation on the farm itself by natural processes. It is essential to mobilize all available accessible and affordable plant nutrient sources in working capital to optimize productivity of cropping system. This study clearly indicates that burning or removal of crop residues declined soil total organic carbon content as well as crop yields. In contradictory, cultivation of Vertisol for the soybean-safflower sequence over 15 year under semiarid condition the sustainable yield index was not related with SOC buildup and profile SOC stock (Srinivasarao *et al.* 2012). Many researchers, Hegde (1996), Manna *et al.* (1996) and Swarup (1998) concluded that the continuous application of organic and manure substantially improved crop yield and the SOC under different soils and cropping systems employed. They also recommended that under tropical and subtropical climatic conditions, organic matter applications are necessary to obtain good results. The rate of organic matter application to soils was also determined by above researchers on the basis of utilization of nutrients by the crops. In five years study in black soil Manna *et al.* (2001) observed that continuous application of 75% recommended dose of chemical fertilizers coupled with 5 tonnes of compost to soybean crop increased yield and soil organic carbon, TN and SMBC. They further concluded that combined use of compost + 50% fertilizer dose increased yield of soybean by 13% to 16% over fertilizer alone. Substitution of chemical fertilizers by trash compost, press mud cake, spent wash ash in comparison with manure and vermicompost was established by Jadhav *et al.* (2000) and also concluded that due to addition of organic matter press mud cake increased SOC along with soil available nutrients.

Supplementing the chemical fertilizers with organic manures can arrest deterioration in soil biological activities. Thus, ideal way to sustain soil health and crop productivity, integrated plant nutrient supply strategies should be developed. Soil organic matter replenishment is the cornerstone to regenerating soil health. Sustenance of soil health, biological activities and productivity with continued and timely applications of balanced fertilizers with organic matter in Inceptisol, Alfisol and Vertisol has clearly been indicated by Manna *et al.* (2005). Plant residues are in the field or returned as compost as much as possible to improve soil available plant nutrients. The necessary removal of organic material in the form of harvested crops is compensated for by growing green manure crops or by amending with compost, which may actually be composed of community food waves, thus tightening the nutrient loop. Imbalanced fertilizer should be avoided or eliminated.

Effect on labile carbon, WSC and AHC

The data revealed that the $KMnO_4$ - extractable carbon ranged from 418 to 750 mg/kg in these treatments. The highest labile carbon was observed in treatment T_5 (750 mg/kg) receiving *in-situ* decomposition of sugarcane crop residues + cellulose decomposer +PSM + 8 kg urea + 10 kg SSP + biomethanated spent wash and lowest in treatment T_2 (418 mg/kg) under removal of sugarcane trash. The per cent labile carbon to TOC varied from 6.2 (T_2) to 8.5% (T_4) in these treatments (Table 3). The highest value of labile carbon to TOC recorded in the treatment T_4 and lowest in treatment T_2 under removal of sugarcane trash. In the present experiment WSC ranges from 30.0 to 70 mg/kg. The highest WSC was observed in treatment T_5 (70 mg/kg) and lowest amount of WSC (30 mg/kg) was observed in the treatment under removal of sugarcane trash (T_2) and T_3. The per cent WSC to TOC varied from 0.4 to 0.7. The highest level of WSC to TOC recorded in treatment T_5 (0.78%). The highest AHC recorded in treatment T_6 (3 180 mg/kg) and lowest in T_2 (1906 mg/kg) under removal of sugarcane trash done. The AHC to TOC ratios varied from 27.2 to 29.11%. The per cent AHC to TOC, the highest value was observed in treatment T_9 (29.1%) receiving *in-situ* decomposition of sugarcane crop residues + 50% press mud +50% spent wash (29.11%)and lowest in T_5 (27.2%) receiving *in-situ* decomposition of sugarcane crop residues + spent wash.

