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Litter quality drives nitrogen release, and agricultural management (organic vs. conventional) drives carbon loss during litter decomposition in agro-ecosystems

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ABSTRACT

Litter decomposition and nutrient mineralization are crucial in agricultural systems to maintain soil fertility and plant growth. Given that these processes are governed by soil microbial activity, agricultural management that affects soil microbial communities may significantly alter rates of decomposition and N release of the same litter. We hypothesized that organic compared to conventional management enhances litter decomposition and litter N release, and that this effect is stronger for litter of low quality (high C:N ratio).

We tested these hypotheses using litter from 4 maize cultivars with varying initial litter quality (different C:N ratios and lignocellulose index). These litters were left to decompose in soil with different management history, yet in the same experimental field site. The field experiment consisted of randomized plots with 11 years of organic or conventional agricultural management (organic vs. mineral fertilization). During the 11 years, in year 3 and 4, two specific organic amendments were applied as soil health treatments (SHT: chitin or compost, and a control without SHT). The maize litter was contained in litter bags, buried in the top 10–15 cm soil and collected after 1, 2 and 3 months. We quantified the litter carbon (C) and nitrogen (N) loss, and soil dissolved organic carbon (DOC), mineral and dissolved organic nitrogen (DON) at each sampling time. We also determined the fungal biomass in the decomposing litter after 3 months of decomposition.

Litter C loss was higher in soil under organic compared to conventional management, irrespective of litter quality. In contrast, the rate of N release from the litter was determined by initial litter quality (higher N release from low C:N litter) and not by agricultural management. In soil under organic management the concentrations of DOC, mineral N and DON were larger than in conventional managed soil, which may have stimulated microbial activity and therefore, litter decomposition. Fungal biomass in the decomposing litter negatively correlated with the amount of N in the decomposing litter, but was not affected by management system or litter cultivar.

Overall, we found that in agroecosystems initial litter quality (C:N) is a main driver of litter N release, whereas soil management is a main driver of decomposing litter C loss. Our results show the importance of integrating both litter quality and soil management to enhance our understanding of litter decomposition and N release, and to harness the ecosystem services provided by crop litter in agricultural fields.

1. Introduction

In agro-ecosystems crop and soil management are pivotal for sustainable food production. In order to maintain soil fertility, it is important to return organic matter to the soil, either via soil organic fertilization or by incorporation of crop residues. It is well known that both organic fertilization and crop residue addition to soils has favourable effects on soil properties such as maintaining soil organic matter (SOM), control erosion and improving soil water regulation (Wilhelm et al., 2004; Lal, 2008; Diacono and Montemurro, 2010). There is a wealth of literature on the effects of litter quality on the decomposition process (Aulakh et al., 1991; Seneviratne, 2000; Bray et al., 2012; Wickings et al., 2012; Hobbie, 2015). Generally, these studies show that high litter quality (low C:N, low lignin:N) increases

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litter decomposition rate (Berg and McClaugherty, 2008). However, these studies focus on differences between plant species whereas litter quality effects within species (i.e. between cultivars) received much less attention. Since choosing a different cultivar is often a more realistic option for a farmer than choosing a different crop or mixing crops, it is important to investigate whether differences in crop cultivar litter quality have quantitatively important effects on the carbon (C) and nitrogen (N) dynamics in soil. Furthermore, apart from the litter quality also the soil environment and thus, agricultural soil management can be an important modifier of litter decomposition and mineralization. With this research we assess the main and possible interactive effects between agricultural soil management (conventional versus organic) and crop cultivar litter quality on the litter decomposition process and litter N release over time.

The main drivers of litter decomposition are the litter quality, the size and composition of the decomposer community, and the physical-chemical environment in which the litter decomposes (Swift et al., 1979). Therefore, it can be expected that the impact of agricultural management on abiotic and biotic soil properties may interact with the effect of litter quality on the decomposition process. For instance, it has been shown that organic management increases soil organic carbon (SOC) stocks (Gattinger et al., 2012) and enhances soil microbial biomass and activity compared to conventional management (Lori et al., 2017; Martínez-García et al., 2018). Consequently, these changes may feedback to enhanced decomposition of fresh litter in organic managed soil. Simultaneously, changes in the microbial community composition and functionality may facilitate decomposition of low quality litter (high litter C:N ratio and lignin). For instance, promoting practices that improve soil health such as the addition of soil organic amendments or decreasing tillage, enhances the abundance of saprotrophic fungi, thus, changing microbial functionality compared to conventional management (Gleń-Karolczyk et al., 2018; Martínez-García et al., 2018; Clocchiatti et al., 2020). Since fungi need relatively less N for their growth than bacteria (fungi have higher C:N ratio than bacteria) (Hodge et al., 2000), a saprotrophic community dominated by fungi may decompose recalcitrant litter (lower quality litter; low N content) faster.

Organic soil amendments are not only applied to enhance soil fertility by improving C and N cycling, but also to control soil-borne plant diseases. Especially under organic agriculture, other organic amendments than crop residues are often applied based on their envisaged disease-suppressive effects (such us chitin and compost; Korthals et al., 2014). The effects that these organic amendments have on soil properties may also affect the decomposition rate of crop residues differing in litter quality (Barel et al., 2019). Thus, different types of organic amendments may distinctly influence the overall microbial community composition and function and their effect may last for several years after their addition (Lupatini et al., 2017; Martínez-García et al., 2018; Barel et al., 2019). However, the effect of the organic amendments on microbial soil processes is expected to decrease with time since the amendment addition. In our previous research (Martínez-García et al., 2018), we observed that after 6 years of the addition of several types of organic amendments, there was a higher fungal:bacterial ratio in soil from plots that received chitin compared to soil from plots that received compost, however, there was not a legacy effect on the soil microbial respiration and catabolic profile. It is important to know the extent of the effect of the soil amendments on soil processes to optimize their use.

