



Priming of soil organic carbon decomposition induced by corn compared to soybean crops



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ABSTRACT

The rate of soil organic carbon (C_S) loss via microbial respiration (decomposition rate k , y^{-1}), and the rate of stabilization of vegetation inputs (C_V) into C_S (humification rate h , y^{-1}) are usually considered independent of C_V . However, short-term laboratory studies suggest that the quality and quantity of C_V controls k , which is often referred to as a priming effect. We investigated how the chemical composition of different residues, (corn and soybean) controls k and h under field conditions in a no-till ecosystem. Using C_V -driven shifts in $\delta^{13}C$, we estimated changes in carbon (C) stocks, k and h of both the labile particulate organic matter fraction (C_{POM}) and the stabilized mineral associated organic matter fraction (C_{MAOM}). After two years of high C inputs (corn: $4.4 \text{ Mg ha}^{-1} \text{ y}^{-1}$ aboveground and C:N = 78; soybean: $3.5 \text{ Mg ha}^{-1} \text{ y}^{-1}$, C:N = 17), we found no changes in C_{POM} and C_{MAOM} stocks in the top 5-cm of soil or in deeper layers. However, C_{MAOM} in corn had higher k (0.06 y^{-1}) and C output fluxes ($0.67 \text{ Mg ha}^{-1} \text{ y}^{-1}$) than in soybean (0.03 y^{-1} and $0.32 \text{ Mg ha}^{-1} \text{ y}^{-1}$), but similar rates and fluxes in C_{POM} in the top 5-cm of soil. In addition, while C inputs to C_{POM} were also similar for both crops, C inputs from C_V to C_{MAOM} were higher in corn ($0.51 \text{ Mg ha}^{-1} \text{ y}^{-1}$) than in soybean ($0.19 \text{ Mg ha}^{-1} \text{ y}^{-1}$). Overall, corn plots had higher k and C inputs into C_{MAOM} and therefore higher C cycling in this fraction. Our data suggests that the type of crop residue strongly influences C cycling in the topsoil of no-till cropping systems by affecting both the stabilization and the decomposition of soil organic matter.

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1. Introduction

Soil organic carbon (C_S) is a major component of the global carbon (C) cycle that influences productivity in terrestrial ecosystems; its accumulation can reduce the buildup of CO_2 in the atmosphere (Bauer and Black, 1994; Lal, 1997; Reeves, 1997; Berthrong et al., 2009). Carbon stocks and fluxes are strongly affected by land use. Agriculture is one of the main perturbations of the global C cycle with a large contribution to global atmospheric CO_2 emissions (Schimel, 1995; Foley et al., 2005). Agriculture modifies C_S stocks by changing: (1) C inputs from vegetation (C_V) or the fraction of C_V that is stabilized (or humified) in organic matter,

and (2) C outputs as CO_2 from microbial respiration of C_S . Hénin and Dupuis (1945) formalized this mass balance framework as follows:

$$\frac{dC_S}{dt} = hC_V - kC_S \quad (1)$$

where h (y^{-1}) is the humification rate and k (y^{-1}) is the decomposition rate of C_S . It is well known that microorganisms decompose fresh biomass inputs and release C as CO_2 from respiration while retaining most nitrogen (N), depending on the C:N ratio of the biomass inputs (Swift et al., 1979). The retained N and the non-respired organic C stabilizes in organo-mineral associations that decompose at a much slower rate than fresh inputs. Therefore, C_S is mostly formed by microbial byproducts such as exudates and components released through breakup of dead microorganisms that are protected from decomposition by association with clay and silt particles and occlusion in soil aggregates (Hassink and Whitmore, 1997; Balesdent et al., 2000).

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In corn and soybean cropping systems, the residues returned to the soil by these two crops differ in amount and composition. Corn C inputs usually exceed those of soybean by 1.4– to 1.8-fold, albeit with a much higher C:N ratio (Buyanovsky and Wagner, 1986; Allmaras et al., 2000; Huggins et al., 2007). In agricultural systems, a higher return of residues is often associated with higher soil organic matter contents (e.g. Campbell et al., 1991; Rasmussen and Smiley, 1997). Nevertheless, several knowledge gaps remain regarding the specific mechanisms that determine changes in h and k as consequence of changes in quantity and composition of residue inputs.

It is often assumed that k of C_5 depends mainly on temperature, humidity, and soil physical properties (Wildung et al., 1975; Bunnell et al., 1977; Kowalenko et al., 1978; Buyanovsky and Wagner, 1986; Power et al., 1986; Hendrix et al., 1988; Gregorich et al., 1998). However, experiments in laboratory conditions challenge this assumption and suggest that k is also affected by the so-called priming effect. In priming, k is a function of the amount and quality of the fresh residues being decomposed (Fontaine et al., 2003, 2007; Blagodatskaya and Kuzyakov, 2008; Crow et al., 2009; Chemidlin Prévost-Bouré et al., 2010; Guenet et al., 2010; Kuzyakov, 2010; Larionova et al., 2011; Guenet et al., 2012; Shahzad et al., 2012; Zhu and Cheng, 2012; Paterson and Sim, 2013). In forest soils, priming seems to operate because increasing net primary productivity does not translate systematically into increases in C_5 , due to a simultaneous acceleration of soil organic matter decomposition (Sulzman et al., 2005; Crow et al., 2009).