Increasing level of fertilizer increases labile pool of carbon after harvest of maize such as $KMNO_4$- extractable carbon, WSC and AHC and it was greater in the treatment receiving 100% recommended dose of NPK fertilizers. Further it was observed that, interaction effect of all the labile pools is statistically significant (Table 3). Our results resembled with Manna *et al.* (2008) that the active pools of SMBC comprised 4.3 to 8.5% of SOC in Vertisols and 3.2 to 5.6% of SOC in Alfisols. The WSC comprised 0.80 to14.1% of SOC in Vertisols and 1.5 to 4.9% of SOC in Alfisols. The AHC comprised 15–40.3% of SOC in Vertisols and 10.5 to 25% of SOC in Alfisols. Thus, the maintenance of soil organic pools is a major challenge in tropical climates (Lal 2009). Researchers have identified specific pools of SOC with functional significance in the turnover of organic matter in the soil (Fortuna *et al.* 2003). Soil microbial biomass C, WSC, AHC and $KMnO_4$-extratable carbon are considered to be the most active and highly labile fractions of SOC.

Table 3 Effect of *in-situ* recycling of sugarcane crop residues crop and its industrial wastes on active pools of carbon after harvest of maize (0 to 30 cm soil depth)

Treatment	Labile C ($KMnO_4$ Extract, $mgkg^{-1}$)				Labile Carbon/TOC (%)				WSC (mg/kg)				WSC/TOC				AHC (mg/kg)				AHC/TOC (%)			
	F0	F1	F2	Mean	F0	F1	F2	Mean	F0	F1	F2	Mean	F0	F1	F2	Mean	F0	F1	F2	Mean	F0	F1	F2	Mean
T1	546	585	794	642	7.7	7.1	6.8	7.2	30	30	60	40	0.4	0.3	0.5	0.4	1990	2102	3078	2390	41.0	24.4	17.9	27.8
T2	348	438	468	418	5.3	6.4	6.8	6.2	30	30	30	30	0.4	0.4	0.4	0.4	1864	1874	1982	1906	28.1	27.6	28.9	28.2
T3	427	490	496	471	6.2	7.1	6.4	6.6	30	30	30	30	0.4	0.4	0.4	0.4	1826	2021	2223	2024	26.7	29.3	28.7	28.2
T4	596	686	742	675	9.9	8.1	7.5	8.5	30	30	60	40	0.5	0.4	0.6	0.5	1719	2471	2970	2387	28.0	29.3	30.0	29.1
T5	670	780	801	750	9.7	7.8	7.6	8.4	30	60	120	70	0.4	0.6	1.1	0.7	1849	2772	2899	2507	26.7	27.5	27.5	27.2
T6	685	735	799	740	8.8	7.4	5.9	7.4	30	30	33	31	0.4	0.3	0.3	0.3	2082	2864	4592	3180	26.9	28.9	29.7	28.5
T7	630	725	783	713	7.1	8.0	8.0	7.7	30	60	87	59	0.4	0.7	0.9	0.6	2498	2632	2984	2705	27.9	29.0	30.5	29.1
Mean	557	634	698	630	7.8	7.4	7.0	7.4	30 ‘	39	60	43	0.4	0.4	0.6	0.5	1975	2391	2961	2443	29.3	28.0	27.6	28.3
CD (P=0.05) (T)	53				1.1				18.9				0.21				347				0.44			
CD (P=0.05) (F)	32				NS				8.60				0.11				199				NS			
T × F	98				2.0				27.6				0.35				598				3.20			

Burning of crop residues did not encourage labile pools of carbon, however, incorporation of press mud compost, and *in-situ* sugarcane trash substantially improved labile carbon pools. Further, it was observed that combined application of organics and chemical fertilizer significantly improved labile carbon pools. The similar results are also corroborated with the finding of Manna *et al.* (2007a, b). These pools improved better soil nutrient supply such as nitrogen, phosphorus, sulphur and other nutrients in response to nutrient management practices (Janzen *et al.* 1992). The improvement of soluble phase of carbon (labile pools) acted as bio-energy as the evidence of better improvement of soil microbial biomass C. The rapid decline in pool size of water extractable carbon with soil depth is due to its decomposition and particularly, sorption to mineral components (Kaiser and Guggenberger 2000, Hassouna *et al.* 2010). Reduction in the active pools of C was recorded with the use of imbalanced fertilizer from top soil to below 30 cm. Such a reduction leads to depletion in soil fertility through a decrease in labile nutrients, lowered bioavailability of nutrients and enhanced decomposition process (Manna *et al.* 2005). Likewise, removal of above-ground biomass or burning of trash is not advisable because of such practice deplete labile pools of active C pools that resulted in decline in crop yields. Reductions of aggregate size classes might be one of the reasons due to lower content of WSC and AHC as these act as binding agents in rhizosphere soil.