The quality of the litter added to the agricultural soil is crucial for the process of decomposition and N mineralization (Hättenschwiler et al., 2005; Parton et al., 2007) and will eventually determine the amount of N available for crop growth over time. Thus, litter with high N concentration and low lignin is usually associated with faster litter decomposition, especially at early stages of decomposition (Cornwell et al., 2008; Hobbie, 2015). Simultaneously, N concentration will determine the balance between litter N release and immobilization in the litter microbial biomass (Parton et al., 2007; Hobbie, 2015). Under farming conditions most of the studies comparing decomposition of different litter quality have focused on changes in inter-specific traits (Bray et al., 2012; Wickings et al., 2012; García-Palacios et al., 2016; Barel et al., 2019). Only recently, two studies have addressed intraspecific differences, i.e. among crop cultivars (Ruhland et al., 2018; Liu et al., 2019). These studies found that cultivars with high litter quality (low C:N, lignin:N and/or higher concentration of labile C groups) had higher decomposition rate. These decomposability litter traits were also linked to higher litter capacity for SOC sequestration when incorporated in the soil (Liu et al., 2019). These studies already highlight the importance of crop cultivar selection to increase C and N mineralization from crop residues in agricultural fields. However, these studies focussed on decomposition and did not report on the release of N, neither did these studies tested the potential role of different agricultural management in the decomposition of the litter of different cultivars.

The C and the N release from decomposing litter are essential for biological soil processes. Especially, in agroecosystems, maximizing N release from crop residues can be used as a tool to decrease the use of N applied through fertilizers. In general, N release and immobilization is controlled by initial litter N concentration (Parton et al., 2007) and the decomposer community can alter respiration patterns during low quality litter decomposition (Manzoni et al., 2008). However, at a local agro-ecosystem scale, other factors such as soil N availability, may contribute to the amount of litter N release. For instance, higher levels of mineral N availability caused by fertilization can increase microbial activity and, thus, N release and mineralization (Berg and McClaugherty, 2008). Therefore, to fully understand local variation of the decomposition process it is necessary to consider local-scale parameters, such as soil nutrient availability, that are usually not included in litter decomposition studies (Bradford et al., 2015).

With our field experiment, we tested the possible interactive effect between intraspecific variation in litter quality, management system (conventional vs. organic) and the legacy effect of two organic amendments applied 7 years before the current experiment as soil health treatments (SHT: chitin or compost, and a control without SHT) on the initial plant litter decomposition process and litter N release. We know from our previous field study conducted 7 months before this experiment started in the same experimental plots, that long term organic management increased fungal and bacterial biomass, as well as microbial catabolic activity compared to conventional plots (Martínez-García et al., 2018). Our current experiment complements the results of our previous research by testing *in situ* the litter decomposition process. We used litter from several maize cultivars, which were grown simultaneously under the same environmental conditions, to study the effects of within-species variation on the litter decomposition and N release dynamics over the first three months of the decomposition in spring.

We specifically hypothesized that organic management compared to conventional accelerates litter C loss and litter N release (N loss), and that this effect is stronger for low quality litter (high C:N ratio and lignin content).

2. Material and methods

2.1. Study site and design

This study was conducted during the spring of 2016 at Vredepeel long-term experimental farm (The Netherlands: N-51°32′ 24.958'', E−5° 51′13826''). The soil texture is 1.1% clay, 3.7% silt and 94.9% fine sand, the mean annual temperature is 10.2 °C and the mean annual precipitation is 766 mm (Korthals et al., 2014). Several soil parameters were measured in September 2015 showing that the amount of SOM is 3.85%, total C is 1.95%, total N is 0.90% and pH is 6.35 (more details can be found in Martínez-García et al., 2018). Since 2005, different agricultural practices have been applied using a split-plot randomized block design with four levels of replication (Fig. S1). A complete description of the experimental set up is described in Martínez-García et al. (2018). This experiment was conducted in plots under conventional or organic agricultural management that received chitin or compost amendments twice, in 2007 and 2009, as soil health treatments to suppress plant-parasitic nematodes and soil-borne fungi (Korthals et al., 2014). Control plots (without the addition of a SHT) were also included. The chitin added originated from shrimp debris, and the compost consisted of 65% wood, 10% leaves, and 25% grass. The amount of organic matter added with the chitin amendment was double than with the compost amendment (14 kg/ha vs. 7 kg/ha respectively), and the amount of N was 7.6 times more with the chitin than with the compost amendment (1300 kg/ha vs. 175 kg/ha) (more details can be found in Korthals et al., 2014). Plots were randomly arranged in 4 blocks to account for spatial variability. Therefore, the total number of studied plots was 24.

Conventional and organic management differed with respect to the fertilization and the weed management. While conventional managed plots received mineral N-based fertilizers and pig slurry, organic managed plots received pig manure and pig slurry (more detailed information in Martínez-García et al. (2018); Table A1). Despite the differences in fertilization types, there are no significant differences on the amount of SOM, total C or total N (see Martínez-García et al., 2018). Growth of weeds was controlled by using glyphosate (Round-Up) in the conventional treatment and physically by harrowing the first 5 cm of soil in the organic treatment. In the year of the experiment, the litterbags were placed in the soil after the weed management to avoid them to be damaged by the harrowing or affected by the herbicide.

