



Contents lists available at ScienceDirect

Soil Biology & Biochemistry

journal homepage: www.elsevier.com/locate/soilbio

Greater humification of belowground than aboveground biomass carbon into particulate soil organic matter in no-till corn and soybean crops

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ARTICLE INFO

Article history:

Received 4 December 2014

Received in revised form

4 February 2015

Accepted 7 February 2015

Available online xxx

Keywords:

Particulate organic matter

Root carbon inputs

Carbon isotopes

Humification rate

Corn

Soybean

ABSTRACT

Quantifying the amount of carbon (C) incorporated from decomposing residues into soil organic carbon (C_S) requires knowing the rate of C stabilization (humification rate) into different soil organic matter pools. However, the differential humification rates of C derived from belowground and aboveground biomass into C_S pools has been poorly quantified. We estimated the contribution of aboveground and belowground biomass to the formation of C_S in four agricultural treatments by measuring changes in $\delta^{13}\text{C}$ natural abundance in particulate organic matter (C_{POM}) associated with manipulations of C₃ and C₄ biomass. The treatments were (1) continuous corn cropping (C₄ plant), (2) continuous soybean cropping (C₃), and two stubble exchange treatments (3 and 4) where the aboveground biomass left after the grain harvest was exchanged between corn and soybean plots, allowing the separation of aboveground and belowground C inputs to C_S based on the different $\delta^{13}\text{C}$ signatures. After two growing seasons, most of the new C_{POM} was primarily derived from belowground C inputs, even though they represented only ~10% of the total plant C inputs as residues. Belowground biomass contributed from 60% to almost 80% of the total new C present in the C_{POM} in the top 10 cm of soil. The humification rate of belowground C inputs into C_{POM} was 24% and 10%, while that of aboveground C inputs was only 0.5% and 1.0% for soybean and corn, respectively. Our results indicate that roots can play a disproportionately important role in the C_{POM} budget in soils. Keywords Particulate organic matter; root carbon inputs; carbon isotopes; humification rate; corn; soybean.

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1. Introduction

In the soil–plant system, carbon (C) stabilized into soil organic matter has two distinct origins: aboveground inputs (leaves, stems, and floral structures) and belowground inputs (roots, and rhizodeposition). Studies examining the effect of management practices on soil organic carbon (C_S) in agricultural soils have often contrasted tilled and no-till systems (Lal, 1997; Peterson et al., 1998; Díaz-Zorita et al., 2002). Yet, far less attention has been given to the potential impact on the C_S balance of changes in C allocation to

belowground and aboveground C inputs in different crops and cropping systems, in part because of the difficulties involved in quantifying and tracking C from belowground residues.

Decades ago, Broadbent and Nakashima (1974) proposed that belowground C inputs have a relatively greater influence on the C_S balance than aboveground C inputs. Subsequent reports from long-term residue management studies seemed to support this assertion (Campbell et al., 1991; Balesdent and Balabane, 1996; Clapp et al., 2000). The potential greater stabilization of belowground C inputs into C_S has been attributed principally to the inherent physical protection within soil aggregates of root-derived C (Gale et al., 2000; Wander and Yang, 2000; Puget and Drinkwater, 2001). However, studies quantifying the contributions of belowground

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and aboveground C inputs to C_5 remain scarce (Rasse et al., 2005), particularly in crops of contrasting litter chemistry and in no-till agroecosystems. Consequently, a clear understanding of the dynamics of C derived from belowground inputs and its implications for agricultural management remains elusive (Kong and Six, 2010).

Our current understanding of the biological processes that explain the formation of soil organic matter has been summarized in several plant-soil simulation models. These models differ in the algorithms used to estimate aboveground and belowground biomass humification into C_5 . The CENTURY model (Parton et al., 1988) separates biomass inputs into metabolic and structural pools. For the metabolic and structural pools the fraction of the decomposed C that is stabilized in the active C pool is slightly higher for belowground (0.45 g g^{-1}) than for aboveground dead biomass (0.40 g g^{-1}). Once in the active pool the origin of the C does not affect the stabilization in the slow or passive pools. In the ROTH-C model (Coleman and Jenkinson, 1996) the humification coefficient depends on the type of material but is the same for all C inputs above- and belowground. The more recent C-Farm model (Kemanian and Stöckle, 2010) also uses the same humification coefficient for shoot and root C inputs, and adds C from root exudates, albeit at a lower humification rate. Thus, these simulation models do not account for a potentially larger role of belowground inputs in C_5 formation, probably because of the absence of quantitative data for model parameterization.