Effect on particulate organic matter carbon

In-situ recycling effect of sugarcane crop residues and its industrial wastes on particulate organic matter carbon (POMC), total organic carbon (TOC) and POMC/TOC after harvest of maize are presented in Table 4. The POMC was observed in the range of 1064 to 2014 mg/kg in these treatments. The highest POMC (2014 mg/kg) was recorded in treatment T_7 and lowest in treatment T_2 (1064 mg/kg), while the POMC observed in the order of $T_7>T_4>T_5>T_3>T_1>T_2$. Further, the per cent POMC to TOC was observed in the range of 11.5 to 22.3%. The highest level was recorded in treatment T_7 and lowest in treatment T_1 having burning of sugarcane trash and removal of stubbles (11.5%).

The increasing level of fertilizers increased particulate organic matter pool after harvest of maize and it was maximum in treatment receiving 100% recommended dose of fertilizers. Further, it was observed that the interaction effect of treatment combinations were statistically significant. In case of per cent POMC to TOC was varied within the range of 13.3 to 21.8, however, the highest per cent POMC to TOC observed in treatment T_7 and lowest in the treatment T_1 receiving burniging of sugarcane trash and removal of stubbles (13.3%) after harvest of maize (Table 4). Further, the interaction effect of all the treatments was statistically significant. It was observed that the maximum POMC concentration was found in 100% recommended dose of NPK fertilizers.

Particulate organic C is the precursor for the formation of soil MBC, soluble fraction of C and the humic and non-humic fractions of carbon in the soil, and hence, is a key attribute of soil quality. Soil organic matter (SOM) is protected against decomposition by various mechanisms. Among the physical stabilization, or protection from decomposition is due to accumulation of POM-C in soil, which are normally present in aggregate size classes. In addition to that each SOM pool, changes in land use and management practices by which SOM compounds undergo protection and release. Particulate organic matter fractions showed significant variations with fertilizer and manure treatments at a depth of 0–30 cm in the soybean-maize system in this study. POMC fraction is affected by tillage and residue input, aggregation and aggregate mineralization (Chan 2001). The large pool of POM maintains soil structure and macro-aggregation (Campbell *et al.* 1999). These pools enhance labile and stabilized SOM fractions in the soil. In this study these ratios of POMC/TOC relatively contributed greater amount in the treatment receiving NPK + press mud

Table 4 Effect of *in-situ* recycling of sugarcane crop residues and its industrial wastes on POMC (passive pool of C) after harvest of maize (0 to 30 cm soil depth)

Treatment	POMC (mg/kg)				POMC/TOC (%)			
	F0	F1	F2	Mean	F0	F1	F2	Mean
T1	946	1332	1350	1209	12.4	16.0	11.5	13.3
T2	923	1080	1190	1064	13.9	17.5	15.7	15.7
T3	1320	1499	1615	1478	19.3	21.7	20.8	20.6
T4	1184	1705	2036	1642	19.3	20.2	20.6	20.0
T5	1092	1631	1902	1542	15.8	16.3	18.0	16.7
T6	1175	1590	1879	1548	15.2	16.1	12.1	14.5
T7	1891	1962	2188	2014	21.4	21.6	22.3	21.8
Mean	1219	1543	1737		16.8	18.5	17.3	
CD (P=0.05) (T)	155				0.056			
CD (P=0.05) (F)	90				0.634			
T × F	270				1.553			

compost as compared to burning of crop residues. Aggregate stability is act as an indicator of soil susceptibility to runoff and erosion (Barthes and Roose 2002).