Several crops have been grown since 2006 (potatoes, lily, carrot, maize, peas and wheat) in between these ones, *Secale cereale* was grown as cover crop. More details regarding crop rotation and yield can be found in Martínez-García et al., 2018 (Table A2).

Using this design, a litter decomposition experiment was carried out in the field to assess the decomposition of litter from 4 maize cultivars of contrasting litter quality, using C:N ratio and lignocellulose index as proxies for litter quality (Taylor et al., 1989; Talbot and Treseder, 2011).

2.2. Selection of the maize cultivars

In September 2015, green leaves from 42 cultivars of maize (*Zea mais*) variety Coryphee where collected from an experimental farm in Meterik (The Netherlands: N 51°, 27′ 26.803″, E 6°,1′,19.918″), dried at 60 °C during three days and grinded to calculate total C and N content using a CN Element Analyzer (LECO TRUSPEC CN, CEBAS-CSIC, Spain). The C:N ratio of the 42 cultivars ranged from 24 to 39 (Fig. S2a). From the 42 maize cultivars, we selected 12 cultivars that were representative of the entire range of green leaves C:N ratio (Fig. S2a). In October 2015, natural senesced leaves still attached to the plant and without symptoms of fungal growth were collected from these cultivars. Total C and N were calculated using the same method. The C:N of the senesced leaves ranged from 18 to 29 (Fig. S2 b). Eventually, 4 cultivars (Ctv1 to Ctv4) that were representative of the senesced leaf litter C:N range were selected (Fig. S2b) and cellulose and lignin were assessed by the method of Van Soest et al. (1991). Several chemical parameters were used to determine the quality of the initial naturally senesced litter (Table 1). C:N and lignocellulose index (LCI = lignin/lignin + cellulose) were used as proxy for litter quality (Taylor et al., 1989; Talbot and Treseder, 2011). Dried litter from the 4 selected cultivars was cut in 2 cm^2 pieces and used to fill 72 litterbags (10 cm^2) made from polyester fabric (mesh size < 0.05 mm) and closed with stainless steel staples. Each litterbag contained 4 g of dried litter.

2.3. Litter decomposition experiment

In April 2016, two weeks after wheat (*Triticum aestivum*) was sown, three litterbags from each litter quality were buried in each plot. Litterbags were buried vertically at a depth between 10 and 15 cm, in between wheat rows and separated 20 cm from each other. After 27, 59 and 89 days (Time 1, Time 2 and Time 3 respectively) one litterbag from each cultivar was collected from each plot, freeze-dried and cleaned from ingrown roots. Litter and ingrown roots were weighted separately, and litter was ground using a ball-mill. Each sample was separated into two subsamples, one for chemical analysis and the other one for microbial analysis. Total N and C of decomposing litter was calculated by sample combustion and gas-chromatography using a CN Element Analyzer (LECO TRUSPEC CN, CEBAS-CSIC, Spain).

Fungal biomass in the litter was determined based on ergosterol biomass. Ergosterol extraction was performed as in Gonçalves et al. (2013). In brief: 0.5 g of freeze-dried litter sample were suspended in 2 ml of methanol and subsequently treated with 0.5 ml of 2 M aqueous sodium hydroxide, heated in a microwave oven (1 min; 2450 MHz and 750 W), and the ergosterol was extracted with pentane (ca. 6 ml). The pentane was evaporated in a sand bath at 55 °C, and the ergosterol was re-dissolved in 1 ml of methanol. High performance liquid chromatography (HPLC) was used to quantify ergosterol concentration using a Merck LiChroCART 250–4 (LiChrospher 100). The conversion factor of 5.5 mg ergosterol mg^{-1} fungal dry mass (Gessner and Chauvet, 1993) was used to estimate fungal biomass. PLFA analysis was initially considered as method to quantify the microbial community in the litter more broadly, however interference of plant PLFAs from the litter with those of the fungae precluded this option. Nevertheless, PLFA analysis of the soil microbial communities was performed on soils collected 7 months before the litter decomposition experiment started, and this data provided insights into management effects on the soil microbial community in relation to the management (Martínez-García et al., 2018).

2.4. Soil samples and soil parameters

At every litterbag sampling time, 9 soil samples were collected from each plot, 20 cm next to the location where the litterbags were placed. Soil was collected using a soil auger of 2 cm diameter and soil was sampled from the top 0–15 cm. Soil samples from the same plot were pooled together. The pooled samples were sieved over 2 mm and air-dried at 40 °C for two days. The dried soil was used to quantify dissolved organic carbon (DOC), total dissolved organic nitrogen (DON) and dissolved mineral nitrogen (N–NH_4, N–NO_3, N–NO_2). DOC, total dissolved N and mineral N were obtained via a 1:10 soil to $CaCl_2$ (0.01 M) extraction of 3 g of dried soil (Houba et al., 2000). The extractions were equilibrated by horizontally shaking for 2 h and centrifuging at 1800 g (3000rp) during 10 min. The supernatant was filtered through a 0.45 μm cellulose acetate membrane filter and a subsample of the extraction was used for the measurements. Dissolved mineral N, total dissolved N and DOC were measured on a segmented flow analyzer SKALAR San++ system SFA (Skalar Analytical B.V., Breda, The Netherlands). Dissolved organic nitrogen was measured as the difference between total dissolved N and mineral N.

Table 1
Litter quality parameters of the 4 maize cultivars at Time 0. C: Carbon, N: Nitrogen, LCI: Lignocellulose Index = lignin/lignin + cellulose.

