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How the chemical composition and heterogeneity of crop residue mixtures decomposing at the soil surface affects C and N mineralization

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ABSTRACT

The effects of plant litter characteristics on its decomposition in soil or at the soil surface is of primary importance for adequate management of nutrients and carbon (C) in agro-ecosystems. However, understanding the influence of mixtures of residues, which is actually the most common situation encountered in agriculture, is still poorly known in cultivated soils. Therefore we analyzed the effect of mixing leaf and stem litters from 25 species of plants (main crops and cover crops), representative of agricultural systems in subtropical conditions, on subsequent C and nitrogen (N) mineralization. We characterized the chemistry of leaves, stems and mixtures and determined the heterogeneity of the mixtures using Gower's similarity coefficient. We incubated crop residues at the surface of a sandy loam soil at 25 °C over 120 days and continuously measured the mineralization of C and N. The 25 mixtures represented a wide range of chemical qualities and heterogeneity. Significant differences in C mineralization and soil N accumulation clearly differentiated crop families (notably Poaceae species vs. Fabaceae species), and plant parts (stems vs. leaves). The differences between observed and expected values for C mineralization were low or nil, indicating mostly an additive effect of mixing. Significant synergetic effects existed for only 7 species and resulted in an average additional 9% C mineralized. For N, an antagonistic effect was observed only with Fabaceae mixtures having high average N content and high chemical heterogeneity. We concluded that the decomposition of mixtures appeared mainly controlled by their average chemical composition and to a less degree by their chemical heterogeneity. In these cases, the availability of N in the mixtures appeared to increase the microbial N immobilization, reducing the net accumulation of mineral N in the soil.

1. Introduction

No-till systems use a large diversity of crop plant species that directly influence the cycles of carbon (C) and nitrogen (N) in soil (Jensen et al., 2005). In these cropping systems, the crop residues form mulch at the soil surface composed of a mixture of different plant parts (Lal et al., 2007; Thippayarugs et al., 2008). Physical factors (of soil or residue) and biological processes either individually or in combination can drive decomposition, but the intrinsic characteristics, or functional traits, of crop residues are important in controlling their decomposition rate in soils (Trinsoutrot et al., 2000; Jensen et al., 2005; Aulen et al., 2012). In general, leaves have higher rates of C and N mineralization than stems (Cobo et al., 2002; Abiven et al., 2005; Thippayarugs et al., 2008) due to their more readily decomposable tissue composition, lower lignin content and higher total N content (Quemada and Cabrera, 1995; Bertrand et al., 2006).

Many studies have been performed to better understand the effect of plant residue quality on C or N mineralization using plant leaves, stems or mixtures (shoots), with residues incorporated into the soil (e.g., Abiven et al., 2005; Bertrand et al., 2006; Thippayarugs et al., 2008) or left on the soil surface (Quemada and Cabrera, 1995;

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Cobo et al., 2002; Li et al., 2013a, b). However, in field conditions, different types of plant residues often decompose together in a mixture (Hättenschwiler et al., 2005). Indeed, this question is attracting much attention, particularly in the field of ecology, in investigations of the role of functional diversity (in this case, diversity of plant traits) on ecosystem functioning (Hättenschwiler et al., 2005). Trait-similarity measures are used to characterize differences in chemical and physical characteristics of plant litters and to analyze non-additive effects (Gessner et al., 2010; De Bello et al., 2013). The C and N mineralization of litter mixtures can differ from that expected based on the decomposition of single components because the composition of the residue can modify the processes involved in decomposition (Hoorens et al., 2002; Gartner and Cardon, 2004; Berglund et al., 2013). The decomposition of residue mixtures has been reported to exhibit synergistic effects (i.e., higher rates of decomposition than expected) (Quemada and Cabrera, 1995; Zeng et al., 2010), negative effects (i.e., lower rates than expected) or additive effects (i.e., rates equal to those expected) (Liu et al., 2007; Li et al., 2013a, 2013b). However, high variations in the range of responses of decomposition rates to mixing have been observed (Gartner and Cardon, 2004) depending on the type of residue, time scale and process considered (e.g., mass loss, C mineralization or N dynamics). Non-additive effects of mixing residues were assumed to result from the chemical heterogeneity of the mixtures (Harguindeguy et al., 2008) and particularly to the transfer of N between N-rich and N-poor litters (Berglund et al., 2013). Despite its acknowledged importance, this issue has been rarely addressed in agricultural systems, (Garnier and Navas, 2012). In this context, the published studies about residue mixtures usually involved a small number of species, which makes it difficult to generalize the findings (Gartner and Cardon, 2004). In addition, these studies have analyzed most often C mineralization or that of N, but rarely both together (e.g., Quemada and Cabrera, 1995; Shi and Marschner, 2014), which is needed to understand the interactions between decomposition and N dynamics in soil.

