Co-accumulation of microbial residues and particulate organic matter in the surface layer of a no-till Oxisol under different crops

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ABSTRACT

In the absence of significant mechanical disturbance such as under permanent no-till (NT), crop type should be a prominent factor controlling soil organic C (SOC) pools. Microbial cell residues have been shown to be influenced by plant species and are believed to contribute significantly to soil organic matter formation. We performed a study to investigate the co-accumulation of microbial cell wall residues (glucosamine, GlcN and muramic acid, MurN) and organic C (total and particle-size fractions) in the surface layer (0- to 5-cm depth) of an Oxisol after 7 yr under NT, as affected by different crop types. SOC content associated with pigeon pea [*Cajanus cajan* (L.) Millsp.] was 20% and 18% higher than that with corn (*Zea mays* L.) or sunflower (*Helianthus annuus* L.), respectively. The highest particulate organic C (POC) content in soil was also found under pigeon pea, which showed values 54, 46, and 48% higher than under corn, sunflower, and oilseed radish (*Raphanus sativus* L. var. *oleiformis* Pers.), respectively. Changes in POC explained most of the variation in SOC. The positive impact of pigeon pea on POC and SOC was attributed to rapid decomposition of its residues, due to their low C/N ratio, followed by selective preservation of lignin-rich particulate organic matter. The accrual of POC was closely associated with the accumulation of fungal and bacterial cell wall residues. This may be due to preferential feeding of fungi and bacteria on recently deposited plant-derived C sources present in the form of particulate organic matter. This observation is consistent with a recent model suggesting that microbial residues play a greater role in the formation of SOC than previously considered. We emphasize that this effect was mediated by the accumulation of POC and influenced by crop type.

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1. Introduction

In Brazil, no tillage (NT) is practiced on about half of the agricultural land (FEBRAPDP, 2012). Some of the areas recently converted to NT are located in tropical areas with warm winters. Rapid C mineralization under this tropical condition hampers the increase in SOC content. A prominent factor in NT system that can control the SOC content is the choice of the plant type. Since the plant material represents a primary resource for SOC formation (Oades, 1988; Kögel-Knabner, 2002), the nature of plant used to compose crop rotations should be investigated as a factor determining SOC build-up in NT systems, especially in the soil surface layer. In this layer, the close contact of plant materials returning to the soil (aboveground and roots) should influence the sensitivity of SOC to plant types.

The plant effect on the SOC pools can be mediated by soil microorganisms. A large proportion of plant-derived C passes through microbial biomass before being transformed into SOC. Therefore, microbial residues have been considered as a significant resource for soil organic matter formation (Kögel-Knabner, 2002). In recent models of SOC dynamics, microorganisms are not seen just as catalysts of plant material transformation in soil (Miltner et al., 2011). They rather represent a substantial source of SOC precursors (Kindler et al., 2006; Simpson et al., 2007; Liang et al., 2011; Liang and Balser, 2011). The necromass of fungi and bacteria in soil, assessed by contents of GlcN and MurN, respectively (Amelung et al., 2008), has been evidenced as an important fraction of soil organic matter, more important than considered in past decades (Kindler et al., 2009; Miltner et al., 2011). It has been shown that the microbial necromass provides the molecular origin and "fingerprint" for SOC formation (Guggenberger et al., 1999; Amelung, 2001; Ding et al., 2011). Therefore, the assessment of microbial residues can be used to examine the contribution of bacterial and fungal necromass to the SOC buildup as influenced by

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different plant species (Chantigny et al., 1997; Liang et al., 2007a,b; Ding et al., 2011).

According to the patch fragment formation cycle proposed by Miltner et al. (2011), the contribution of microbial-derived C to SOC, after incorporation of plant material in soil, occurs through the following processes: (i) plant residues entering soil support the growth and reproduction of soil microbial cells; (ii) substrate becomes limiting and microorganisms starve; (iii) microbial cells disintegrate into fragments; (iv) the cell wall fragments remain in soil and form a substantial part of the SOC. Considering the sequential events of this cycle, it is expected that plant materials that maximize microbial growth in soil foster microbial C accumulation contributing in turn to SOC buildup.

Specifically, the microbial C accumulation in surface layer of NT soils can be due to the protection of microbial-derived C in microaggregates (Simpson et al., 2004). Considering that a marked characteristic of the Oxisols is the high microaggregation, it is expected that, under NT, microbial residue could be significantly related to SOC build up in this soil type. The relationship between microbial residue and specific soil organic pools (total and particle-size fractions) in Oxisols under NT needs to be further studied.

We investigated the co-accumulation of the microbial cell wall residue and organic C (total and particle-size fractions) in the surface layer (0- to 5-cm depth) of an Oxisol after 7 yr under NT, as affected by different crop types. We further aimed to ascertain the validity of the microbial-derived C accumulation cycle in soil proposed by Miltner et al. (2011).

2. Materials and methods

2.1. Characterization of the experimental area

The field experiment was initiated in 2002 at Jaboticabal, SP, Brazil, (21°14′ S, 48°17′ W; altitude of 550 m). Climatologically, the area belongs to the tropical/megathermal zone or Köppen's Aw (a tropical climate with dry winters and an average temperature greater than 18 °C during the coldest month). Mean annual rainfall is 1417 mm, peaking between October and March, with a relatively dry season from April to September.