Maize Cultivar	C (%)	N (%)	C/N	Lignin (%)	Lignin/N	Cellulose (%)	N/Cellulose	LCI
Ctv 1	41.79	2.12	19.71	4.18	1.97	33.52	0.063	0.111
Ctv 2	42.03	1.78	23.61	5.71	3.21	35.65	0.050	0.138
Ctv 3	42.65	1.64	26.01	4.81	2.93	35.73	0.046	0.119
Ctv 4	42.14	1.41	29.89	5.7	4.04	36.26	0.039	0.136

2.5. Data analysis

We tested the effect of agricultural management (conventional or organic), the legacy effect of the SHT (chitin, compost or control), and the effect of the 4 maize cultivars with contrasting litter chemistry on the percentage of litter C and N loss and on litter C:N ratio after 1, 2 and 3 months of decomposition, and on fungal biomass in litter after 3 months of decomposition.

Percentage of litter C and N loss were calculated using the initial and final litter mass and the respective C and N concentration;

$$\text{Litter C loss (\%)} = 100*[(Ci*Mi)\text{-}(Cf*Mf)]/(Ci*Mi) \qquad [1]$$

$$\text{Litter N loss (\%)} = 100*[(Ni*Mi)\text{-}(Nf*Mf)]/(Ni*Mi) \qquad [2]$$

where *Ci* and *Ni*; and C*f* and *Nf* are initial and final C or N concentration respectively; and *Mi* and *Mf* are initial and final litter biomass inside the litterbag (Handa et al., 2014). These parameters were calculated after 1, 2 and 3 months of decomposition. Linear mixed-effect (LME) models were used to assess at each sampling time the effects of agricultural management, legacy of the SHT, cultivar, and their interactions, on the percentage of C and N loss, and litter C:N. Block and root weight were included as random factors to account for the spatial variability and the potential effect of roots in the litterbag. The effect of the treatments on fungal biomass in the decomposing litter was assessed at Time 3. Similarly, changes of soil chemical properties (DOC, mineral N and DON) with treatments over time and their interactions were also tested using LME and including Block as a random factor.

All LME models were run using the R package "lme 4". Normality and homogeneity of model residuals was checked following Zuur et al. (2010) protocol. When the residuals where not normally distributed the variables were transformed using the inverse transformation or log transformation. For significant treatment effects the significance of pairwise comparisons were tested using a posthoc Tukey test with "multcomp" package (Hothorn et al., 2008).

The relationship between litter quality (total C and N, percentage of C and N loss and the C:N ratio of the decomposing litter) and fungal biomass in decomposing litter, and the relationship between litter quality and dry root biomass inside the litterbags after 3 months of decomposition, were tested with Spearman's rank correlation, using the "rcor" function in the "Hmisc" R package.

3. Results

3.1. Effect of agricultural management and litter quality on the litter C loss, N loss and fungal biomass

Organic agricultural management increased litter C loss after two and three months of decomposition, however, it did not have an effect on the N release from the decomposing litter (Table 2; Fig. 1a and b). Maize cultivar was the main factor explaining litter N release across the duration of the experiment (Table 2, Fig. 1b). As expected, cultivar 1 (that had lowest C:N ratio at the start), had the highest N loss (Table 2, Fig. 1b). Cultivar 3 had lower C loss than the other cultivars after two months of decomposition, but no other differences were observed in C loss for the other cultivars (Fig. 1a). The C:N ratio of the decomposing litter decreased with time. Litter C:N decreased faster over time when the litter was decomposing in soil subjected to organic management compared to in soil under conventional management (Table 2, Fig. 1c). As from Time 0 across all subsequent sampling times the C:N ratio of the decomposing litter of cultivars 1 and 2 was always significantly lower than the C:N ratio of cultivars 3 and 4 (Fig. 1c). Contrary to our expectation, we did not find an interactive effect between cultivar (litter quality) and management on the C and N loss of the litter (Table 2). Overall, the percentage of litter N loss was higher after one month of decomposition than after two months and increased again after three months (Fig. 1b).

After 3 months of decomposition (Time 3) fungal biomass growing in decomposing litter was not affected by the management (conventional vs. organic and SHT) or the litter cultivar (Table 2). However, fungal biomass increased in decomposing litter with lower total N and higher C:N ratio (Fig. 2; Table 3). Also, at Time 3, total N in decomposing litter, C and N loss percentages were positively correlated with root weight (Table 3).

Table 2
Impact of agricultural management (Agr; conventional and organic), soil health treatment (SHT; chitin, compost and control), cultivar (Ctv: Ctv 1 to Ctv 4) and their interactions on C and N loss, litter C:N ratio, and fungal biomass (Ergosterol, at Time 3) in litter after 1, 2 and 3 months of decomposition (Time 1, 2 and 3). d.f. indicates degrees of freedom and bold p-values indicate significant effects.

