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Non-labile plant C contributes to long-lasting macroaggregation of an Oxisol

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ABSTRACT

Decomposition of plant material influences soil aggregation dynamics in ways that are still poorly understood, especially for Oxisols, in which oxides are believed to play a dominant role. In an incubation experiment, we investigated (i) the effect of plant material addition from selected monocot and dicot species on soil organic C (SOC), carbohydrate composition, fungal and total microbial biomass, and aggregation of an Oxisol; and (ii) the relationship among these properties and C mineralization patterns. The experiment was carried out at 25 °C for 180 d after addition of 11 plant materials (4 g C kg^{-1} soil) and a control (no plant material added). Mineralization of C during the incubation was described considering two pools of C (labile and non-labile) using a first-order plus linear fitting. Compared to the control, corn materials showed larger pentose input, greater mineralization rates for the non-labile C pool (k), greater soil pentose content (xylose + arabinose) and larger mean weight diameter of soil water-stable aggregates at 180 d of incubation. These effects were independent of changes in SOC content, suggesting that total C accrual and macroaggregation may be decoupled processes in this Oxisol. Our results support the hypothesis that the non-labile plant C pool contributes to the long-lasting stability of macroaggregates of this Oxisol and that this effect is mediated by plant and soil pentoses. We propose that plant pentose content and the decomposition rate of the slow pool (k) are useful parameters for the prediction of plant effects on aggregation dynamics of Oxisols and the selection of soil conservation practices.

1. Introduction

The choice of plant type should be considered when selecting management strategies aimed at reducing soil vulnerability to physical degradation. Plant materials can act as natural soil conditioners by increasing soil water-stable aggregation, and the magnitude and duration of plant material effects on soil aggregation are hypothesized to depend on their biochemical composition (Monnier, 1965; Abiven et al., 2008). Although different plants generally have similar constituents, the relative proportion of these will influence decomposition and consequently, can cause differences in soil aggregation dynamics (Martens, 2000). However, the influence of specific plant-derived compounds on soil aggregation is still poorly understood.

During the initial period of plant material decomposition, microbial growth due to labile C availability results in large but transient increases in soil water-stable aggregation (Monnier, 1965). By contrast, the remaining fraction of plant carbohydrates, especially from cell walls, shows a slower but long-lasting rate of breakdown, which partly explains the presence of significant amounts of plant-derived carbohydrates in soil (Cheshire et al., 1973). The possible role that these residual plant-derived carbohydrates can play in soil aggregation processes has not been studied. This feature is of interest because increased water-stable aggregates reduce soil vulnerability to physical degradation through long periods without plant C inputs, such as during fallow periods.

According to the classical soil aggregation model proposed by Oades and Waters (1991), the oxides in Oxisol are the dominant stabilizing agents and may prevent the expression of aggregate hierarchy, which according to those authors, exists in soils where aggregate stability is controlled by organic materials. Considering that model, it might be expected that aggregation of Oxisols is less sensitive to the plant materials than other soil types. However, several studies have shown that Oxisol aggregation is affected by plant type (Silva et al., 1998; Salton et al., 2008; Martins et al., 2009). Little is known about the main mechanisms explaining this plant effect on Oxisol aggregation.

A recent field study showed that water-stable aggregation of an Oxisol was closely related to plant pentose inputs and soil xylose

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content, rather than variation in total SOC content (Martins et al., 2012a). We hypothesized that the slow decomposition of the residual plant-derived carbohydrate C was responsible for this effect. A study under controlled conditions could contribute to verifying whether the plant effect on soil aggregation is mainly related to residue decomposition and the residual effect of their carbohydrate composition rather than other crop-induced effects (e.g., wetting–drying cycles, root growth and exudation). Therefore, our objective was to study, under controlled conditions, the influence of decomposing plant materials and their carbohydrate composition on water-stable aggregation of an Oxisol.

2. Materials and methods

2.1. Incubation experiment

An incubation experiment was performed using soil samples taken from 0- to 20-cm depth of a kaolinitic Oxisol from Jaboticabal, SP, Brazil. Some mineralogical properties of this soil were previously described (Martins et al., 2009). Moist samples were brought to the laboratory, sieved through a 6.30-mm mesh sieve and stored at 4 °C. A representative amount of this soil sample was air-dried for physical and chemical characterization. An additional aliquot was oven dried at 105 °C to quantify water content for its further adjustment during the incubation experiment. The properties of the soil were: pH ($CaCl_2$), 4.5; SOC, 10.2 g kg^{-1}; total N, 0.83 g kg^{-1}; sand, 510 g kg^{-1}; clay, 484 g kg^{-1}.

