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Decomposition of mulched versus incorporated crop residues: Modelling with PASTIS clarifies interactions between residue quality and location

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Abstract

Crop residue management has been shown to significantly affect the decomposition process of plant debris in soil. In previous studies examining this influence, the extrapolation of laboratory data of carbon and/or nitrogen mineralization to field conditions was often limited by a number of interactions that could not be taken into account by a mere experimental approach. Therefore, we demonstrated the interactive effect between crop residue location in soil (mulch vs. incorporation) and its biochemical and physical quality, in repacked soil columns under artificial rain. Decomposition of ^{13}C and ^{15}N labelled rape and rye residues, with associated C and N fluxes, was analysed using the mechanistic model PASTIS, which turned out to be necessary to understand the interacting factors on the C and N fluxes. The influence of soil and residue water content on decomposition and nitrification was evaluated by the moisture limitation factor of PASTIS. This factor strongly depended on residue location and to a smaller extent on physical residue properties, resulting in a lower decomposition rate of about 35% for surface placed compared to incorporated residues. Irrespective of its placement, the biochemical residue quality (e.g. N availability for decomposition, amount of soluble compounds and lignin) was responsible for a faster and more advanced decomposition of about 15% in favour of rye compared to rape, suggesting only a limited interaction between residue quality and its location. Net N mineralization after nine weeks was larger for rye than for rape, equivalent to 59 and 10 kg NO_3^-–N ha^{-1} with incorporation, and 71 and 34 kg NO_3^-–N ha^{-1} with mulch, respectively. This net N mineralization in soil resulted from the interaction between soil water content, depending on residue placement, and N availability, which was determined by the biochemical residue quality. Moisture limitation appeared more important than N limitation in the decomposition of mulched residues. Modelling of gross N mineralization and immobilization also revealed that leaving crop residues at the soil surface may increase the risk of nitrate leaching compared to residue incorporation, if (i) soil water content under mulch is larger than with residue incorporation (more gross N mineralization), and (ii) availability to the applied C-source is limited (less gross N immobilization). Scenario analyses with PASTIS confirmed the importance of moisture conditions on the decomposition of mulched residues and the small interaction between biochemical crop residue quality and its location in soil.
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Keywords: Crop residue decomposition; Water dynamics; Carbon and nitrogen mineralization; Modelling

1. Introduction

Crop residue management in agricultural soils has received much attention to control soil erosion and in carbon sequestration studies (e.g. Blevins and Frye, 1993; Guérif et al., 2001). Adapted tillage practices also determine the initial location and distribution of crop residues in soil that, in turn, act directly on soil physical

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properties such as soil water characteristics and structural properties (Franzluebbers, 2002). In addition, crop residue location and/or distribution pre-determines gradients in the organic matter content of the soil, in the decomposing microbial biomass and their activity (Dominy and Haynes, 2002). At a small scale, i.e. at the soil/residue interface and the detritusphere, the presence of residue particles leads to strong gradients of residue-derived C, residue- and soil-N, microbial biomass and enzymatic activities (Gaillard et al., 1999). The characteristics and size of the so-called detritusphere have been shown to be influenced by the biochemical quality of the decomposing residues and by the nature and intensity of water fluxes (Gaillard et al., 2003; Poll et al., 2006). Limited availability of mineral N to the decomposer communities has been assumed to be the main reason for the slower decomposition of crop residues with limited contact with the soil. The combined effect of: (i) distance from soil (either due to residue particle size or distribution) and (ii) low residue N content (e.g. Angers and Recous, 1997; Magid et al., 2006) accounts for this. At a larger scale, e.g. in the field, the combined effect of limited soil-residue contact and N limitation generally results in a slower decomposition rate for mulched than for incorporated residues (e.g. Douglas et al., 1980). However, the effect of residue location on decomposition interacts with residue quality and soil water dynamics (Schomberg et al., 1994). Those interactions should be taken into account when translating laboratory results to field conditions and require the use of models allowing this.