		C Loss		N Loss		C:N ratio		Ergosterol	
	d.f	F	p-value	F	p-value	F	p-value	F	p-value
Time 1									
Agr	1	1.55	0.216	3.53	0.064	1.46	0.231		
SHT	2	0.62	0.541	0.16	0.849	1.33	0.270		
Ctv	3	1.03	0.382	6.99	**0.001**	9.57	**0.001**		
Agr:SHT	2	0.19	0.823	1.88	0.161	2.95	0.059		
Agr:Ctv	3	0.36	0.785	1.01	0.395	1.27	0.290		
SHT:Ctv	6	1.31	0.264	1.04	0.406	0.93	0.479		
Agr*SHT* Ctv	6	0.99	0.440	1.17	0.332	0.97	0.451		
Time 2									
Agr	1	7.67	**0.007**	1.34	0.252	6.30	0.014		
SHT	2	0.61	0.548	1.61	0.206	0.92	0.403		
Ctv	3	5.65	**0.002**	18.57	**0.000**	19.90	**0.000**		
Agr:SHT	2	2.60	0.082	5.70	**0.005**	2.60	0.082		
Agr:Ctv	3	0.09	0.966	0.38	0.771	0.43	0.729		
SHT:Ctv	6	1.02	0.419	0.58	0.741	0.39	0.882		
Agr*SHT*Ctv	6	0.19	0.979	0.39	0.884	0.37	0.895		
Time 3									
Agr	1	4.65	**0.035**	1.71	0.196	17.70	**0.000**	1.45	0.233
SHT	2	0.24	0.786	2.29	0.110	2.35	0.103	0.22	0.807
Ctv	3	2.04	0.118	28.38	**0.000**	22.99	**0.000**	1.33	0.271
Agr:SHT	2	0.10	0.902	1.01	0.369	1.56	0.218	0.71	0.495
Agr:Ctv	3	2.48	0.070	0.85	0.473	0.48	0.695	1.20	0.317
SHT:Ctv	6	0.64	0.700	0.95	0.463	0.90	0.504	0.91	0.491
Agr*SHT*Ctv	6	0.20	0.974	0.61	0.720	0.95	0.473	0.21	0.972

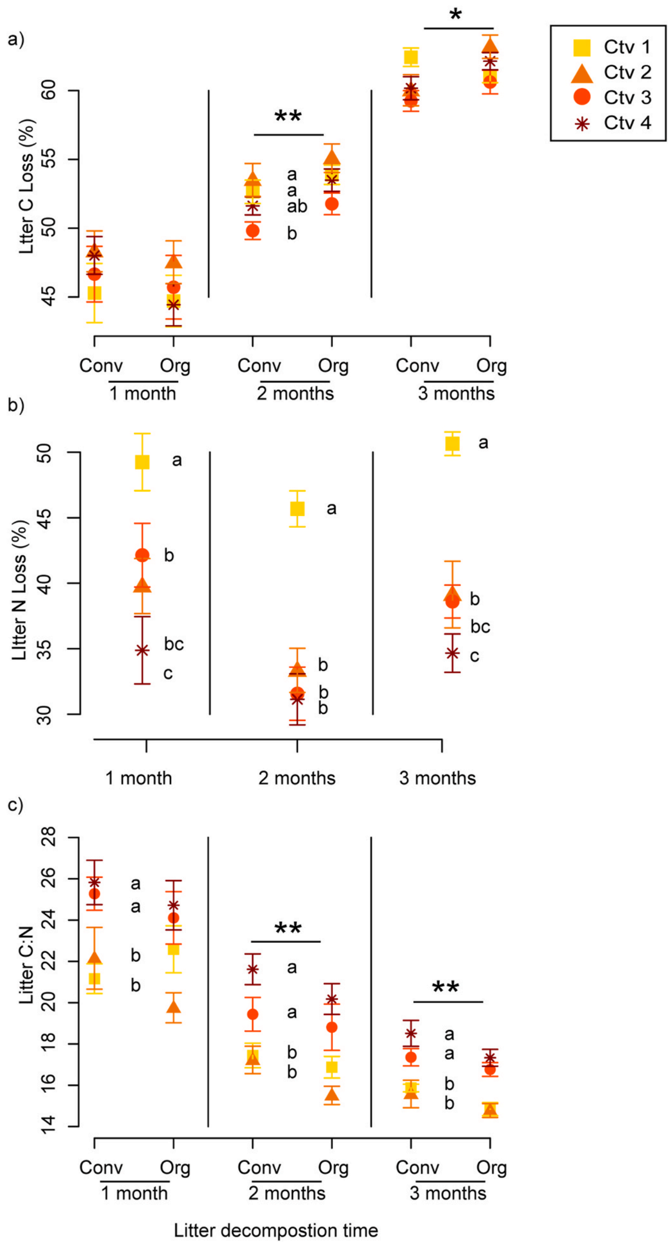

Fig. 1. Litter (a) C and (b) N loss (%) and (c) litter C:N ratio of the different maize cultivars (Ctv 1–4) in plots under conventional (Conv) and organic (Org) management after 1, 2 and 3 months of litter decomposition. Vertical lines separate the results from each LME at each sampling time. Asterisks indicate significant differences among conventional and organic management when LME proved significance of the factor management; * ($P < 0.05$) and ** ($P < 0.01$). Letters indicate significant differences among cultivars when LME proved significance of the factor cultivar ($P < 0.05$) at each sampling time.

3.2. Legacy effect of SHT soil organic amendments

A legacy effect of the SHT on litter decomposition was noticeable after two months of decomposition, but not after 1 or 3 months. After two months of decomposition, plots that had received chitin as SHT showed higher litter C loss under organic compared to conventional management (Tables 2 and 54.7% vs. 51.5% respectively). Contrastingly, plots that received compost as SHT had higher N loss under conventional than under organic management (Table 2, Fig. 3a). After two months of decomposition litter C:N ratio was higher in the treatment combination consisting of conventional+compost than in organic+compost. Litter C:N ratio was not affected by chitin application history (Table 2, Fig. 3b).

