

Soil Organic Carbon stabilization in compost amended soils

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Abstract

The molecular characteristics and the hydrophobic properties of natural organic matter represent a driving force in the long term stabilization of soil organic carbon. Laboratory incubations and field experiments were carried out to evaluate the effect of humified composts on the biochemical stability of soil organic components. Humic extracts and bulk composts were able to promote a stable incorporation of labile compounds in the humic hydrophobic domains thereby strengthening the incorporation of OC in soil size fractions and reducing the OC mineralization. The comparison of different soil organic matter managements in three agricultural soils, provided sound indications that soil amendment with mature hydrophobic green compost promote a significant incorporation of added organic materials in bulk soils and soil aggregates allowing a larger organic carbon stabilization in respect to conventional organic management practices

Keywords: SOC stabilization, compost, humic substances, hydrophobic protection

Introduction, scope and main objectives

The soil organic carbon (SOC) represent the largest reservoir in the global carbon cycle of terrestrial biosphere pools, accounting for 1500-1770 Pg, as compared to C stocks of vegetation (450-650 Pg) and fossil fuels (1000-1940 Pg). Despite the unavoidable uncertainties and approximations in the estimate of total SOC stocks for different geographical areas and land uses, global soil carbon levels of cultivated lands have decreased historically and continue to decline. Even though the term C sequestration is considered not adequate for the definition of the whole range of SOM managements (1), there is an increasing shared consensus on the powerful role of long term SOC stabilization for the maintenance and improvement of OC stocks in croplands and forest systems. The current conceptual depictions of SOC accumulation, are inclined to support the major role of physical protection mechanisms on SOM stabilization (2). The current techniques for SOC sequestration, rely on the application of minimum or no tillage intervention, coupled with crop rotation, green manure and mulching treatments, that imply the slacken of aggregate dynamics, the incorporation of fresh OM in undisturbed soil aggregates with a decrease of OC losses through lower exposition to microbial decomposition (3).

Complementary sustainable SOM managements for OC sequestration in cultivated soils are focused on the molecular characteristics and biochemical stability of SOM components. (4). A determinant role in SOC sequestration is assigned to humified organic matter which is the most abundant and persistent pool of SOM, and represents the principal potential sink of OC in the biosphere. The current acknowledged representation of soil humus is based on a self-assembled supra-molecular associations of heterogeneous molecules, deriving from the selective degradation of plant residues and OM inputs, integrated by the incorporation of microbial by-products (5). The multiple components are held together by weak dispersive forces that stabilizes the supra-molecular structures in a high pliable assembly of contiguous hydrophilic and hydrophobic domains. The progressive accumulation of hydrophobic and recalcitrant molecules in the humic superstructures constitute the most hydrophobic environment in soil, tightly impermeable to aqueous solvent irrespective to solution pH (6). This hydrophobic barrier may hence provide a biochemical hindrance to microbial decomposition thus developing a dynamic mechanism of hydrophobic protection toward the more biolabile organic compounds released in soil solution by crop residues, plant roots exudates and microbial degradation of crop biomolecules.

Therefore a rising attention is focused on promising SOM managements based on the improvement of quantity and quality of soil humic materials, carried out with the use of highly humified OM inputs such as compost (7). The mature compost is an important reservoir of humic substances that may effectively support the SOC sequestration in agricultural soils. The objective of the present work is to provide evidence on the effectiveness of humified composts in the incorporation and stabilization of SOM. Here we report the results of different laboratory tests and field experiment on the SOC sequestration provided by hydrophobic protection of mature composts and compost humic substances.

Methodology

▪ **Experiment 1.** In a laboratory incubation experiment, a labile ^{13}C -labeled 2-decanol (^{13}C 2dec.) was partitioned in two water dissolved humic acids, extracted from lignite (HAL) and compost (HAC), of different hydrophobicity as determined by NMR spectroscopy. A soil sample was incubated for three months with the following treatments: control; soil+ ^{13}C -2 dec. alone; soil+HAL/ ^{13}C -2dec., soil +HAC/ ^{13}C -2dec. for a total of 36 bulk soil samples (4 treatment, 3 times, 3 replicates). The soils were sampled at initial incubation (t_0), after 2 weeks (t_1) and after 12 weeks (t_2).

The residual ^{13}C -OC content was determined in bulk soils, particle-size fractions and soil humic substances by Gas Chromatography Isotope Ratio Mass Spectrometry

▪ **Experiment 2.** In one year laboratory test, a sandy-loam (P) and silt-loam (L), soils were incubated with the following treatments: P or L= no addition (control); AG1/AG2= addition of polysaccharides corresponding to 2,000 kg ha⁻¹ and 10,000 kg ha⁻¹; HAL/HAC= humic acids from lignite and composts, corresponding to 900 kg ha⁻¹; CMP= compost corresponding to 10 ton. ha⁻¹. Beside these six control treatments, the samples were treated with the two rates of AG (AG1 and AG2) both before and after each single addition of HAL, HAC, and CMP, for a total of 12 additional treatments. Measurement of OC content in samples was conducted at the following sampling dates: t_0 =at the start of the incubation; t_1 =after 2 weeks; t_2 =after 33 weeks; t_3 =after 52 weeks.