In a modelled soil profile subjected to water infiltration due to artificial rain, we previously investigated the interaction between water dynamics and biological processes (C and N biotransformation) as a result of the initial location of rape residues. We showed the major impact of water dynamics both on mulch residue decomposition and on the distribution and fate of residue-C and soil- and residue-N in a soil column (Coppens et al., 2006a, b), confirming the earlier conclusions of Schomberg et al. (1994). In order to account for the earlier mentioned interactions, the model PASTIS (Garnier et al., 2003; Findeling et al., 2007) was developed and parameterized to simulate water, carbon and nitrogen fluxes in soil with incorporated and mulched residues. The submodel 'mulch' adopts the concept of two stacked mulch layers, where only the layer in contact with the soil is subject to decomposition (Thorburn et al., 2001; Berkenkamp et al., 2002).

The main aim of this work was to examine the interactions between crop residue quality and residue placement on C and N fluxes in soil and, more in particular: (i) the effect of residue location and quality on water transport and subsequent decomposition due to redistribution of C and N in soil, and (ii) the interaction between residue placement and soil water dynamics on mineralization–immobilization of N and net N availability. Key in this paper is that modelling allows calculation of cumulative carbon mineralization, gross fluxes of nitrogen mineralization and nitrate transport in soil—processes that otherwise are not accessible with our experimental set-up. In addition, scenario analyses were performed to confirm the importance of water availability in the decomposition process of mulched residues and to further explore the interaction with crop residue quality.

2. Materials and methods

2.1. Experimental set-up

The soil used in this study was sampled from the experimental site of INRA, Mons-en-Chaussée, Northern France (Orthic Luvisol). Selected soil parameters are given in Table 1. We sampled the 0–25 cm soil layer, sieved it at field moisture content to pass 2 mm and stored the fine earth in plastic bags at 4 °C prior to use. The soil was pre-incubated for two weeks at 20 °C before the start of the experiment. The initial microbial biomass C was determined by a modified fumigation–extraction method proposed by Vance et al. (1987).

The fresh organic matter added to the soil was mature oilseed rape (*Brassica napus* L., referred to as RAPE) and young rye (*Secale cereale*, referred to as RYE), both labelled ^{13}C and ^{15}N. The oilseed rape residue consisted of a mixture of leaves (25%), stalks (41%), branches (8%) and pods (26%). For the rye residue, only the green leaves were used. Both residues were chopped at 1 cm before application to the soil. The C content and C:N ratio of the residues and the biochemical composition determined by proximate analysis (Van Soest, 1963) are given in Table 2. Residue properties are described in more detail by Coppens et al. (2006b) and Findeling et al. (2007).

Plastic cylinders (PVC, 15.4 cm inner diameter, 30 cm high) with perforated bases were used to contain 25 cm of soil compacted at 1.3 g cm^{-3}. Oilseed rape or rye residues were applied at the soil surface (referred to as SURF) or homogeneously mixed in the 0–10 cm soil layer before compaction (referred to as INC) at a rate of 13.8 g dry matter per column, equivalent to a return of 7.4 t ha^{-1}. Control columns without addition of fresh organic matter (referred to as CTRL) were prepared. At the start of a nine-week incubation period, rain with an intensity of 12 mm h^{-1} was applied with a rainfall simulator on all of

Table 1
Selected characteristics of the soil from Mons-en-Chaussée, France

Parameter	
Clay (%)	13.4
Silt (%)	81.6
Sand (%)	5.0
pH (in H_2O)	8.2
Total C content (%)	0.85
Total N content (%)	0.09
C:N ratio	9.5
Microbial biomass-C (mg C kg^{-1} soil)	128.3
Humified organic matter (mg C kg^{-1} soil)	8372.0
Soluble organic matter (mg C kg^{-1} soil)	31.2

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