Plant materials commonly cultivated in tropical and sub-tropical zones were used in the experiment. A number of monocot (Poaceae family) and dicot species were selected. The plant material from dicots consisted of aboveground biomass from soybean [*Glycine max* (L.) Merr.], bean (*Phaseolus vulgaris* L.), pigeon pea [*Cajanus cajan* (L.) Millsp.], sunn hemp (*Crotalaria juncea* L.), sunflower (*Helianthus annuus* L.) and oilseed radish (*Raphanus sativus* L. var. *oleiformis* Pers.). The plant materials from monocots consisted of aboveground biomass from corn (*Zea mays* L.), grain sorghum [*Sorghum bicolor* (L.) Moench] and pearl millet [*Pennisetum americanum* (L.) Leeke]. The plant materials were collected at the peak of the full flowering period. Additionally, corn roots ($corn_{root}$) collected at full flowering and aboveground corn biomass remaining after harvest ($corn_{harvest}$) were included in the experiment to increase the variety of plant materials in terms of biochemical composition and degradability. The sampling of plant materials was performed at the same site where the soil was collected. In the laboratory, the plant material was washed, dried at 60 °C until it had constant weight, ground to pass a 1-mm sieve, and stored at −10 °C. We analyzed total N and lignin contents and the monomeric composition of neutral carbohydrates (i.e., fucose, rhamnose, arabinose, galactose, mannose, glucose and xylose contents), as previously described by Martins et al. (2012a). These monosaccharides were classified as either hexoses (sum of fucose, rhamnose, galactose, mannose and glucose) or pentoses (sum of arabinose and xylose). This classification is of interest for the study of plant material effects on soil carbohydrates because pentoses are the main group of plant-derived carbohydrates in soil (Cheshire et al., 1973; Cheshire, 1979; Bertrand et al., 2009).

2.2. Soil microcosms

An aliquot of moist soil equivalent to 200 g of dry soil was put in 1-dm^3 plastic containers covered with aluminum foil to maintain darkness during incubation. Soil water content was adjusted to 17% (w/w), which was equivalent to tension of 33 kPa. A pre-incubation was carried out for 15 days at 25 °C aiming to stabilize the microbial activity after adjusting the water content. Afterward, plant materials were mixed into the moist and pre-incubated soil at a rate of 4 g C kg^{-1} dry soil. The resulting rates of pentose, hexose, total N and lignin inputs are presented in Table 1. Plastic containers with the same amount of soil and physical disturbance, but with no plant material added, were used as controls. The incubation was carried out under aerobic conditions at 25 °C. The moisture was corrected three times per week.

The experimental treatments consisted of 11 plant materials and one control, with 9 replications per treatment for a total of 108 containers set up in a completely randomized design. Three replicates of each incubation treatment were harvested 7 d, 90 d and 180 d after initiation of the incubation. Soil aggregation was analyzed at each sampling period. We determined SOC, total N, microbial biomass C (MBC) and fungal biomass (estimated by ergosterol) contents as well as carbohydrate composition in the 180 d soil samples to evaluate factors linked with the persistence of water-stable soil aggregation. Mineralization of C was measured during the entire incubation period in the 180 d containers.

2.3. C mineralization

The CO_2 evolved was trapped in 25-mL glass vials containing 10 mL of 0.5 mol L^{-1} NaOH. Afterward, the trapped CO_2 was back titrated with 0.5 mol L^{-1} HCl, after adding 2 mL of 1 mol L^{-1} $BaCl_2$ to precipitate Na_2CO_3 (Hopkins, 2008). The measurements occurred 12 times during the first 7-d period, 15 times during the 8- to 90-d period and 6 times for the 91- to 180-d period.

2.4. Soil microbial biomass and ergosterol

Soil MBC content was determined using the fumigation–extraction procedure (Vance et al., 1987). Briefly, 25 g of moist soil (17%, w/w) was fumigated with chloroform for 24 h at ambient temperature (≈22.5 °C). The same amount of moist soil, incubated for the same period but without fumigation, was used as a control. Carbon was extracted with 50 mL of 0.25 M K_2SO_4 from the fumigated and unfumigated soil. The C content in the extracts was determined by oxidation/titration method of Walkley and Black (1934). A k_{ec} factor of 0.45 was used to estimate MBC (Wu et al., 1990) from extractable C.

A 15-g aliquot of moist soil was freeze-dried to measure the content of ergosterol, which is a biomarker of fungal biomass (West et al., 1987; Djajakirana et al., 1996). For extraction of ergosterol, a 6-mL aliquot of methanol was added to 4 g of soil in 20-mL

Table 1
Input of carbohydrates (pentoses and hexoses), N and lignin from plant materials with the addition of 4 g C kg^{-1} soil. Inputs were estimated considering the amount of C added to soil and the results of plant composition analyses presented by Martins et al. (2012a).

Treatment	Organic input			
	Pentoses (g kg^{-1} soil)	Hexoses (g kg^{-1} soil)	N (g kg^{-1} soil)	Lignin (g kg^{-1} soil)
Poaceae				
Corn	0.95	2.08	0.10	1.38
$Corn_{harvest}$	1.22	2.29	0.05	1.55
$Corn_{roots}$	0.99	1.99	0.06	1.77
Pearl millet	1.05	2.05	0.11	0.68
Grain sorghum	0.85	1.61	0.11	0.51
Dicots				
Pigeon pea	0.42	1.58	0.22	1.17
Sunn hemp	0.72	2.06	0.14	0.27
Soybean	0.41	1.66	0.24	1.29
Bean	0.48	1.38	0.31	1.05
Sunflower	0.30	1.48	0.22	0.46
Oilseed radish	0.46	1.57	0.19	0.49