▪ **Experiment 3.** Within a three-years field trials, three agricultural soils were subjected to the following SOM managements: TRA (Traditional)=ploughing at 35 cm depth, followed by surface harrowing with addition of mineral fertilizers; MIN (Minimum tillage)=no ploughing, with addition of mineral fertilizers; GMAN (Green manure)= as TRA treatment with Leguminous crops interlaced between two main annual cycles and used to totally or partially replace nitrogen fertilizer; COM-1/COM-2 (Compost)=as the TRA plots with addition of hydrophobic mature green compost corresponding to 2.7 and 5.4 ton.ha⁻¹ of OC. The SOM stabilization was evaluated with the following analyses: TOC content and Thermochemolysis-Gas Chromatography Mass Spectrometry (THM-GC-MS) of bulk soils and water stable aggregates.

Results and Discussion

Experiment 1 The result of ^{13}C -OC distribution showed that biolabile ^{13}C -labeled 2-decanol was protected from mineralization when incorporated into the hydrophobic domains of the added HAs. At the end of incubation, the residual ^{13}C -labeled OC recovered in bulk soil was equal to 28, 45, and 58% of the original content for samples containing the labeled alcohol alone or with HA-L and HA-C, respectively. The distribution of ^{13}C -OC among soil particle sizes indicated that the protection was most effective in the finer soil fractions revealing a large incorporation promoted by hydrophobic humic acids in the silt- and clay-sized particles (Table 1). This finding confirms the importance of associations between fine textural fractions and microbially recalcitrant OM and suggests that SOM accumulation due to hydrophobic protection preferentially occurs within organo-mineral association of finer soil particles. In all soil treatments the added labelled decanol was also incorporated in the native SOM pools, with a larger partition observed in soil sample with compost HA.

Table 1: Variation of total organic carbon (TOC) and ¹³C-labelled organic carbon (¹³C-OC) in the bulk soil and sum of particle-size fractions with incubation time and soil treatment (from Spaccini et al., 2002)

Treatments	<i>t</i> ^a	Bulk soil ^b				Sum of fractions ^b							
		TOC ^c		¹³ C-OC		TOC ^c		¹³ C-OC					
		%	δ‰ ^c	%TOC	mg	%	%tot	2000 < μ > 0.1		< 0.1 μ ^d			
								mg	%tot ^e	δ‰ ^c	mg		
Control	<i>t</i> ₀	1.8	-26.3a			1.43	79.4					-25.0	
	<i>t</i> ₁	1.7	-26.2			1.35	79.4					-25.3	
	<i>t</i> ₂	1.5a	-26.3a			1.42	94.6					-25.2	
¹³ C-2 dec	<i>t</i> ₀	1.8	-13.9b	0.47ab	10.2a	1.49	82.7	3.14a	30.8	49.0	6.94		
	<i>t</i> ₁	1.7	-18.5	0.29	6.0	1.37	80.6	3.60	59.5	14.0	2.40		
	<i>t</i> ₂	1.3b	-21.3d	0.19c	2.9c	1.28	98.5	1.90c	64.5	9.0	0.90		
¹³ C-HAC	<i>t</i> ₀	1.9	-13.4c	0.46a	10.4a	1.50	78.9	3.40a	32.4	52.9	7.0		
	<i>t</i> ₁	1.8	-14.4	0.42	9.1	1.50	83.3	3.70	40.6	49.0	5.30		
	<i>t</i> ₂	1.7c	-20.8e	0.20d	4.2d	1.61	94.7	3.80d	90.4	-16.4	0.38		
¹³ C-HAL	<i>t</i> ₀	1.8	-13.5b	0.50b	10.8b	1.44	80.0	4.21b	39.0	40.7	6.60		
	<i>t</i> ₁	1.7	-13.9	0.49	10.2	1.47	86.5	5.12	50.2	38.8	5.15		
	<i>t</i> ₂	1.7c	-18.9f	0.30e	6.1e	1.72	100	5.94e	96.0	-18.2	0.21		

Experiment 2 The humified organic materials added to soils, were capable to reduce the biological mineralization of labile polysaccharides due to progressive interaction with the humic domains of added exogenous organic matter. The main difference in OC retention was observed among treatments when mixtures of stable organic matter (CMP, HAC, HAL) were added with labile material (AG) in both P and L soils, regardless of the order of addition. Both bulk compost and HAC treatment induced progressive significant decrease of OC losses, at subsequent incubation time, in the two soils, with a final larger OC preservation in the sandy-loam soil. The soil treatment with compost CMP or humic acid from compost HAC progressively increased the overall OC sequestration, retaining at the end of incubation from 120% to 160% of the initial OC content in respect to control soil. A lower OC sequestration was shown by all samples at the higher polysaccharides rate. In this case, treatments with CMP increased OC retention during incubation time, up to 110% and 120% of the initial OC content, while the retention exerted by HAC and HAL was in the range of 85–76% and 58–53%, respectively, of the initial OC content. The results showed that the soil addition with compost may effectively stabilize the labile organic matter entering the soil by incorporation into stable humified organic matter.