Estimating the humification of C from different biomass pools into C_5 is especially challenging in the field. Several methods have been proposed for this purpose. One method is based on the use of long-term field experiments in which aboveground residues are either returned to the soil or removed after harvest, using a bare-soil treatment as a reference (Larson et al., 1972; Barber, 1979; Plénet et al., 1993; Kätterer et al., 2011). The issue with this method is that the residue removal creates an extreme condition, exposing the soil to rain and wind erosion. Another widely used approach is the use of litter-bag incubations (Parker et al., 1984; Robinson et al., 1997; Moretto et al., 2001). Here, the primary concern is soil disturbance that arises from placing litter bags into the soil, sometimes at different depths. A third method uses $\delta^{13}\text{C}$ natural abundance isotopic techniques in long-term experiments (Angers et al., 1995; Bolinder et al., 1999) or with pulse-labeled ^{14}C or ^{13}C (Kisselle et al., 2001; Kong and Six, 2010).

Isotopic tracing of natural ^{13}C is potentially useful for identifying the source of C in C_5 and its turnover rate in many ecosystems. The method is useful when a system 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 particularly useful case is when the soil exhibits an intermediate isotopic composition derived from mixed C_3 and C_4 vegetation ($\delta^{13}\text{C} = -18$ to -21‰), because it allows researchers to follow simultaneously the decline of $\delta^{13}\text{C}$ in the soil after the introduction of C_3 plants and its enrichment after the introduction of C_4 plants (Andriulo et al., 1999; Bayala et al., 2006). The tracing of natural ^{13}C abundance has been applied to both bulk soil and to different soil fractions (Martin et al., 1990; Gregorich et al., 1995; Desjardins et al., 2006).

Because C_5 is heterogeneous in composition and turnover, it is often separated into different fractions via chemical or physical fractionation. One fractionation method separates organic matter (and therefore C_5) into particulate and mineral-associated organic matter (Cambardella and Elliott, 1992). Organic C in these fractions is defined as C_{POM} and C_{MAOM} , respectively. C_{POM} corresponds with relatively young, minimally transformed C compared to the fresh inputs, and is less associated with mineral constituents of the soil than C_{MAOM} . In contrast C_{MAOM} is more stable through time, likely due to association with the mineral fraction. Combining isotopic tracing with organic matter fractionation can provide a powerful method to unravel the fate of C in soils.

The objectives of this study were to estimate: (1) the proportion of C present in the C_{POM} fractions derived from aboveground or belowground biomass residues, and (2) the rate of humification of C from aboveground and belowground residues into C_{POM} . We tested the following hypotheses in this no-till system, where aboveground residues are not mechanically incorporated into the soil: (i) C_{POM} will be relatively rich in C derived from belowground biomass (i.e. a more than proportional representation of belowground inputs in C_{POM}) and, (ii) belowground C inputs will have a higher humification rate into C_{POM} than aboveground C inputs. To address these hypotheses, we studied C_{POM} decomposition and formation by measuring changes in soil $\delta^{13}\text{C}$ natural abundance in no-till plots of corn and soybean, two crops with contrasting C:N ratio in the residues left at harvest. These plots were established in a field that was previously a C_3/C_4 pasture, and in which we manipulated aboveground C inputs. Originally, our goal was to estimate the contribution of aboveground and belowground C inputs to the C_{MAOM} fraction as well. However, we reported previously that there is priming of C_{MAOM} under continuous corn (Mazzilli et al., 2014), and this makes it impossible to solve for the decomposition rate of and humification rate into C_{MAOM} using the same methodology applied to C_{POM} . Therefore, this paper focuses exclusively on the dynamics of C_{POM} as affected by belowground and aboveground C inputs.

2. Materials and methods

2.1. Study site and experimental design

The experiment was located in northwest Uruguay, 10 km south of Paysandú ($31^\circ 21' \text{ S}$ and $58^\circ 02' \text{ W}$; 61 m above sea level), within 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 a mean annual rainfall of 1200 mm distributed on average uniformly throughout the year, but with large inter-annual variations. The research site has a $\sim 1\%$ slope and soil that is a fertile Typic Argiudol. The soil particle-size distribution in the first 0.1 m is 212, 559 and 229 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 arundinaceum* (Schreb.) Darbysh.) and three years of crops at 1.7 crops per year (Ernst et al., 2009). From 1993 until the beginning of the experiment in 2007 the site was not cultivated and was gradually colonized by bermudagrass (*Cynodon dactylon* (L.) Pers. – a perennial C_4), maintaining a variable abundance of annual ryegrass (*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot) and white clover (both C_3 species). This land use history provides an intermediate soil $\delta^{13}\text{C}$ signature ($-21.5\text{‰} \pm 0.2$ in the first 10 cm depth for C_{POM}) and allows differentiating C inputs from both C_3 and C_4 plants.

The experiment was established in April of 2007. The experimental area was treated with glyphosate at a rate of $3.0 \text{ kg a.i. ha}^{-1}$ in April of and subsequently at a rate of $1.5\text{--}2.0 \text{ kg a.i. ha}^{-1}$ depending on weed infestation and weather conditions. Crops were no-till sown on December 6 in 2007 and November 28 in 2008. Pre- and post-emergent herbicides were applied in all treatments to control weeds as needed, and insects and diseases were controlled chemically based on regular insect and disease population monitoring. Prior to sowing, 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 all corn plots were side dressed with 69 kg N ha^{-1} as urea.

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