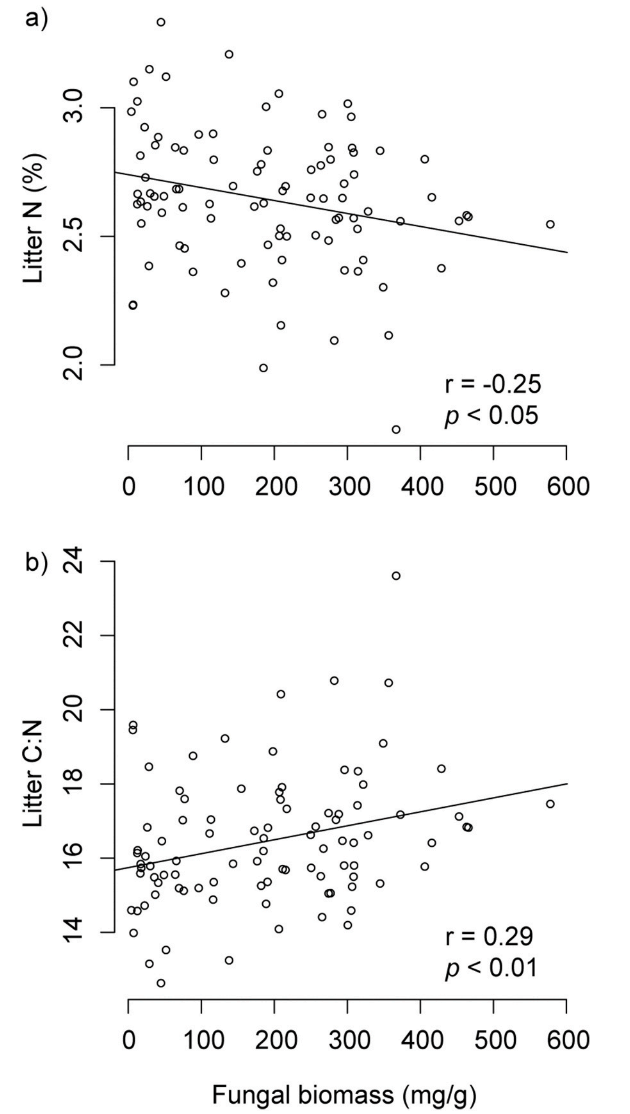

Fig. 2. Spearman's correlations between fungal biomass in decomposing litter and; (a) litter N (%), and (b) litter C:N ratio, after three months of litter decomposition.

Table 3
Spearman's correlation coefficients between litter chemical parameters (Total C and N, C:N, C and N Loss) and fungal and root biomass in litterbags after 3 months of decomposition.

	Spearman's Correlation after 3 months of litter decomposition				
	Total C	Total N	C:N	C Loss	N Loss
Fungal biomass	0.14	−0.25*	0.29**	−0.19	0.01
Root biomass	−0.09	0.51***	−0.52***	0.32**	0.47***

3.3. Soil dissolved organic C and organic and mineral N

In the soil the levels of DOC, mineral N and DON changed over time and responded significantly to agricultural management (Table 4). Soil DOC, mineral N and DON were higher at Time 1 (Fig. 4a,b,c). Organic management enhanced soil DOC concentrations across the experiment (Fig. 4a) and mineral N and DON in Time 2 and 3 (Fig. 4 b,c).

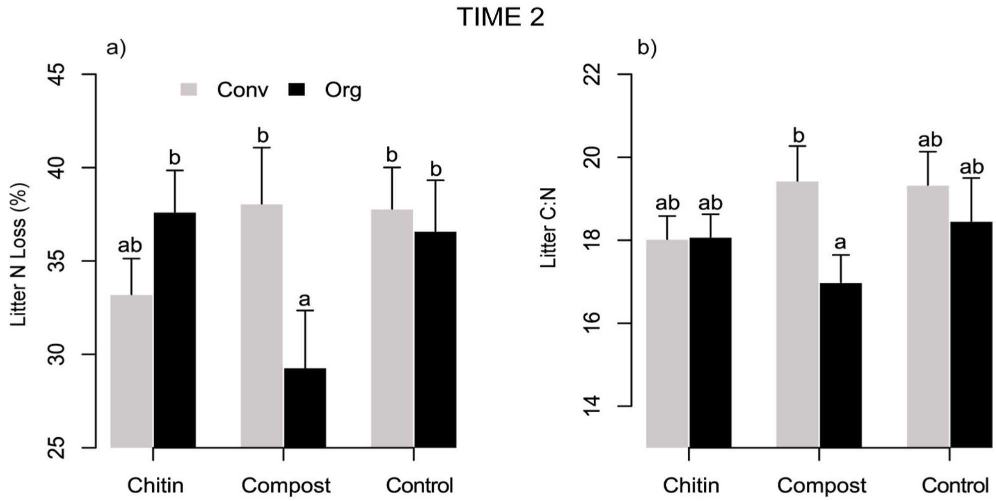

Fig. 3. Legacy effect of the SHT (chitin, compost and control) on average; (a) litter N loss (%) and, (b) litter C:N ratio across all maize cultivars, after two months of litter decomposition. Bars are means + 1 SE. Different letters indicate significant differences ($P < 0.05$).

Table 4
Impact of time (Time 1, 2 and 3), agricultural management (Agr; conventional and organic), soil health treatment (SHT; chitin, compost and control) and their interactions on dissolved organic carbon (DOC), mineral nitrogen (mineral N) and dissolved organic nitrogen (DON) in soil. d.f. indicates degrees of freedom and bold p-values indicate significant effects.

		DOC		Mineral N		DON	
	d.f.	F-value	p-value	F-value	p-value	F-value	p-value
Time	2	**9.93**	**0.0004**	**346.53**	**<.0001**	**16.63**	**<.0001**
Agr	1	**4.85**	**0.041**	**18.72**	**0.0004**	**13.84**	**0.002**
SHT	2	1.02	0.380	1.32	0.291	0.73	0.494
Time:Agr	2	2.25	0.120	6.35	**0.004**	**7.91**	**0.001**
Time:SHT	4	1.08	0.380	1.17	0.339	0.22	0.925
Agr:SHT	2	0.69	0.515	0.68	0.519	0.42	0.659
Time:Agr:SHT	4	1.11	0.368	1.64	0.186	1.30	0.287

4. Discussion

Agricultural management and litter decomposability traits of fresh litter are essential factors to consider for carbon and nutrient management in agroecosystems. With this experiment, we showed that, under the same climatic conditions, agricultural management is the main driver of C loss, whereas litter quality is the main driver of N loss. However, we did not observe an interactive effect of agricultural management and litter quality on the processes of decomposition and N mineralization.