The quality and quantity of C_V may affect rates of both k and h , particularly in no-till crops where mechanical breakdown and mixing with soil is absent. To evaluate the influence of C_V properties on h , it is useful to apply the decomposition cascade framework of Swift et al. (1979), in which a portion of C_V ($1 - h$) is lost through microbial respiration but most N and non-respired C remain in the soil. Based on this framework, one can propose that residues with a C:N ratio closer to that of soil organic matter may have higher h than residues with high C:N. This idea is also supported by recent results showing that decomposers decrease their C use efficiency when consuming high C:N ratio residues, therefore decreasing h (Manzoni et al., 2008). In agricultural systems, soybean and corn represent two extreme C:N ratios, and we expect that h for soybeans should be higher than that for corn. However, sparse experimental evidence suggests the opposite (Huggins et al., 1998, 2007); no clear mechanism explaining these putative differences in h rates has been proposed. Furthermore, another factor that may control h is the ratio between C_5 and the corresponding C_5 saturation level (Hassink and Whitmore, 1997). The C_5 saturation is defined as the amount of C that can be protected in organo-mineral associations in soils and seems to depend on soil texture. A soil with C_5 closer to saturation should have lower h than one with lower C_5 , a concept that has been incorporated in simulation models (Kemanian and Stöckle, 2010). Therefore, the saturation effect has to be considered when interpreting experimental determinations of h .

While testing these ideas is important, estimating k and h and identifying the sources of C leaving or entering a soil C compartment remain challenging. Among the existing methods, isotopic tracing of natural ^{13}C is particularly useful, especially when a soil originally grown or managed with C_3 plants ($\delta^{13}\text{C} = -26\text{‰}$) is substituted with C_4 plants ($\delta^{13}\text{C} = -12\text{‰}$) or vice versa (Balesdent et al., 1988). A soil with an intermediate isotopic composition derived from mixed C_3 and C_4 vegetation ($\delta^{13}\text{C} = -18$ to -21‰) allows researchers to follow simultaneously the decline of $\delta^{13}\text{C}$ in the soil following the introduction of C_3 plants and its enrichment after the introduction of C_4 plants

(Andriulo et al., 1999; Bayala et al., 2006; Desjardins et al., 2006). When isotopic tracing and soil fractionation are combined (i.e. size separation of C_5 into particulate organic C, C_{POM} , and mineral associated organic C, C_{MAOM} , as proposed by Cambardella and Elliot (1992)), both C inputs and outputs from each fraction can be estimated (Martin et al., 1990; Gregorich et al., 1995; Huggins et al., 1998).

Here, our objectives were to estimate decomposition rate of C_5 (k) and the humification rate (h) for different soil fractions (C_{POM} and C_{MAOM}) under crop biomass inputs that differ strongly in quantity, quality, and isotopic composition. We hypothesize that, if priming influences k , soils receiving inputs from corn will have higher k than soils receiving soybean inputs in no-till systems. In addition, crop inputs from soybean with a lower C:N ratio should have higher h compared to corn residues with a high C:N. To address these hypotheses, we measured C fluxes in the plant-soil system using $\delta^{13}\text{C}$ natural abundance as a tracer, and estimated k and h in no-till corn and soybean systems. Our experiment started from an old pasture of mixed C_3 and C_4 plants that was converted to no-till agriculture, allowing us to follow both the enrichment and depletion of C_5 with $\delta^{13}\text{C}$ due to inputs of corn or soybean.

2. Materials and methods

2.1. Study site and experimental design

The experiment was located in northwest Uruguay, 10 km south of Paysandú (31° 21' S and 58° 02' W; 61 m above sea level), in the Northern Campos region of the Rio de la Plata grasslands (Soriano, 1992). The climate is meso-thermal sub-humid with a mean daily temperature of 25 and 13 °C in summer and winter, respectively, and an annual rainfall of 1200 mm distributed on average uniformly throughout the year, albeit with large intra- and inter-annual variations. The soil at the site was a fertile Typic Argiudol with a 1% slope. Soil particle-size distribution is uniform throughout the first 0.20 m, with 209, 564 and 227 g kg^{-1} of sand, silt, and clay, respectively.

Between 1940 and 1970 the study site was under continuous annual cropping of wheat (one crop per year) in conventional tillage (inversion tillage plus several secondary operations). From 1970 to 1993 annual crops were rotated with pastures in a six-year rotation consisting of three years of white clover (*Trifolium repens* L.), birdsfoot trefoil (*Lotus corniculatus* L.), and tall fescue (*Lolium arundinacea* L.) and three years of crops, with 1.7 crops per year on average (Ernst and Siri-Prieto, 2009). From 1993 until the beginning of our experiment in 2007 the site was not cultivated and was gradually colonized by bermudagrass (*Cynodon dactylon* L. – C_4 perennial), maintaining a variable abundance of annual ryegrass (*Lolium multiflorum* L.) and white clover.

Our experiment was established in April of 2007 with two treatments arranged in three randomized blocks. The treatments were continuous corn (corn) or continuous soybean (soybean). The experimental area was initially treated with glyphosate at a rate of 3.0 kg a.i. ha^{-1} and subsequently at a rate of 1.5–2.0 kg a.i. ha^{-1} depending on weed infestation and weather conditions. Crops were sown on December 6th in 2007 and November 28th in 2008. Pre- and post- emergent herbicides were applied in all treatments to control weeds as needed, and insects and diseases were controlled chemically as needed based on insect and diseases population monitoring. Prior to sowing, all plots were fertilized with 150 kg ha^{-1} of ammonium phosphate (27 kg N ha^{-1} and 30 kg P ha^{-1}). At the six-leaf stage, 69 kg N ha^{-1} as urea were applied in corn plots. All crops were no-till planted in 30 × 5.2 m plots with 0.52-m row spacing.

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