Effect on SOC stock

Effect of *in-situ* recycling of sugarcane crop residues and its industrial wastes on SOC stock after harvest of maize is presented in Table 5. The SOC stock was observed in the range of 25.93 to 48.74 Mg/ha. The highest SOC stock was observed in treatment T$_6$ receiving *in-situ* recycling of sugarcane crop residues + pressmud compost (48.74 Mg/ha) and lowest in treatment (T$_2$) having removal of sugarcane trash (T$_3$, 25.93 Mg/ha). Further the increasing levels of fertilizers significantly increases SOC stock and maximum SOC stock was observed in treatment receiving 100% recommended dose of NPK fertilizers after harvest of soybean (Table 5).

Table 5 Effect of *in-situ* recycling of sugarcane crop residues and its industrial wastes on SOC stock after harvest of maize (0 to 30 cm soil depth)

Treatment	SOC (Mg/ha)			
	F0	F1	F2	Mean
T1	29.37	32.76	44.84	35.66
T2	24.95	25.52	27.31	25.93
T3	26.89	26.26	29.45	27.53
T4	23.19	40.46	38.79	34.15
T5	27.51	40.03	39.98	35.84
T6	46.81	38.73	60.70	48.74
T7	34.11	35.15	38.69	35.98
Mean	30.40	34.13	39.97	
CD (P=0.05) (T)	3.506			
CD (P=0.05) (F)	5.061			
T × F	NS			

Soil organic carbon (SOC) generally increases with carbon input before the soil become carbon saturated. Inorganic fertilizer alone or in combination with organic manures, has been widely shown to increase SOC content (Purakayastha *et al.* 2008). This reflects the considerable carbon supplementation to soil with the applied fertilizers. Balanced fertilization is expected to increase SOC because of greater carbon input associated with enhanced primary production and crop residues returned to the soil. High rate of carbon sequestration in the soybean-maize system is due to the soil being under a unique nutrient management and secondly, due to high biomass production in sugarcane. Inadequate amount of decomposition of sugarcane trash lead to even modest oxygen demand for microbial activity resulting in improved humification of organic matter under aerobic conditions. Consequently, the overall organic matter decomposition rates are higher in arable soils. This results in a net accumulation of organic matter in soils that remain for several years. In this study, application of decomposed sugarcane trash along with inorganic fertilizer led to higher accumulation of carbon in the soil. The amount of SOC stock changes significantly in the 100% recommended dose of fertilizer (Table 5). The issue of climatic change and active and slow fractions of SOC and associate nutrients on productivity is needed more attention. Diversified cropping systems with better management substantially improved SOC in semiarid-tropic soils of India (Manna *et al.* 2008, 2012).

Effect on passive pools of carbon

Effect of *in-situ* recycling of sugarcane crop residues and its industrial wastes on passive pools of carbon viz. humic acid, fulvic acid and HA/FA ratio have been analyzed from post harvest soils of maize. The humic acid was observed in the range of 41.72% to 60.17% (Table 6). The highest humic acid was observed in treatment T$_7$ receiving *in-situ* recycling of sugarcane crop residues + 50% press mud + 50% biomethanated spent wash (60.17%), while lowest

Table 6 Effect of *in-situ* recycling of sugarcane crop residues and its industrial wastes on humic acid and fulvic acid fraction matter after harvest of maize (0 to 30 cm soil depth)