Experiment 3 After three year of SOM managements, the minimum tillage showed a final positive increase of TOC in respect to traditional ploughing, only in a silty-loam soil, while the overall larger variability in SOC content shown by both conventional SOM managements GMAN and MIN, throughout the experimentation period and all experimental sites, suggests that these practices were not able to persistently stabilize OC. Conversely, notwithstanding an initial priming effect and a consequent decrease in SOC content observed in two experimental sites in the first year, the soil amendment with hydrophobic mature composts (COM-1 and COM-2) produced a significant stabilization of SOM revealing a persistent incorporation of SOC in both bulk samples and soil aggregates. Depending on soil bulk densities of different experimental sites, the field plots added with compost were able to maintain in all the ploughed horizons (0.30 m), a significant percentage of cumulative added OC, that ranged from the 52 to 63% and from the 50 to 80%, for the low and high doses of compost addition respectively. This data corresponded to a stable OC incorporation of 2.1 to 4.1 Mg ha⁻¹ year⁻¹, that represented on average about the 75% of annual OC additions (2.7 and 5.4 Mg OC ha⁻¹ year⁻¹).

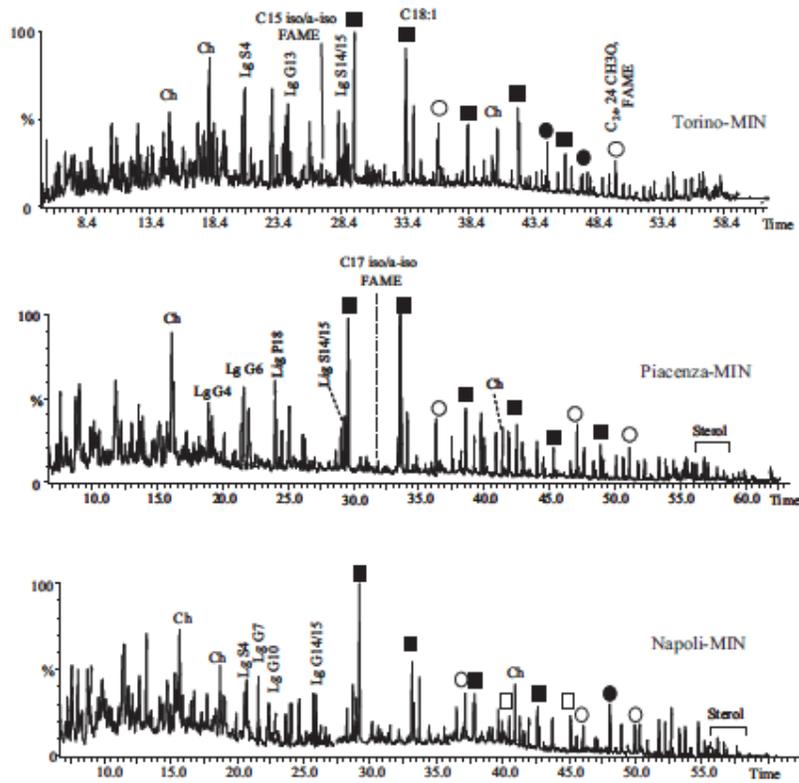


Figure 2 Representative total ion chromatograms of thermochemolysis products released from soil samples (●) alcohol; Ch, carbohydrate; (□) alkyl-dioic acid DIME; (■) FAME; (○) hydroxy-FAME; Lg, lignin.

The molecular characterization of SOM by THM-GC-MS analyses (Figure 2) revealed an effective incorporation of hydrophobic organic components from compost materials into bulk soils and water stable aggregates of each experimental sites. Increasing amounts of lignin components, fatty acids, *n*-alkanes and various biopolyesters derivatives such as long chain hydroxy-alkanoic and alkane-dioic acids were found in all compost amended soils. Moreover the inclusion of stabilized OM was indicated by the calculation of structural indices associated with the decomposition of lignin monomers. The aldehydes and benzoic acids forms of guaiacyl and syringyl lignin structures result from the progressive oxidation of lignin monomers. Conversely the corresponding homologues, holding integer methoxylated side chains, are indicative of unaltered lignin components, which retain the propyl ether intermolecular linkages. The ratio of relative amounts of oxidized acidic structures over those of the corresponding unaltered monomers are useful indicators of the bio-oxidative transformation of lignin components. The steady larger values found in both MIN and GMAN treatments and the corresponding progressive decrease of decomposition index in compost amended plots, further highlight the modification of SOM quality and the SOC stabilization promoted by the humified mature composts.

Conclusions

The results of laboratory and field experiment suggest that hydrophobic protection and the accumulation of alkyl and aromatic hydrophobic compounds, such as lignin and lipid components, may effectively contribute to OC accumulation in soil. The soil amendment with humified mature compost may be exploited to improve the biochemical stability of SOM, reduce the OC mineralization of the labile organic matter pools thus improving the OC stabilization and the sequestration potential of agricultural soils

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