In line with our hypothesis, enhancement of C loss in organic vs. conventional was evident from the second month of decomposition, when litter C loss was over approximately 50% of its initial biomass C. This may explain why shorter studies (for example, 30 days in Diekötter

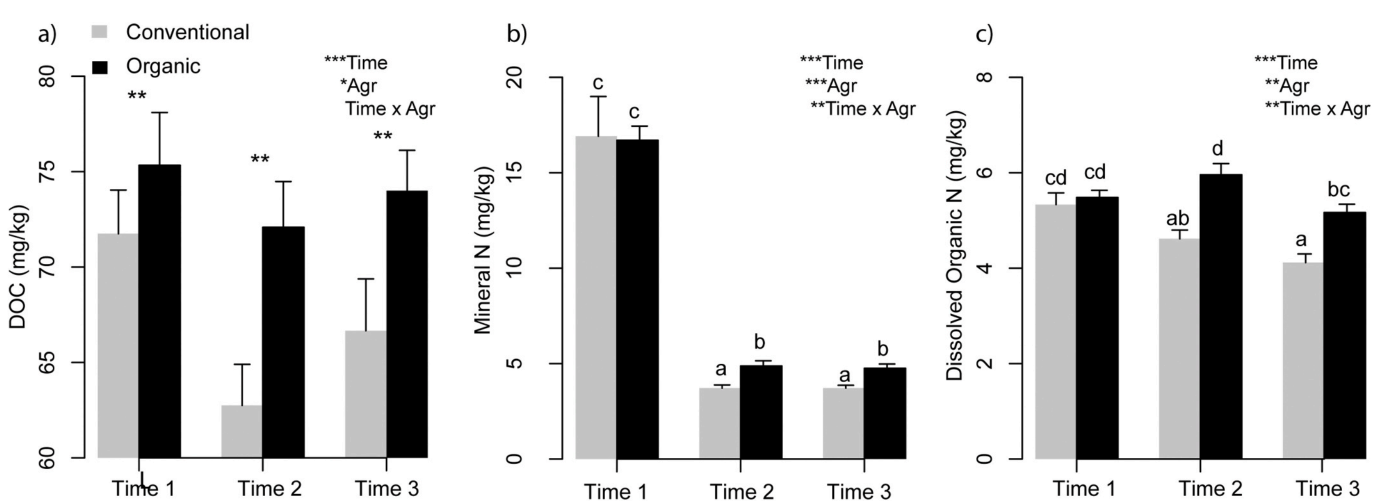

Fig. 4. Soil levels of (a) dissolved organic C, (b) mineral N and (c) dissolved organic N in sampling times 1, 2 and 3, in the organic and conventional systems. Bars are means + 1 SE. Different letters and asterisks indicate significant differences; letters ($P < 0.05$) and ** ($P < 0.01$).

et al. (2010)) that also compared litter decomposition between organic and conventional management did not find significant differences. Our findings agree with Dominguez et al. (2014) who compared litter decomposition between organic and conventional farming, and found faster litter decomposition in soil under organic practice compared to conventional managed soil. We propose that the underlying mechanism of enhanced litter decomposition is the increase in microbial biomass and catabolic activity caused by the long term (11 years) organic fertilization in our field study (Martínez-García et al., 2018). This is in line with the global meta-analysis of Lori et al. (2017) that compares conventional and organic systems and reports that organic farming enhances total microbial abundance and activity in agricultural soils. Data on microbial biomass and catabolic activity were collected in the autumn of 2015, whereas the litter decomposition experiment was carried out during the spring of 2016. Microbial properties in between these two seasons may have slightly changed (Bardgett et al., 1999; Bell et al., 2009), but the effect of the organic management at increasing microbial biomass and activity compared to conventional management should still be present, moreover the effect of the management should be stronger the longer the managements are maintained.

Differences in weed management between organic and conventional systems may have effects on the microbial community composition and functionality. For instance, in organic management mechanical weeding (harrowing the upper 5 cm of soil) will disturb microbial communities and break part of the mycorrhizal fungal mycelium. In contrast, the use of glyphosate in conventional management, will increase soil microbial respiration in the days after application (Nguyen et al., 2016) and being degraded relatively fast (in less than 32 days) by the soil microbes (Araújo et al., 2003; Nguyen et al., 2016). With our experimental design we cannot conclude on the effects of weeding practices on the litter decomposition process. Rather, we study the effect of conventional vs. organic management with the aim to include the diversity of factors that these two management systems involve. Moreover, during the experimental period of litter decomposition there were no differences in management related to soil disturbances, as during this period there was no harrowing or pesticide application.

We had expected that the effect of organic management in enhancing decomposition would be stronger for low quality litter compared to high quality litter. However we did not find interactive effects in the C loss between the starting litter quality and organic or conventional management system. Our initial expectation was based on the possibility that the enhancement of the soil fungal saprotrophic community caused by the organic fertilization, would cause higher fungal colonisation of the litter, which would facilitate the decomposition of more recalcitrant litter (De Boer et al., 2005; de Vries et al., 2006). After 3 months of decomposition our results showed that management did not affect fungal biomass in litter. However, fungal biomass negatively correlated with the quality of the litter after three months of decomposition, being more abundant in more recalcitrant litter (less total N and higher C:N). Contrary to expectations, higher fungal abundance in litter did not cause a speed up of litter decomposition (there was not a significant correlation with C loss). Interestingly, although we did not find higher fungal biomass in litter decomposing in organic plots, we suggest that microbial communities in soil of organically managed plots were generally able to accelerate C loss and were more efficient in terms of N use since litter C:N ratio decreased faster in the organic than in the conventional system, while N losses remained the same in both management systems.