Treatment	Humic acid (%)				Fulvic acid (%)				Humic acid/ Fulvic acid (%)			
	F0	F1	F2	Mean	F0	F1	F2	Mean	F0	F1	F2	Mean
T1	44.42	45.69	47.10	45.74	34.13	35.03	35.2	34.79	1.30	1.30	1.34	1.31
T2	44.27	45.36	45.90	45.18	39.00	42.05	42.84	41.30	1.04	1.08	1.07	1.06
T3	43.07	43.72	43.89	43.56	33.37	33.94	34.59	33.97	1.29	1.29	1.27	1.28
T4	40.16	42.37	42.63	41.72	33.16	35.99	36.16	35.10	1.24	1.18	1.18	1.20
T5	45.20	45.68	45.89	45.59	48.33	48.78	49.00	48.70	0.94	0.94	0.94	0.94
T6	43.38	45.21	46.29	44.96	41.10	41.97	42.32	41.80	1.06	0.08	1.09	0.74
T7	59.30	60.53	60.67	60.17	48.06	48.68	48.77	48.50	1.23	1.24	1.24	1.24
Mean	45.85	47.07	47.61		39.68	40.98	41.33		1.16	1.02	1.16	
CD (P=0.05) (T)	0.17				0.27				0.008			
CD (P=0.05) (F)	0.07				0.09				0.003			
T × F	0.23				0.34				0.010			

in treatment T6 receiving sugarcane crop residues + press mud compost (41.72%). The fulvic acid varied from 33.97% to 48.7%. The highest level of fulvic acid was observed in treatment T_5 receiving *in-situ* recycling of sugarcane crop residues + biomethanated spent wash (48.7%) while lowest in treatment T_3 receiving *in-situ* recycling of sugarcane crop residues (33.97%). Similarly, the HA/FA ratio varied from 0.74 to 1.31%. Further, it was observed that application of increasing levels of fertilizers increases HA, FA and HA/FA ratio and maximum passive pools were observed in application of 100% recommended dose of NPK fertilizers after harvest of maize (Table 6).

Changes in humic acid (HA) and fulvic acid (FA) concentrations and HA/FA ratios among treatments were higher in the surface soil (0-30 cm). The HA and FA content and HA/FA ratios did not vary significantly in these treatments (Table 6). Manna *et al.* 2005 also reported that HA and FA is more recalcitrant pools of C, however its improvement through different nutrient management systems in soil needs several years. However, regular application of NPK with manure improved contain of soil humus. The passive fractions of C and N pools changed significantly indicating that balanced fertilization either alone or in combination with manure influenced C and N restoration of passive pools.

Effect on soil mass of water stable aggregate size class

The data pertaining to particulate organic matter carbon (POMC) and soil mass of water stable aggregate size class as influenced by in situ recycling of sugarcane crop residues and its industrial wastes in Vertisol after harvest of maize are presented in Table 7. In all the treatments, rewetted aggregate size distributions were dominated by macro-aggregates (2 000 to 250 μm) that accounted for 62.8 to 68.9% of dry soil weight. However, micro- aggregates (250- to 53μm) accounted for 18.9 to 23.3 % of the dry soil weight (Table 7).

Table 7 Effect of *in-situ* recycling of sugarcane crop residues and its industrial wastes on soil mass of water stable aggregates size class (g/kg) after harvest of maize (0 to 30 cm soil depth)

Treatment	Water stable aggregates size			
	> 2000	2000 to 250	250 to 53	< 53
T1	82.8	627	232	10.8
T2	85.8	672.6	203	11
T3	87.4	675	211.4	18.2
T4	95.2	639.8	213.8	11.6
T5	101.8	688.8	188.8	11.4
T6	107.6	671.2	200.8	13.2
T7	102.8	651	200.4	15.4
T8	96.4	666.4	206.4	16.2
T9	109	676.2	190.4	19.6
Initial	102	663.8	185.8	14.4
SE ±	2.9	4.06	3.26	0.7
CD (P=0.05)	8.7	12.2	9.8	2.1