The soil of the experimental area is an Oxisol (Rhodic Eutrudox), based on USDA Soil Taxonomy (Soil Survey Staff, 2010). In the 0–20 cm layer, the mean clay, silt and sand contents were 555, 63 and 381 g kg^{-1}, respectively, as determined by the pipette method (Gee and Bauder, 1986). Other properties of the soil were presented in detail by Martins et al. (2009).

2.2. Experimental design

The experiment was conducted using a split-block design as described in details in Martins et al. (2009, 2012). Two sets of treatments were composed of 2 summer crop sequences and 7 winter crops, totaling 14 plots per experimental block. The treatments were randomized across each other in strips in an otherwise randomized complete block design with three replications (blocks). Each plot was 40 m long by 15 m wide.

The summer crop sequences (sown in October–November) were (i) continuous corn cultivation and (ii) soybean [*Glycine max* (L.) Merr.]–corn rotation. The winter crops, sown in February–March of each year in the same plots, were (i) corn, (ii) sunflower, (iii) oilseed radish, (iv) pearl millet [*Pennisetum americanum* (L.) Leeke], (v) pigeon pea, (vi) grain sorghum [*Sorghum bicolor* (L.) Moench]; and (vii) sunn hemp (*Crotalaria juncea* L.). The chemical properties of the plant materials are shown in Table 1. The plant biomass input in the last year (summer and winter growing seasons) under different crop sequences is presented in Table 2.

Table 1
Properties of plants (aboveground and belowground materials) used in this study as winter crops (adapted from Martins et al., 2012).

Winter crops[a]	Parameter (g kg^{-1} plant dry mass)			C/N
	Organic C	Total N	Lignin	
Aboveground				
Corn	459 (1)[b]	11.8 (0.2)	158 (5)	39 (1)
Pearl millet	455 (0)	13.3 (0.5)	77 (17)	34 (1)
Sorghum	468 (2)	13.3 (1.3)	60 (10)	35 (3)
Pigeon pea	491 (0)	27.4 (0.2)	144 (14)	18 (0)
Sunn hemp	469 (1)	15.6 (0.3)	32 (2)	30 (0)
Sunflower	431 (0)	23.6 (0.2)	50 (10)	18 (0)
Oilseed radish	445 (1)	21.1 (0.5)	55 (5)	21 (1)
Roots				
Corn	459 (3)	7.4 (0.4)	203 (8)	62 (2)
Pearl millet	461 (7)	9.7 (0.7)	122 (22)	47 (5)
Sorghum	461 (2)	7.7 (0.2)	101 (11)	60 (2)
Pigeon pea	468 (1)	8.4 (0.3)	123 (3)	56 (2)
Sunn hemp	474 (2)	7.2 (0.3)	40 (10)	66 (3)
Sunflower	459 (0)	5.6 (0.2)	144 (3)	82 (3)
Oilseed radish	448 (3)	9.1 (0.4)	38 (12)	49 (3)

[a] The parameters were determined for each type of plant in a representative sample from plant materials of all plots cultivated with the same plant species in the last winter growing season before soil sampling.
[b] The values in parentheses represent the standard error of the means ($n = 2$).

Soil sampling took place after finishing the seventh year of the experiment, on 4 September, 2009, before sowing the summer crops for the next growing year (2009/2010). Random sampling was performed in each plot. Twenty subsamples from a depth of 0–5 cm were used to make a composite soil sample of each plot.

2.3. Soil C and N

Total soil C content, considered as the SOC content in the absence of carbonates, was determined in a previous study (Martins et al., 2012) by dry combustion (LECO TruSpec CN, Leco Corp.,

Table 2
Annual plant biomass input under different summer and winter crop sequences. The plant biomass input is the sum of the biomass (aboveground and belowground plant materials) produced per area by summer and winter crops until the full flowering period in the last growing season before soil sampling. Detailed determination procedures were described by Martins et al. (2012).

	Plant biomass (kg m^{-2})[a]		
	Aboveground	Roots	Total input
Summer crops (S)			
Soybean–corn rotation	1.46 A	0.16 A	1.62 A
Continuous corn	1.24 B	0.13 B	1.37 B
F-test	76.78*	91.29*	78.97*
CV (%)	6	7	6
Winter crops (W)			
Corn	1.41 a	0.13 ab	1.54 a
Pearl millet	1.47 a	0.14 ab	1.61 a
Grain sorghum	1.32 a	0.11 b	1.43 a
Pigeon pea	1.36 a	0.17 a	1.53 a
Sunn hemp	1.30 a	0.13 ab	1.44 a
Sunflower	1.37 a	0.14 ab	1.51 a
Oilseed radish	1.23 a	0.17 a	1.40 a
F-test	0.78[ns]	5.08**	0.71[ns]
CV (%)	16	15	15
S × W interaction			
F-test	2.68[ns]	1.52[ns]	2.00[ns]

CV: coefficient of variation.
[ns]: Not significant.
* $P < 0.05$.
** $P < 0.01$.
[a] Different uppercase letters for summer crops and lowercase letters for winter crops represent significant differences based on Tukey's test ($\alpha = 0.05$).