In contrast to litter decomposition, litter quality was the main driver of litter N-release, with higher percentage of N release occurring in litter with higher N content. Previous studies have found similar results using litter of different plant species (Parton et al., 2007) or mixtures of several plant species (Hättenschwiler et al., 2005). In our experiment we focused on *intra*specific differences in litter quality, since this is relevant for agricultural management wherever it is possible to choose cultivars of the same crop species based on desired plant and litter traits. Different litter traits can control the bottom-up effects on soil microbial properties and their mediated ecosystem services (Mulder et al., 2013). Our results show that using cultivars with high-decomposability traits (such as low C/N, low lignin concentration, low lignin/N; Table 1) is beneficial to enhance N release and hence, potentially increase of mineral N availability to the next crop regardless of the agricultural management. Nevertheless, agricultural management did show significant impacts on mineral N availability in soil, being larger in organically managed than in conventional managed soil. This can be attributed to the N mineralised from soil organic matter other than the fresh litter. Our previous research in this experimental field showed that the amount of SOM between conventional and organic plots did not differ significantly (Martínez-García et al., 2018), and therefore, the higher DON in the field may be indicative of higher microbial capacity to mineralize N, either because of its higher abundance, or because of functional complementarity within the microbial community caused by resources preferences among microbial taxa (Hättenschwiler et al., 2011).

Soils with higher levels of carbon and nutrients available for microbes may have faster litter decomposition (Bradford et al., 2014) and N mineralization (Weintraub and Schimel, 2003). We found that soil under organic management had higher levels of DOC, mineral N and DON compared to conventional managed plots, particularly after 2 and 3 months of decomposition, which is in agreement with the higher litter C loss in plots under organic management. The higher microbial nutrient availability in organic plots may have enhanced the microbial growth and activity, accelerating the decomposition process and C and N dynamics.

The SHT did not influence the percentage of C loss from the litter across the experiment after 7 years of the last addition. However, after two months of decomposition, litter N loss in organic+compost plots was lower than in the other treatments, whereas C loss was similar. These results indicate that soil microbes in organic+compost used less N from the decomposing litter to mineralize the same amount of C. Our experimental design cannot test the cause of the temporary difference in microbial capability to mineralize litter in Time 2. We suspect that the underlying cause is the different nutrient requirement of the microbial community in these plots since the amount of nutrients available in soil among SHT was the same. Nevertheless, after 3 months of decomposition, differences in litter N loss converged, and litter N loss and litter C:N were the same among SHT. Therefore, we conclude that after 7 years from the SHT application, there was not a legacy effect on the overall litter decomposition process.

We found roots growing in some of the litterbags after two and three months of decomposition. Roots growing inside the litterbags may stimulate litter decomposition because microorganisms can use the root exudates and increase biomass and activity (Kuzyakov, 2010). Indeed, we found a positive correlation between the amount of roots growing inside the litterbag and the C and N loss percentages. Nevertheless, the effect of roots on litter decomposition did not overrule the effect of management system and litter cultivar on C and N loss, as shown by the LME that include roots as a random factor.

In this experiment we chose to assess the effect of the soil microbial community on the litter decomposition process, since microbes are main drivers of litter decomposition and soil carbon energy flows (Hättenschwiler et al., 2005). Moreover, the mesh size of the litter bags also allowed for micro-fauna such as protists and nematodes to enter, which are the main soil fauna present in arable soils. Soil meso- and macrofauna were on the other hand, excluded from the litterbags by using a small mesh size ($<$0.05 mm). Therefore, our results on C and N loss from the litter in our experiment may be somewhat underestimated because meso and macrofauna can speed up the litter decomposition process by fragmenting the litter and adding faeces (Frouz, 2018) and by altering microbial community composition (Hättenschwiler et al., 2005). Similarly, other factors such as the initial leaf size (leaves were cut into 2 cm^2 pieces) and the season of maize litter introduction to the soil which generally would happen in September/October after the maize harvest may influence absolute decomposition rates. For instance, higher temperature in spring compared to autumn may increase microbial activity and therefore decomposition rate. However, these factors occur across litter quality and agricultural management treatments, and therefore we expect similar treatment effects on the C and N loss rates irrespective of the timing or the initial size of the litter.

5. Conclusions

Our results reinforce the importance of considering both agricultural management and cultivar litter quality for maintaining soil functioning. First, organic management accelerates the process of litter decomposition, i.e. litter C loss. Second, cultivar litter quality determines litter N mineralization, whereas soil levels of mineral and organic N during decomposition are promoted under organic management. The adoption of these management practices by farmers will contribute to enhance internal recycling of C and nutrients from crop residues, which improves sustainability of agricultural productivity. Both C and N from decomposing litter are sources of energy and biomass for soil microbes, which are key to enhance soil health and provide soil ecosystem services (Nielsen et al., 2015). Furthermore, N release provides a primary source of mineral N for crop growth and consequently, decrease the need of external N fertilizers. Still, further research is needed to evaluate the feedback of enhanced litter decomposition and associated N release on the productivity and nutrient status of the crop through the growing season.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.soilbio.2020.108115.

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