The relative weight of soil increased with decrease in aggregate size classes and significant ($P \leq 0.05$) differences due to sugarcane residues and fertilizer treatments were observed in all aggregate size classes (>2 000; 250 to 2 000 and 53- to 250-μm) except in the silt + clay fractions (<53-μm). The burning of crop residues and removal of trash significantly reduces aggregate size classes as compared to in situ decomposition of sugarcane trash. The recommended dose of fertilizer (NPK) + press mud compost and *in-situ* recycling of sugarcane trash + press mud compost (T_6) improved macro-aggregates in the cultivated soil by 8.8 per cent over burning of sugarcane trash and removal of stubbles (T_1). Application of sugarcane residues and chemical fertilizer /*in-situ* crop residue decomposition significantly improved larger macro-aggregates (>2 000-μm) as compared to burning of crop residues. Thus, alternate wetting and drying condition resulted after continuous intensive conventional tillage operations and removal of above ground residues induced a rapid mineralization of aggregates associated SOM which collapsed the aggregates (>2 000-μm diameter size class) compared to integrated nutrient management. The results were resembled with the earlier findings of Manna *et al.* (2007a and b). The correlation between reduction in aggregates and loss of SOM with cultivation has been used to explain aggregate hierarchy theory by many authors (Tisdal and Oades 1982, Cambardella and Elliott 1992, Six *et al.* 2000). Increasing cultivation intensity with repeated application of inorganic fertilizers caused reduction of macro-aggregates. It is because of no significant release of water-soluble carbon and hydrolysable carbohydrates (which acted as binding agents) from below ground biomass decomposition upon microbial action. This perhaps resulted in loss of soil aggregates (Jastrow *et al.* 1996 and Six *et al.* 1998). Some of the forms of soil degradation occurring in the region are nutrient depletion, soil structure degradation, and removal or less input of manure as the consequence of a decrease in concentration of soil organic matter. Furthermore, particulate organic matter carbon (POMC), which is associated with the sand size fraction (50-2 000 m) in soil (Cambardella and Elliott 1992), is more sensitive indicator of soil quality changes than total organic matter (Chan 2001). Organo-mineral fractions of specific particle size (<53 m) have been shown to have distinct properties with respect to their composition and turnover (Sohi *et al.* 2001).

After harvest of maize, the relative weight of soil mass of water stable aggregates increased with decrease in aggregate size classes, and significant ($P \leq 0.05$) differences due to fertilizer and *in-situ* sugarcane crop residues and industrial wastes decomposition treatments were observed in all aggregate size classes (>2 000; 250 to 2 000 and 53 to 250μm) except in the silt + clay fractions (<53μm). The burning of crop residues and removal of sugarcane trash (T_1) significantly reduces aggregate size classes as compared to *in-situ* decomposition of sugarcane trash and industrial wastes. The *in-situ* recycling of sugarcane crop residues + press mud compost (T_6) and *in-situ* decomposition of sugarcane crop residues + biomethanated spent wash (T_5) along with recommended dose of NPK fertilizers (F_2) improved macro -aggregates in the cultivated soil by 8.8% over burning of sugarcane trash and removal of stubbles (T1) (Table 7). Application of chemical fertilizers and *in-situ* sugarcane crop residues and industrial wastes decomposition significantly improved larger macro-aggregates (>2 000μm) as compared to burning of crop residues. These results were resembled with the findings of Manna *et al.* (2007a and b).

Effect on carbon management index, carbon pool index and carbon labiality index

Effect of *in-situ* recycling of sugarcane crop residues and its industrial wastes on carbon management index (CMI), carbon pool index (CPI) and carbon labiality index (CLI) after maize harvest are presented in, Table 8. The CMI after harvest of maize was observed in the range of 51.36 to 94.24 and the highest CMI observed in treatment T_5 receiving *in-situ* recycling of sugarcane crop residues + biomethanated spent wash and lowest in treatment T_2 having *in-situ* recycling of sugarcane stubbles (51.36). The highest value of CPI was observed in treatment T_6 receiving *in-situ* recycling of sugarcane crop residues + press mud compost (1.89) and lowest in treatment T_2 receiving *in-situ* recycling of sugarcane stubbles (1.16). Further the CLI was varied from 0.44 to 0.63 and the highest CLI observed in T_4 receiving *in-situ* recycling of sugarcane crop residues + pressmud cake and lowest in T_2 having *in-situ* recycling of sugarcane stubbles (0.44) in these treatments (Table 8). Increasing fertilizer levels significantly increases the CMI, CLI and CPI after harvest of maize crop and it was found maximum in application of 100% recommended dose of NPK fertilizers (Table 8).