Thus, the primary objective of the present study was to quantify, in an agricultural context, the effect of mixing crop residues (leaf and stem) left at the soil surface on their decomposition (C mineralization) and the associated soil N dynamics. We had the aim of exploring a wide variety of quality of mixtures in order to be better able to generalize the results for arable crops. To do so, we used crop residues (leaves, stems and mixtures of leaves and stems) obtained from 25 different crop species grown in field, from five botanical families, mainly Fabaceae and Poaceae, and incubated them under controlled conditions. We tested the proposed hypothesis from Harguindeguy et al. (2008) that the effects of mixing crop residues will depend on both the average chemical quality of mixtures, and of the heterogeneity of the components of these mixtures and that these factors would affect C and N dynamics differently.

2. Materials and methods

2.1. Collection of plant material

Twenty-five representative species of plants (main crops or cover crops) of agricultural systems in Brazil were studied (Table 1). The plants selected included eleven Fabaceae (legumes), ten Poaceae (Gramineae), two Brassicaceae, one Euphorbiaceae and one Asteraceae. The plants were cultivated during the spring/summer (14 species) and autumn/winter (11 species) in a Typic Hapludalf soil under a no-till system in the experimental area of the Soil Department (29°41′ S, 53°48′ W; approximately 90 m elevation) of the Federal University of Santa Maria in the state of Rio Grande do Sul, Brazil. The region has a subtropical climate with a mean annual precipitation of 1686 mm and a mean air temperature of 19.3 °C. For the previous 12 years, the experimental site had been cultivated using a no-till system. All the crops were managed according to the technical recommendations for the area. Plant shoots with 3 field replicates were collected at flowering and harvest for species of cover crops and main crops, respectively. The leaves senescing

Table 1
Description, agricultural use of crops used and proportion of their leaves and stems determined in field (% total of DM).

Latin name	English name	Family	Plant use	% Leaves[a]	% Stems	REF[b]
Phaseolus vulgaris	Bean	Fabaceae	Main crop	43 ± 3.1	57 ± 3.7	1
Glycine max	Soybean	Fabaceae	Main crop	38 ± 3.2	62 ± 2.1	2
Zea mays	Maize	Poaceae	Main crop	26 ± 3.6	74 ± 3.9	3
Helianthus annuus	Sunflower	Asteraceae	Main crop	39 ± 4.2	61 ± 5.1	4
Crotalaria juncea	Sunn hemp	Fabaceae	Cover crop	19 ± 2.3	81 ± 4.6	5
Canavalia ensiformis	Jack bean	Fabaceae	Cover crop	72 ± 4.9	28 ± 3.8	6
Stizolobium niveum	Gray mucuna	Fabaceae	Cover crop	42 ± 3.6	58 ± 2.9	7
Pennisetum glaucum	Millet	Poaceae	Cover crop	32 ± 4.1	68 ± 2.5	8
Sorghum bicolor	Sorghum	Poaceae	Main crop	55 ± 3.5	45 ± 4.3	9
Crotalaria spectabilis	Showy rattlebox	Fabaceae	Cover crop	30 ± 3.1	70 ± 3.1	10
Avena strigosa	Black oat	Poaceae	Cover crop	48 ± 2.0	52 ± 2.7	11
Vicia sativa	Vetch	Fabaceae	Cover crop	62 ± 1.8	38 ± 3.5	12
Triticum aestivum	Wheat	Poaceae	Main crop	42 ± 4.1	58 ± 3.3	13
Raphanus sativus oleiferus	Oilseed radish	Brassicaceae	Cover crop	38 ± 2.2	62 ± 3.3	14
Secale cereale	Rye	Poaceae	Main crop	29 ± 3.1	71 ± 4.2	15
Pisum arvensis	Pea	Fabaceae	Cover crop	68 ± 2.4	32 ± 2.4	16
Triticosecale rimpaui	Triticale	Poaceae	Main crop	44 ± 2.8	56 ± 3.9	17
Brassica napus oleifera	Oilseed rape	Brassicaceae	Main crop	28 ± 3.6	72 ± 2.8	18
Hordeum vulgare	Barley	Poaceae	Main crop	50 ± 3.3	50 ± 2.0	19
Lolium multiflorum	Ryegrass	Poaceae	Cover crop	37 ± 3.2	63 ± 2.9	20
Ricinus communis	Castor bean	Euphorbiaceae	Main crop	52 ± 5.1	48 ± 4.4	21
Cajanus cajan	Dwarf pigeonpea	Fabaceae	Cover crop	34 ± 3.2	66 ± 3.7	22
Lupinus angustifolius	Blue lupine	Fabaceae	Cover crop	57 ± 2.7	43 ± 4.3	23
Lupinus albescens	Native lupine	Fabaceae	Cover crop	51 ± 3.7	49 ± 4.1	24
Oryza sativa	Rice	Poaceae	Main crop	50 ± 2.9	50 ± 3.4	25

[a] Proportion of leaves and stems in the total dry matter (DM) of shoots determined at flowering for cover crops and harvest for main crops. Means ($n = 3$) ± standard deviation (S.D.).

[b] Reference.