The soluble carbon fraction is an important pool with respect to soil organic matter turnover in agricultural soils, as it acts as a readily decomposable substrate for soil microorganisms and as a short-term reservoir of plant nutrients (Garcla-orencs *et al.* 2010). Labile carbon fractions, such as SMBC, WSC, AHC and KMn0_4-C, all increased after the addition of press mud and *in-situ* decomposed organic matter addition in combination with chemical fertilizer application. Whitbread *et al.* (1998) suggested that the soil carbon management index (CMI) can be used to describe soil fertility as it is a more sensitive indicator of the rate of change in SOC in response to soil management changes, than single measures such as the total SOC. In the present study, CMI was more significantly enhanced by the organic treatments than by burning or removal of crop residues. This was probably due to the increase in annual carbon input and the variations in organic matter quality, thus modifying the liability of carbon to KMn0_4 oxidation. These results are similar to those reported by Blair *et al.* (2006) who reported that manure alone and manure with inorganic fertilizer significantly increased CMI in comparison to any other chemical fertilizer treatment. The greatest decline in CMI occurred in the exploitative maize-spring oat rotation with a significantly higher CMI in the maize-spring oat–red clover rotation, which can be related to the amount of cultivation, fallow and red clover in the rotation. These changes in CMI are closely reflected in the maize yield reductions which occurred in 12 years rotations (Blair *et al.* 2006).

The incorporation of *in-situ* recycling of sugarcane crop residues + 50% press mud + 50% spent wash (T_9) also increased labile carbon (CL) by 28% over burning of the residues (T_1). However, the significant increase in carbon management index (CMI) was reported due to incorporation of green manure in T_8. It was also concluded that increasing of CMI increases in CPI values in this experiment. In a short term experiment conducted on C dynamics in sugarcane cropping by Ball-Coelho *et al.* (1993) in Brazil and showed that mulch management also significantly increased CLI and CMI.

Application of *in-situ* sugarcane residues incorporation

Table 8 Effect of *in-situ* recycling of sugarcane crop residues and its industrial wastes on CMI, CLI and CPI after harvest of maize (0 to 30 cm soil depth)

Treatment	CMI				CPI				CLI			
	F0	F1	F2	Mean	F0	F1	F2	Mean	F0	F1	F2	Mean
T1	69.57	72.53	98.12	80.07	1.30	1.43	2.01	1.58	0.57	0.51	0.49	0.53
T2	42.31	53.93	57.86	51.36	1.14	1.16	1.17	1.16	0.37	0.46	0.49	0.44
T3	52.46	60.76	60.04	57.75	1.17	1.18	1.32	1.22	0.45	0.52	0.46	0.47
T4	76.21	86.02	92.40	84.88	1.05	1.44	1.69	1.39	0.74	0.60	0.55	0.63
T5	85.44	97.44	99.84	94.24	1.19	1.72	1.81	1.57	0.72	0.57	0.55	0.61
T6	86.56	91.46	97.82	91.95	1.33	1.69	2.64	1.89	0.65	0.54	0.42	0.54
T7	78.14	90.76	98.03	88.98	1.53	1.55	1.68	1.59	0.52	0.59	0.59	0.57
Mean	70.10	78.99	86.30		1.24	1.45	1.76		0.57	0.54	0.51	
CD (P=0.05) (T)	7.92				0.20				0.09			
CD (P=0.05) (F)	4.27				0.12				NS			
T × F	13.1				0.35				0.15			

with pressmud retained greater amount of TOC, SMBC, WHC and AHC) in the treatment receiving pressmud compost along with sugarcane crop residues. In the study the physically protected carbon POMC was greater in the treatment receiving fertilizer in combination with decomposed pressmud compost as compared to burning of sugarcane trash. After harvest of maize the highest recalcitrant fraction of carbon, i.e. HA was observed the treatment T_7. This study clearly indicated that resistant fraction of carbon might be accumulated more where decomposed organic matter was applied regularly. The present study shows that after harvest of maize the maximum SOC stock was highest in the treatment T_6. It clearly indicated that greater the below and above ground biomass production enhance SOC stock and SOC sequestration potential.

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